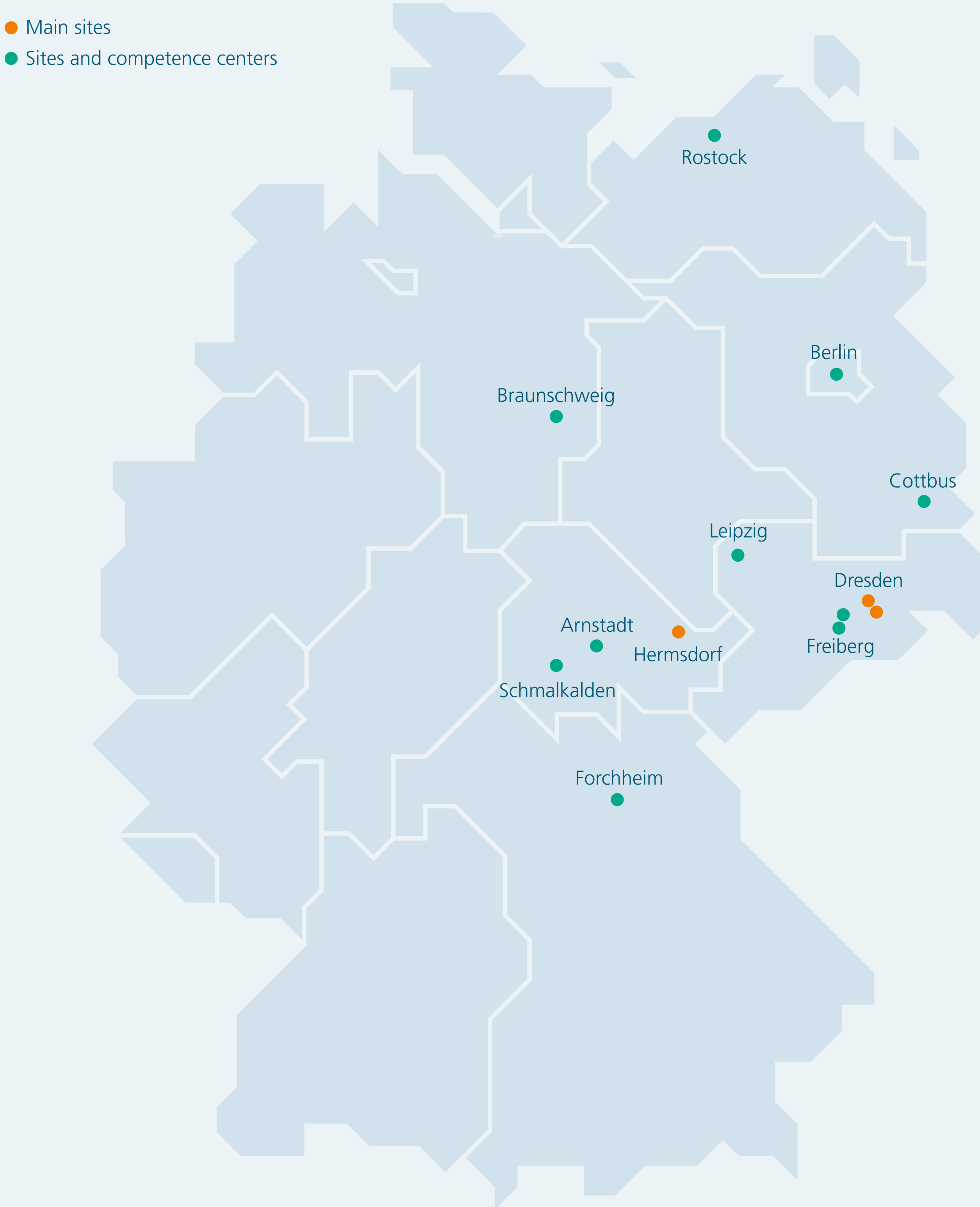
Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Annual Report 2022/23



Fraunhofer IKTS sites.

Cover:
Ceramic stack system for the simultaneous filtration and photocalatytic oxidation of water.

Annual Report 2022/23

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

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Foreword

Dear friends and partners of IKTS,

with this annual report, IKTS once again looks back on a very successful year. Our total budget is again about the € 80 million threshold, with a very stable earnings situation and, fortunately, growing industry income. Due to the expected difficulties in implementing the SAP system at Fraunhofer level, the exact figures are not yet available; however, this is not critical for us thanks to our positive development. One important point is that we were once again able to invest an amount in the double-digit million range (more than € 11 million) in equipment. This means that we can continue to be available to you as an excellently equipped and competent partner, and offer you the entire value chain of ceramic engineering, including upscaling and non-destructive testing technologies for process monitoring at the highest level. In the field of sensor technology, we are now tapping into "augmented reality" in order to be able to display test results visually with ease. This is of importance with regard to current megatrends, such as the "Metaverse". A particularly great success is the initiation of a strategic cooperation with South Korea (City of Gumi) in this field. I would like to take this opportunity to thank Prof. Henning Heuer and his team as well as Dr. Tae-Young Han. The activities of Dr. Han in particular have made it possible for South Korea to become our most important partner overseas. We also see high synergies with our Portuguese site, which is closely linked to the Fraunhofer Center for Assistive Information and Communication Solutions AICOS, and has developed very well under its director, Thomas Härtling.

Our activities in the area of storage technologies have been highlighted a few times already. In this field, we have developed into one of the largest institutes of the Fraunhofer-Gesellschaft and are working with the highest scientific and technical depth in all relevant areas regarding batteries and hydrogen systems. With regard to batteries, our activities include e.g. Lithium-ion batteries, solid-state batteries, as well as low- and high-temperature sodium batteries for mobile and stationary applications. This also includes recycling as a topic of interest, which we coordinate for the BMBF under the catchword "green battery".

An outstanding success in 2022 was the creation of a joint venture for the production of high-temperature $NaNiCl_2$ batteries between Fraunhofer IKTS (25 %) and Altech Energy Holding GmbH (75 %) – a majority-owned subsidiary of an Australian parent company based in Perth. As part of this joint venture, we are currently building a 100 MW production line in Schwarze Pumpe (Saxony). We have entered into discussions with the Saxon State Chancellery about the acquisition of another 60 hectares of land at the site to be ready to cross the GW threshold in the next stage. Compared with competing technologies, our batteries are characterized by a high level of safety, the use of locally available raw materials and thus lower prices, as well as high cycle stability and a long service life. This gives us the chance to dominate the stationary storage technology market. It also resulted in us winning, once again, the award for the largest industrial project of the year within the Fraunhofer-Gesellschaft. With regard to Altech, I would like to thank the entire team and give praise in particular to Iggy Tan (Executive Group Managing Director), Dr. Uwe Ahrens (Executive Managing Director) and Dr. Carsten Baumeister (CTO). On the IKTS side, this activity is coordinated by Dr. Roland Weidl, how is doing great work with his team.

We would like to repeat such a success this year in the field of fuel cells and electrolysis systems and believe we have the best chances of doing so. For decades, we have been working on high-temperature fuel cells (SOFC – solid oxide fuel cell), which can be used in reverse mode for electrolysis to produce green hydrogen. Compared with other electrolysis systems (alkaline or PEM), these SOE (solid oxide electrolysis) systems have the following unique selling points:

- > 30 % higher efficiency in electricity-to-hydrogen conversion thanks to the utilization of waste heat,
- Co-electrolysis capability, which means in addition to and in parallel with the production of green hydrogen, CO_2 can be reduced to CO in order to produce synthesis gas. This makes SOE particularly suitable for power-to-X processes (e.g. production of e-fuels). SOE is therefore not only CO_2-neutral, but even CO_2-negative,
- SOFC/SOE systems are reversible, which means they can be switched between fuel cell and electrolysis mode.

These advantages are crucial for the envisaged hydrogen economy in the context of the Energy Transition. Using our technologies, we now want to start mass production in a timely manner within the framework of industrial cooperation. Our location in Arnstadt is set to play an important role here.

Next to hydrogen technologies, circulatory technologies are playing an increasingly important role at IKTS. One particular focus of this is "Water". Focusing on this topic, we carried out the IKTS evaluation requested by the Fraunhofer-Gesellschaft at regular intervals over the past year. Our strategy of establishing water as an independent business division has been very positively assessed by the Commission. I would like to thank the Commission for the valuable information on the further development of this area. On the IKTS side, and on behalf of the entire IKTS team, I would like to express our gratitude to Prof. Michael Stelter and Martin Kunath for leading the evaluation process.

It is particularly gratifying that we have been able to expand our recycling technologies to the field of "carbon cycles". As part of an effort to reorganize our portfolio, we have acquired the Freiberg-based Fraunhofer research group Circular Carbon Technologies KKT from Fraunhofer IMWS and integrated it into IKTS. The KKT is closely linked to one of the largest institutes of TU Bergakademie Freiberg, namely the chair of Energy Process Engineering of Prof. Martin Gräbner at the Institute of Energy Process Engineering and Chemical Engineering (IEC). We welcome Prof. Gräbner and his team to IKTS and are pleased that we have been able to further expand our cooperation with TUBAF. Last year, I already highlighted the Fraunhofer Technology Center High-Performance Materials THM, which is operated jointly with TUBAF and Fraunhofer IISB. At IKTS, the KKT is a group within the department of Dr. Matthias Jahn, which is now jointly led by him and Prof. Gräbner. KKT focuses on solutions for low-CO_2 and CO_2-neutral technologies for the energy, chemical and raw materials industries. Great synergies are to be had here with our hydrogen and SOE activities, which we are now going to realize.

Ceramic engineering plays an outstanding role in societal mega-issues, such as the Energy Transition, the circular economy and

the security of supply. It must be safeguarded industrially in Europe and globally. We would like to make our contribution – together with you. You can find more highlights and developing trends from our business divisions in this report.

On behalf of the entire IKTS team, I wish you once again a lot of fun perusing this report and some good project ideas. We are looking forward to our mutual cooperation.

Yours,

A. Michaelis

Alexander Michaelis
April 2023

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Fraunhofer IKTS in profile

Portrait

For more than 30 years, Fraunhofer IKTS has been developing ceramic materials for a steadily growing range of applications. Our development work is derived from the needs of the nine market-oriented business divisions – supplemented by strategic preliminary research at the highest scientific level.

It is our goal to develop complete system solutions and services, but also to solve specific challenges of our partners from industry and science. Our expertise in characterizing materials, components and systems along their life cycle provides us with a unique data pool to carry out new developments more efficiently and faster.

We offer state-of-the-art equipment on more than 40,000 m² of floor space, competent staff and result-oriented research management. This makes us a contact point for companies and research partners to tap the unique properties of ceramic materials for new and improved applications. Our special competences are:

Materials

We qualify ceramics, hardmetals and composites for specific application scenarios and master all necessary manufacturing processes. We open up new fields of application through the targeted combination of structural and functional material properties. We can transfer developments from laboratory to pilot-plant scale and realize the prototypes and pilot series required for market entry, establish industrial manufacturing processes and implement quality processes.

Process engineering

We are one of the world's leading research institutes in the field of complex ceramic-based systems for energy-efficient separation processes, chemical mass transfer and materials recovery. Our approaches are based on the sustainable use of resources and closed material cycles. With state-of-the-art laboratory machinery and pilot plants, we can model, validate and optimize relevant parameters for these processes. With our excellent infrastructure, we are able to realize projects of the most diverse scope and scale.

Data-driven analytics and monitoring

Increasing the market acceptance of new materials requires high-performance analytics and quality control – from raw material evaluation to use and recycling. For the development of new materials and products, the clarification of complex failure mechanisms or the assurance of qualitative standards, we make use of new sensor concepts, robot-assisted measurements and the potential of cloud-based data acquisition and AI-supported data evaluation. In addition, we offer solutions for the process and condition monitoring of manufacturing facilities and thus ensure optimal product qualities, low costs and reduced maintenance efforts.

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

System demonstration

For energy and process engineering systems, we are able to implement targeted system demonstrations based on market and customer requirements on one side and available technological options on the other. Material or technology issues are dealt with at the individual stages of the value chain, prototypes are evaluated on the basis of extensive validation and target/performance analysis of market readiness, as well as production and quality processes suitable for series production are developed. This qualifies us as a complete service provider for the entire process of technology development and the step-by-step transfer of knowledge into the customer's series production.

Project management

Fraunhofer IKTS has proven competences in the planning and execution of research projects of various scopes – from short-term support to supernational large-scale projects. In the field of contract research with small and medium-sized companies, we provide flexible and timely support with customized services or development processes. In complex large-scale projects with various national and international consortium partners, we provide support from the application phase, to project coordination, communication of project outcomes and the development of exploitation strategies.

Cross-site quality management

Quality, traceability, transparency and sustainability are some of the most important instruments for IKTS when it comes to providing partners and clients with valid and reproducible research outcomes in a resource-efficient way. Therefore, Fraunhofer IKTS has a unified management system in accordance with DIN EN ISO 9001, as well as an environmental management system in accordance with DIN EN ISO 14001. Beyond this, the institute and its various divisions are certified according to other guidelines, among them EN ISO 13485:2016, and undergo various regular audits from the industry.

Creator of networks

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

Organizational chart

Institute Management

Institute Director
Prof. Dr. habil. Alexander Michaelis

Materials

Nonoxide Ceramics
Dipl.-Krist. Jörg Adler
- Structural Ceramics with Electrical Function
- Carbid Ceramics and Cellular Ceramics
- Nitride Ceramics and Fiber Composites
- Protective Ceramics
- Filter Ceramics and Exhaust Gas Aftertreatment

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

Processes and Components
Dr. Tassilo Moritz
- Powder Technology
- Shaping
- Component Development and Manufacturing
- Additive and Hybrid Manufacturing

Materials and Process Characterization

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

Environmental and Process Engineering

Nanoporous Membranes
Dr. Hannes Richter
- Zeolite- and Carbon Membranes
- Polymer- and Mixed Matrix Membranes
- Membrane Prototypes

High-Temperature Separation and Catalysis
Dr. Jörg Richter
- High-Temperature Membranes and Storages
- Catalysis and Materials Synthesis

Circular Technologies and Water
Dr. Burkhardt Faßauer
- Biomass Conversion and Nutrient Recycling
- Systems Engineering for Water and Wastewater
- Membrane Process Technology and Modeling
- Technical Electrolysis and Geothermal Energy
- Reaction Engineering Water

Chemical Engineering
PD Dr. habil. Matthias Jahn / Prof. Dr. Martin Gräbner
- Modeling and Simulation
- Process Systems Engineering
- Circular Carbon Technologies

Sites and Competence Centers of Fraunhofer IKTS

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

- Site Forchheim, Bavaria
- Site Berlin, Berlin
- Fraunhofer Project Center for Energy Storage and Systems ZESS, Braunschweig, Lower Saxony
- Fraunhofer Technology Center High-Performance Materials THM, Freiberg, Saxony
- Fraunhofer Smart Ocean Technologies SOT research group, Rostock, Mecklenburg-Western Pomerania
- Biological Materials Analysis research group at Fraunhofer IZI, Leipzig, Saxony
- Circular Carbon Technologies KKT project group, Freiberg, Sachsen
- Cognitive Material Diagnostics project group, Cottbus, Brandenburg
- Fraunhofer Center for Smart Agriculture and Water Management AWAM, Porto, Portugal
- Battery Innovation and Technology Center BITC, Arnstadt, Thuringia
- Industrial Hydrogen Technologies Thuringia WaTTh, Arnstadt, Thuringia
- Application Center Water, Hermsdorf, Thuringia
- Application Center Membrane Technology, Schmalkalden, Thuringia

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

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

Deputy Institute Director / Administrative Director — Dr. Michael Zins
Deputy Institute Director / Marketing and Strategy — Prof. Dr. Michael Stelter
Deputy Institute Director / Site manager Hermsdorf — Prof. Dr. Ingolf Voigt
Deputy Institute Director / Site manager Dresden-Klotzsche — Dr. Christian Wunderlich

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

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

Energy Systems

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

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

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

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

Friedrich Schiller University Jena
Institute for Technical Environmental Chemistry
Prof. Dr. Michael Stelter
Ernst Abbe University of Applied Sciences Jena
SciTec – Materials Engineering
Prof. Dr. Ingolf Voigt

Technische Universität Bergakademie Freiberg
Chemical Technology
Prof. Dr. habil. Martin Bertau
Energy Process Engineering and Chemical Engineering
Prof. Dr. Martin Gräbner

Electronics/Microsystems- and Biomedical Engineering

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

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

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

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

Microelectronic Materials and Nanoanalysis
Dr. Birgit Jost / Dr. André Clausner
- Nanoscale Materials and Analysis
- Nanomechanics and Reliability for Microelectronics

Condition Monitoring and Test Services
Dr. Lars Schubert
- Condition Monitoring Hardware and Software
- Methods for Monitoring Systems
- Model-based Data Evaluation
- NDT Lab**

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

Fraunhofer IKTS in figures

Budget and income

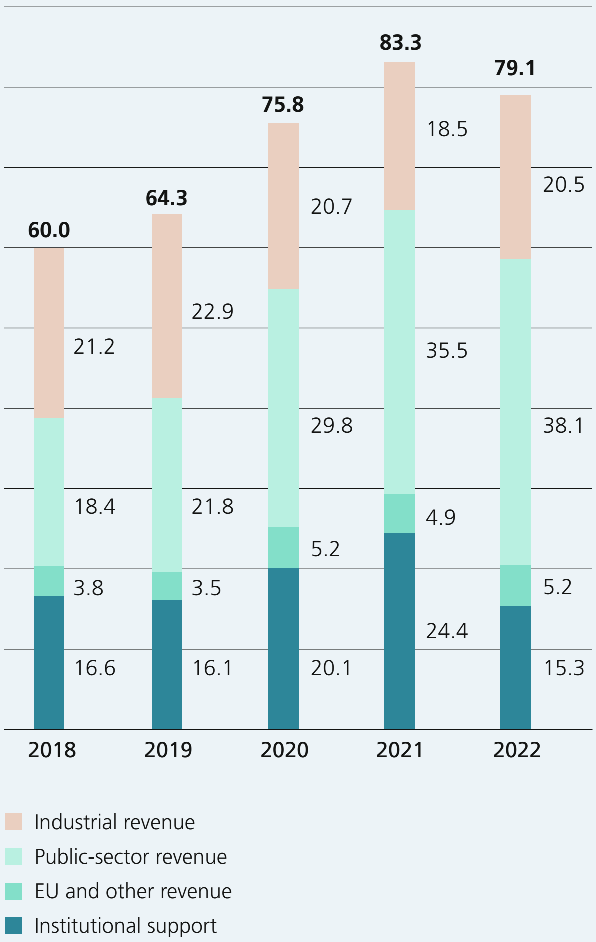
The institute looks back on a very successful year 2022. However, projects are also delayed at Fraunhofer IKTS due to the current world situation. In particular, challenges in the purchase of raw materials and equipment are a major reason that the total budget decreases slightly to about € 80 million. With an investment volume of more than € 11 million, the strategic work areas could nevertheless be further expanded. Through funding in Saxony for the Freiberg site, the Fraunhofer THM was further extended. The states of Bavaria and Thuringia are focusing on investment support in Forchheim and Arnstadt.

According to current projections, projects for € 20.5 million were processed under direct industrial contract. Of this, € 11.8 million is attributed to the headquarters in Dresden-Gruna, € 3.3 million to the Dresden-Klotzsche cost center and € 5.5 million to the Hermsdorf cost center. In terms of the operating budget of € 68 million, this represents an increase of 2 % or € 2.1 million compared with the previous year. It is very pleasing to note that the number of multi-year industrial projects is increasing significantly. Energy and environmental technology projects in particular play a major role here.

Public revenues increased by € 2.8 million to € 38.1 million. Here, the institute continues to benefit from the successful applications of the last three years. However, there has been a significant reduction in available bids with a simultaneous decline in the general success rate. The project situation in 2024 will certainly be strongly influenced by this.

Price increases in the energy sector in 2022 were essentially still limited by existing contracts. The cost explosion in the area of heat supply was countered by consistent savings. At the level of the Fraunhofer Institute Center Dresden, as much as 15 % district heating capacity was saved. In connection with the new framework agreements for energy supply and the expected tariff increases, cost rate increases cannot be avoided in 2023. In connection with the ongoing projects and the cost rates already agreed in previous price years, there will be further burdens on basic funding. This will reduce the scope for in-house research projects.

Revenue (in million euros) of Fraunhofer IKTS for the budget years 2018–2022*

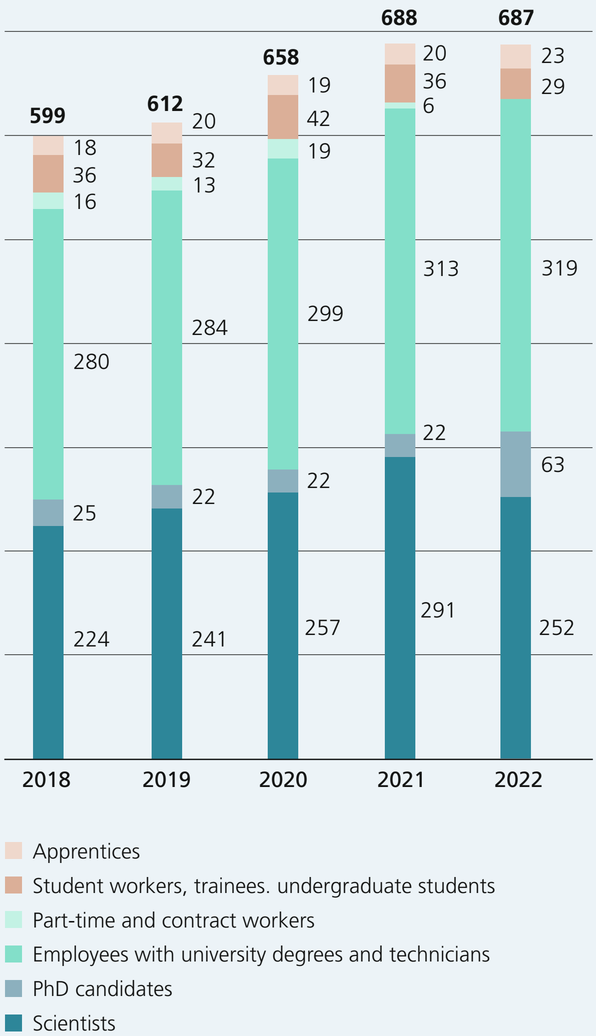


*Revenue projection 10.03.2023

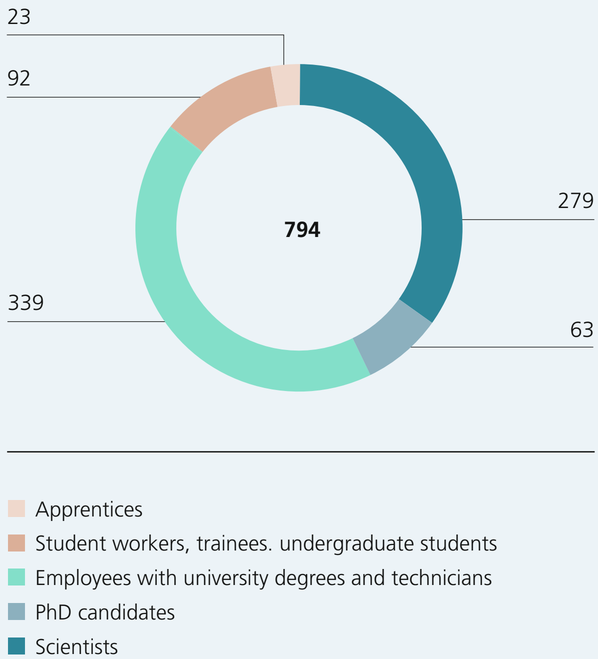
Human resources development

A total of 794 people are employed at the IKTS sites. Work-life balance is a criterion that has become much more important. In all areas, many of the employees choose part-time models. The flexibility to adjust contracts according to individual needs is an important reason for starting at Fraunhofer IKTS. Under the current cost developments, the model of the classical PhD contract in a 50 % part-time model is no longer attractive. Therefore, doctoral studies are increasingly carried out in higher employment rates of up to 100 %. The capacity is dynamically adjusted to the project tasks. The different full-time equivalents are shown in the figure. In the two groups, the total number of scientists has increased by 2. Unfortunately, the number of employed students and diploma students has decreased from

Personnel developments at Fraunhofer IKTS – Number of employees 2018–2022, full-time equivalents



Number of employees of Fraunhofer IKTS in 2022, headcount



103 to 92 at the same time. The connection of further chairs of the TU Bergakademie Freiberg will improve the access for students in 2023. Students of economics now also find topics at Fraunhofer IKTS. It is also worth mentioning that training is increasingly provided in the dual teaching mode. With a total of 23 trainees, the institute also makes an important contribution here and will benefit from its own junior staff in the future.

Fraunhofer IKTS as an employer is well positioned in the market so far. Nevertheless, the acquisition of employees in the scientific and increasingly in the administrative area remains one of the major challenges.

Expanding the infrastructure

An enormous challenge is the introduction of SAP. The system went live on January 10, 2022. This has created a considerable burden in all areas, which has had to be absorbed by increasing staff numbers. Due to the enormous complexity, potential savings and efficiency gains cannot be expected until 2024. The expansion of the technical infrastructure, especially at the Freiberg, Forchheim and Arnstadt sites, has already been presented by Prof. Alexander Michaelis. Thus, IKTS is very well positioned, especially for the large industrial network projects.

Board of trustees

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

The Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft based in Germany is the world's leading applied research organization. Prioritizing key future-relevant technologies and commercializing its findings in business and industry, it plays a major role in the innovation process. It is a trailblazer and trendsetter in innovative developments and research excellence. The Fraunhofer-Gesellschaft supports research and industry with inspiring ideas and sustainable scientific and technological solutions and is helping shape our society and our future.

The Fraunhofer-Gesellschaft's interdisciplinary research teams turn original ideas into innovations together with contracting industry and public sector partners, coordinate and complete essential key research policy projects and strengthen the German and European economy with ethical value creation. International collaborative partnerships with outstanding research partners and businesses all over the world provide for direct dialogue with the most prominent scientific communities and most dominant economic regions.

Founded in 1949, the Fraunhofer-Gesellschaft currently operates 76 institutes and research units throughout Germany. Over 30,000 employees, predominantly scientists and engineers, work with an annual research budget of € 2.9 billion. Fraunhofer generates € 2.5 billion of this from contract research. Industry contracts and publicly funded research projects account for around two thirds. The federal and state governments contribute around another third as base funding, enabling institutes to develop solutions now to problems that will become crucial to industry and society in the near future.

The impact of applied research goes far beyond its direct benefits to clients: Fraunhofer institutes enhance businesses' performance, improve social acceptance of advanced technology and educate and train the urgently needed next generation of research scientists and engineers.

Highly motivated employees up on cutting-edge research constitute the most important success factor for us as a research organization. Fraunhofer consequently provides opportunities for independent, creative and goal-driven work and thus for professional and personal development, qualifying individuals for challenging positions at our institutes, at higher education institutions, in industry and in society. Practical training and early contacts with clients open outstanding opportunities for students to find jobs and experience growth in business and industry.

The prestigious nonprofit Fraunhofer-Gesellschaft's namesake is Munich scholar Joseph von Fraunhofer (1787–1826). He enjoyed equal success as a researcher, inventor and entrepreneur.

Joseph von Fraunhofer.

Retrospective

In 2022, Fraunhofer IKTS presented its research and services at numerous trade fairs in Germany and abroad and as the organizer of several scientific congresses as well as at various events for the general public.

February 3, 2022
NDT4INDUSTRY – Online seminar series on non-destructive testing

In 2022, Fraunhofer IKTS continued to present developments from the field of non-destructive testing (NDT) for industry as part of the NDT4INDUSTRY online seminar series. In January, Natalia Beshchasna spoke about novel in-vitro testing for cardiovascular implants to improve their compatibility and longevity. A system for inline testing of multiaxial carbon fiber fabrics with a width of up to 2.5 metres was presented by Martin Schulze in March. In June, Manuela Heymann focused on a marking solution that can withstand the extreme conditions in metal processing. Peter Krüger combined X-ray and thermography in September to optimize quality assurance in battery production. Detecting defects and wear with AI-based acoustic diagnostics was the topic of Ivan Kraljevski's seminar in November.

In 2023, the concept of the seminar series will change its focus from processes to branches of industry. In the future, the spotlight will be on industrial challenges for which suitable developments from the institute will be presented. Current topics and dates can be found at www.ndt4industry.com.

March 2, 2022
Prof. Michaelis receives international materials research awards
(Bottom image)

On March 2, IKTS Institute Director Prof. Alexander Michaelis became the first European to receive the prestigious "Acta Materialia Hollomon Award for Materials and Society" from Acta Mineralia, Inc. Before that, in October 2021, he had already been honored with the "Rustum Roy Lecture Award 2021" from the American Ceramic Society ACerS. Both awards recognize outstanding contributions to materials science for the benefit of society.

May 30, 2022
Our trade fair highlights
(Top image)

Fraunhofer IKTS was represented at 25 trade fairs in 2022. At the **JEC**, the institute demonstrated inline testing of carbon fiber textiles. Process developments for the energy-efficient and selective separation of valuable materials from hot gas processes by means of filtration were the highlight at **IFAT**. At the **Sensor and Test** and **Electronica** trade fairs, IKTS presented ceramic solutions for sensor technology and power electronics in harsh environments. Electrolysis is central to the decarbonization of industry. At **ACHEMA**, visitors were able to learn about ceramic technologies and a techno-economic assessment offer for efficient power-to-X processes. In addition to a rail testing system, an ultrasonic testing clamp for compression connectors on contact wire lines was presented at **Innotrans**, which detects cracks before they have spread to the surface. For the first time, the Multi Material Jetting (MMJ)

3D printing process allows the sustainable production of functionalized multi-material components in a single printing process. At **CERAMITEC** and **formnext**, the IKTS team provided a first glimpse of this technology, which will be commercialized in 2023. You can find an outlook on the trade fair year 2023 on page 70. We look forward to seeing you at GIFA and COMPAMED 2023, among others!

June 7–8, 2022
Ceramics Vision 2022

(Top image)

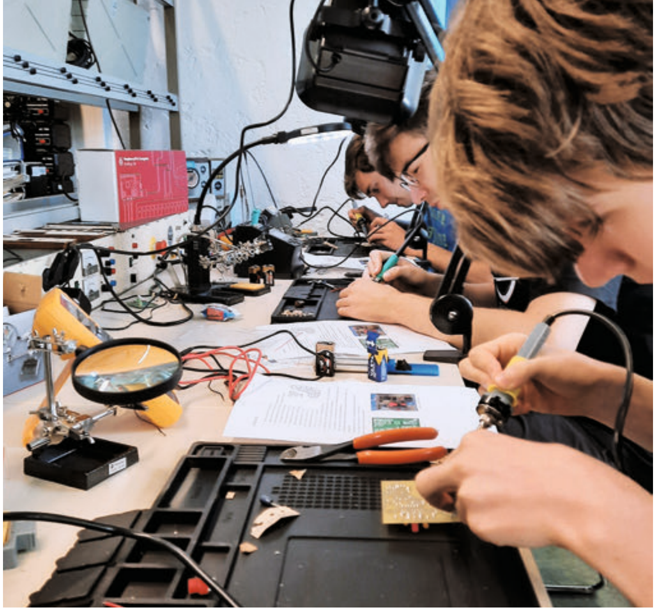
As the culmination of its 30th anniversary year, Fraunhofer IKTS once again hosted Ceramics Vision in Dresden, now in its 11th edition. 60 guests from research and industry, including former employees, took up the invitation. Key technologies and future challenges in the fields of water, decarbonization and digitalization were the main topics of the two-day conference. IKTS looked back on past developments, highlighted the latest ceramic solutions for industry and society and gave an outlook on the next 30 years.

June 18 | July 8, 2022
Science Night in Freiberg und Dresden

(Bottom image)

"sustainable. research. economy. life." was the motto of the Freiberg Night of Science and Business on June 18, where the IKTS team of Fraunhofer THM presented its research on battery technologies and battery recycling.

On July 8, Fraunhofer IKTS in Dresden-Gruna opened its doors to the public for the 19th Dresden Science Night. Hands-on experiments, lectures and laboratory tours brought visitors closer to the diverse applications of advanced ceramics. For example, children and young people were able to build a battery from potatoes, make fingerprints visible through electrochemical processes and clean water with electricity, while the grown-ups looked over the shoulders of researchers as they injection-molded ceramic knee prostheses, used modern sensors to look inside cell phones and microelectronics and learned, from our lectures, why wastewater treatment plants are an important source of raw materials and energy and how corrosion protection and climate protection are linked.



August 18, 2022
IKTS spinoff advances monitoring technology for offshore pressure vessels

Together with Equinor Ventures and the spinoff company CoFounder, Fraunhofer IKTS founded the deep-tech venture "Nicoustic" in Trondheim, Norway. The new company markets a technology for monitoring offshore pressure vessels, which are widely used in the manufacturing industry. Guided ultrasonic waves can be used to monitor closed vessels non-invasively, permanently, from the outside and without downtime for the operator.

August 22–26, 2022
Sensor Space Summer School

(Top image)

The second Sensor Space Summer School of Fraunhofer IKTS took place as a free summer camp in Hermsdorf (Thuringia) with the headline "Feel the Beat". Together with researchers from Fraunhofer IKTS, who had developed the concept for the Summer School, the nine young people spent a week working with circuit diagrams, electronic components and measuring devices. The goal was to build their own ECG device, with which they could measure their own heartbeat at the end of the week. The BMBF-funded STEM student lab Sensor Space is a "maker space" for sensor technology and technical ceramics with the aim of getting students excited about microelectronics, software and technology, and increasing their interest in technical professions.

August 26, 2022
CleanEFX – Prime Minister learns about decarbonization at Erfurter Kreuz

(Bottom image)

More than 20 companies from the Erfurter Kreuz e. V. initiative are working together in the CleanEFX interest group to supply the industrial park at Erfurter Kreuz with climate-neutral energy and process heat. The project idea had been initiated in several workshops by companies and research institutions even before the current geopolitical developments came about. Thuringia's

Thuringia's Prime Minister Bodo Ramelow (2nd from left) and Minister of Economics Wolfgang Tiefensee (3rd from left) with Fraunhofer IKTS Institute Director Prof. Alexander Michaelis (r.) and Prof. Michael Stelter (l.), Deputy Institute Director of Fraunhofer IKTS and Board Member of the Thuringian Renewable Energy Network (ThEEN) e.V.

Minister President Bodo Ramelow and Economics Minister Wolfgang Tiefensee visited the Battery Innovation and Technology Center in Arnstadt to learn more about the concepts for sustainable energy solutions from IKTS researchers and company representatives from the region.

September 3, 2022
Open House at Fraunhofer IKTS Hermsdorf
(Image on the right)

Several hundred interested people visited the Thuringian IKTS site in Hermsdorf for its open house event. From lectures, demonstrations and laboratory tours, they gained insights into current research topics and got to talk with researchers.

September 14–16, 2022
ISPA International Symposium on Piezocomposite Applications
(Bottom image)

At the ninth “International Symposium on Piezocomposite Applications”, accompanied by an industrial exhibition, around 40 engineers and designers from six nations discussed current research results, developments, market requirements and framework conditions for the optimal technology transfer of piezoceramic innovations. The focus was on piezoceramics combined with electronic, functional and structural materials for applications in medical technology, mechanical and automotive engineering as well as semiconductor technology. The symposium opened with a themed workshop by CTS Ferroperm Piezoceramics on “Piezoelectric Materials and Applications”. The next ISPA will take place in 2024.

September 21, 2022
Media breakfast: Renaturation with sewage sludge and mushrooms

Soil is a valuable resource. IKTS agricultural expert Nico Domurath presented a promising technology for the renaturation of waste rock piles at this year’s media breakfast at the Fraunhofer Institute Center Dresden. The project team, consisting of Mattias Hoger (Veolia Klärschlammverwertung Deutschland GmbH), Prof. Christina Dornack and Dr. Paula Penckert (Institute for Waste and Recycling Management at TU Dresden), Natalie Rangno (Institut für Holztechnologie Dresden gemeinnützige GmbH), and Nico Domurath and Marc Lincke (Fraunhofer IKTS), inoculated biologically inactive spoil material with a special mixture of sewage sludge compost and fungal substrates. With this top layer, the team has made a landfill site

in the Leipzig area flourish in a short time. In several follow-up projects with other partners, the new recultivation technique is now also being adapted and tested for old mining dumps.

October 5, 2022
Industry Day Transparent Ceramics

At the event "Transparent Ceramics at Fraunhofer IKTS – Production, Technology, Potentials", guests from industry were shown the new laboratories and pilot plants of the Research and Development Center Transparent Ceramics in Hermsdorf. Guided tours provided information on innovative production methods, quality assurance strategies and potential areas of application. Concrete applications and joint projects were discussed in individual talks.

October 11, 2022
Honored as an Excellent Provider of Apprenticeships in 2022

In a ceremony on October 11, the Dresden Chamber of Industry and Commerce (IHK) once again confirmed that the dual training at Fraunhofer IKTS offers lasting quality with a high success rate. The professions currently taught at the Dresden-Klotzsche site are those of physics laboratory assistant, industrial mechanic, and electronics technician for devices and systems. Our congratulations go to the successful graduates and the chief training representative, Dr. Beatrice Bendjus.

October 12, 2022
30th Anniversary of Fraunhofer IKTS ceremony
(Image on the right)

Under the motto "Hello Future – 30 Years of Fraunhofer IKTS", the IKTS site Hermsdorf celebrated the 30th anniversary of the institute with a ceremony. In addition to the employees, guests and companions from the companies of the Tridelta Campus as well as former employees, including the former long-time director of the institute, Dr. Bärbel Voigtsberger, were invited. Thuringia's Minister of Economics Wolfgang Tiefensee, District Administrator Andreas Heller and Hermsdorf's Mayor Benny Hofmann were also guests.

October 12–13, 2022
AM Ceramics at IKTS in Dresden
(Top image)

Fraunhofer IKTS and Lithoz GmbH welcomed more than 110 international ceramic specialists to the AM Ceramics 2022. The conference focused on the exchange of information on advances in ceramic 3D printing and current material and process developments, as well as on industrial success stories and opportunities for personal networking among the participants. As part of a laboratory tour, IKTS presented its cerAMfacturing 3D printing infrastructure and current ceramic technologies going beyond additive manufacturing, from powder and suspension/raw material development to the selection of manufacturing technology and further functionalization, as well as characterization and evaluation of the manufactured components and systems.

November 3, 2022

Prof. Neugebauer visits former Helmstedt coal mining district

On November 3, the President of the Fraunhofer-Gesellschaft Prof. Reimund Neugebauer visited the former coal mining district of Helmstedt as part of his factfinding mission on structural change, "Fokusreise Strukturwandel", where he learned about regional and decentralized solutions for agricultural structural change in the region with regard to the topics of climate change, world population growth and geopolitical instabilities. IKTS researchers demonstrated a soil density sensor that enables automated soil measurements down to a depth of 2 meters. The sensors, guided by a robot or coupled to a tractor, provide information on the need for loosening up deep soil or on the success of completed tillage operations. In order to effectively consolidate the topics of structural change, the Fraunhofer Institute for Surface Engineering and Thin Films IST, together with Fraunhofer IKTS, is planning to set up an innovation hub through which supraregional initiatives and regional partners can easily network.

November 22, 2022

Fraunhofer communication award for PR campaign

With its #womeninscience campaign, Fraunhofer IKTS put the spotlight on women working in various roles at the institute in 2022. The goal of the campaign, which was launched via the IKTS website and social media, was to increase awareness of the institute, portray it as an attractive employer and promote applications for open positions from women. Maria Kaminski and Marie Kaden from the PR group won second place in the Fraunhofer-wide communication awards contest for planning and implementing the campaign. The video interviews of the campaign can be found on the IKTS YouTube channel.

November 24–25, 2022

Symposium Applied Electrochemistry in Materials Research

(Bottom image)

For the 7th time, experts met in Dresden for the symposium Applied Electrochemistry in Materials Research. Sponsored by seven industrial partners and accompanied by an industrial exhibition, the symposium was dedicated to the topic of materials for electrochemical storage and converters as well as developments and new possibilities in the field of industrial surface technology. The lively exchange and the positive response of the participants has motivated the organizers to continue the series in two years' time.

February 15, 2023

Minister President Michael Kretschmer visits pilot plant in Thallwitz

(Top image)

With the aim of producing high-quality basic materials for a resilient chemical and fuel industry from regional biomass in a CO_2-neutral manner, Fraunhofer IKTS and its partners TU Bergakademie Freiberg, TU Dresden, Ökotec-Anlagenbau GmbH, Sunfire GmbH and DBI Gas- und Umwelttechnik GmbH have been operating a unique pilot plant in Thallwitz near Leipzig since 2019. This plant converts carbon from local biogas by means of high-temperature electrolysis first into synthesis gas and then via Fischer-Tropsch synthesis into basic chemicals, e-fuels and biogenic waxes. After the successful validation of the plant concept, the consortium now plans to bring the process to industrial maturity together with EDL Anlagenbau Gesellschaft GmbH. The Saxon Minister President Michael Kretschmer visited the site in mid-February to find out more about the current project and emphasized the importance of the technology for structural development in the Central German mining region.

Highlights from our business divisions

In focus
page 22–25

Industrial transformation, circular economy and sustainable energy supply are current challenges for society as a whole. Fraunhofer IKTS works across disciplines and locations to develop needs-based and sustainable solutions. Through unique facilities and test fields, we quickly transfer research and development results into application – for the benefit of society, the economy and the environment.

Materials and Processes
page 26–31

This business division is a port of call for all questions concerning the development, production and qualification of high-performance ceramics for a wide range of applications. At its center is the long years of experience with all relevant ceramic materials and technologies for which functionally adequate solutions are developed based on the specific requirements. The business division works to solve issues along the complete process chain. It also functions as a central hub for all other business divisions.

Water
page 32–36

Efficient use and purification of water is of the highest importance. Fraunhofer IKTS provides solutions for the treatment of wastewaters – from multifunctional components to compact overall systems. The combination of various methods, such as filtration, adsorption or sono-electrochemical oxidation, has significant advantages over traditional approaches. Furthermore, specific sensor systems are integrated to increase process efficiency, reduce process costs and enable balancing.

Electronics and Microsystems
page 37–39

The business division gives manufacturers and users unique access to cost-efficient and reliable materials and manufacturing solutions for robust and high-performing electronic components. In addition to sensors and sensor systems, components for power electronics as well as smart multifunctional systems are another focal point. Using innovative test methods and systems, IKTS provides support throughout the complete value chain – from the material through to the integration of complex electronic systems.

Energy
page 40–45

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

Mechanical and Automotive Engineering
page 52–54

High performance ceramics are key components for plant engineering and construction as well as automotive engineering. Because of their outstanding properties, they often constitute the only viable solution. The business division provides wear parts and tools as well as components from high performance ceramics, cemented carbides, cermets and hybridized composites with very specific load profiles. Testing systems for the monitoring of components and production plants based on optical, elastodynamic and magnetic effects are another focal point.

Bio- and Medical Technology
page 46–48

Fraunhofer IKTS makes use of the outstanding properties offered by ceramic materials with regard to the development of dental and endoprosthetic implants as well as surgical instruments. In our certified labs, we use the very best equipment to examine the interactions between biological and artificial materials, leading to improved developments in materials, analytics and diagnostics. To achieve this, we use some of the most unique optical, acoustic and bioelectric methods.

Environmental and Process Engineering
page 55–58

Work in this business division is focused on processes in the field of conventional energy and bioenergy, strategies and methods for water and air purification and for recovering valuable raw materials from residual waste. Many of these approaches aim for closed material cycles. Fraunhofer IKTS uses ceramic membranes, filters, adsorbents and catalysts to implement complex process engineering systems for energy-efficient separation processes, chemical conversion and the recovery of valuable materials.

Non-Destructive Testing and Monitoring
page 49–51

Quality, cost and time are key if products and services are to succeed in the marketplace. Non-destructive testing can contribute significantly to their continuous improvement. Fraunhofer IKTS combines its decades of experience in the testing and monitoring of components and plants with novel measuring technologies, automation concepts and approaches for the interpretation of complex volumes of data. The portfolio of our competencies thus far exceeds that of a typical NDT technology provider.

Materials and Process Analysis
page 59–62

Fraunhofer IKTS offers a comprehensive portfolio in testing, characterization and analysis methods to control material features and production processes. As a service provider accredited and audited multiple times, IKTS supports the analysis of materials fundamentals, application-related questions and developments in measuring technology. Characteristic values are not just determined but interpreted within the context of their specific application in order to reveal the potential for optimization.

Joint Venture Altech Batteries GmbH – the 100 MWh battery factory in Schwarze Pumpe

Dr. Roland Weidl, Prof. Alexander Michaelis

Uwe Ahrens, CEO of Altech Advanced Materials (r.), welcomes German Chancellor Olaf Scholz (l.) during his visit to Schwarze Pumpe (Source: Tudyka.PR).

Site of the future Altech Batteries GmbH in Schwarze Pumpe, Saxony.

Draft 60 kWh cerenergy® module for stationary energy storage.

After more than ten years of development at Fraunhofer IKTS, the commercialization of the ceramic battery cerenergy® is now beginning. A key milestone on this path was reached with the founding of Altech Batteries GmbH in September 2022, in which Altech Energy Holding holds a 75 % stake and the Fraunhofer-Gesellschaft a 25 % stake. The aim of Altech Batteries GmbH is to set up a production line for the solid-state battery cerenergy®.

A sustainable future for former power plant site

The battery factory will be built on a 14-hectare industrial wasteland in the Saxon part of the industrial park Schwarze Pumpe. The planning is already in full swing. For the first line, an annual production of 100 MWh is envisioned.

Fraunhofer IKTS as an experienced development and transfer partner

Accompanying the establishment of production, Fraunhofer IKTS is part of a development project which will accompany the conversion of the battery prototype into a product and the upscaling of production to industrial scale. Teams of experts at three IKTS sites are involved in this task. At the Arnstadt site, the focus is on quality assurance in production, e.g. through in-line controls, as well as final production planning. In Hermsdorf, where cell development has now been going on for more than ten years and a sample production line exists, the cell prototype is being brought to industrial maturity. Furthermore, the manufacturing processes of the ceramic solid-state electrolyte, a sodium-beta-aluminate ceramic, are being adapted to industrial requirements and consquently scaled up.

The team at the Dresden site is responsible for the modeling and design of the 60 KWh module, which is the smallest unit in production, as well as for constructions. Everything must be designed and optimized for operation in containers. A finished container will have a storage capacity in the MWh range.

Target market: stationary energy storage

In the stationary energy storage market segment, the focus is on industrial or large-scale residential storage, in particular the intermediate storage of energy from volatile renewable sources such as wind and sun. The maintenance-free, long-term stable, non-flammable battery cells, whose cathode consists of common salt and nickel instead of lithium compounds, are best suited for this purpose.

Ambitious timescale

Within one year, the factory is planned on the drawing board, including all specifications and consumption. In the following three years, the production plant will be built up, followed by the commissioning phase and the ramp-up to full production.

Parallel to the start of production of the 100 MWh factory, the next step, the expansion to a Gigawatt production facility on a neighboring site in the industrial park, is being planned. The corresponding areas (70 hectares) have already been reserved.

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The Thuringian Water Innovation Cluster ThWIC

Dr. Patrick Bräutigam, Prof. Michael Stelter

The Thuringian Water Innovation Cluster (ThWIC) is one of the winners of the Zukunftscluster Initiative by BMBF. Led by the spokespersons Prof. Michael Stelter and Dr. Patrick Bräutigam an interdisciplinary center will be built over the next nine years, developing new solutions for the sustainable use of water, including their industry transfer. 45 million euros are available for this.

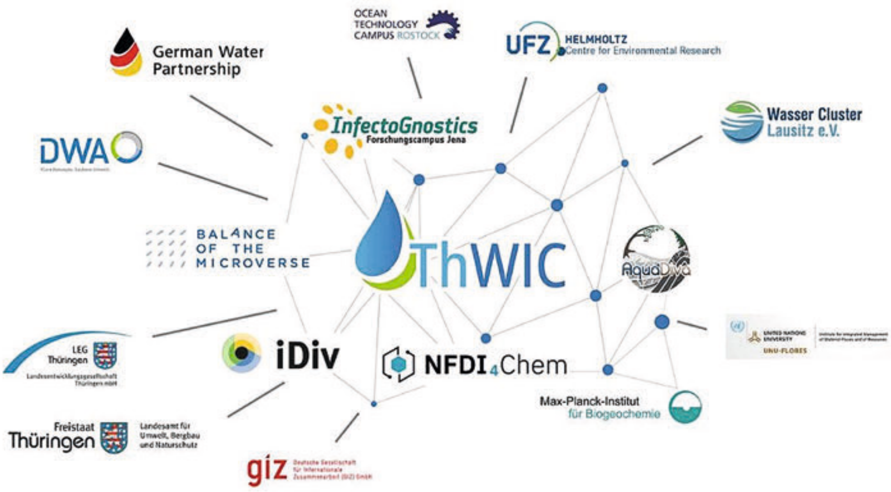
Fraunhofer IKTS is involved in the ThWIC as a co-submitting institution across the entire width of the Water business division and also through its strategy department.

In the first funding period, 22 projects will be funded, 10 of them with direct or indirect participation of IKTS. They range from real-time COD sensors and membranes as technical kidneys to oxidation and cavitation-assisted ozonation, switchable ceramic adsorbers and artificial intelligence for predicting the removability of pollutants in technical processes. The ThWIC's innovation-supporting measures in the area of sustainability and outreach show particular potential for synergies. They enabled Fraunhofer IKTS to position itself in the public, industry and political spheres well before the start of the project, and to demonstrate its capabilities in water technology. The IKTS also has access to data science and sociological research at ThWIC.

ThWIC impressively demonstrates the potential for collaborative technology development and technology transfer across all technology readiness levels (TRL), which lies in the close cooperation between local universities, Fraunhofer IKTS and the numerous local companies. The Chair of Technical Environmental Chemistry at the Friedrich Schiller University Jena and its Advanced Water Technology working group led by Dr. Patrick Bräutigam have become a hub for water research in recent years.

In ten years, ThWIC will be one of the world's leading centers for water issues: pioneering technology and outreach, with a comprehensive range of data and powerful scientific and commercial offers.

Automated, robot-assisted degradation and analysis of water pollutants.



Networking of ThWIC with other local and national partners.

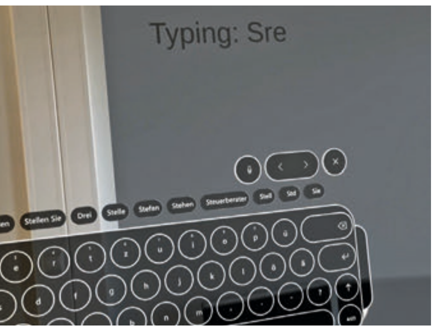
Augmented Reality – multi-user application as first step to Industrial Metaverse

Oliver von Kopp, Dr. Regina Koreng, Tobias Stüwe, Stephan Heilmann, Philipp Horn, Nico König, Viktor Schütz, Simona Simoni, Prof. Henning Heuer

Virtual CAD model of the SoniQ Rail Explorer in the data glasses.

Representation of mesh data and the overlay with the real test object.

Multi-user application: participants and test subjects are displayed as a sphere.



Input into a text field via virtual keyboard.

For an interactive collaboration with international and national project partners, Fraunhofer IKTS develops solutions that include the virtual world – a metaverse. The goal is for project partners to come together and work on hardware and software solutions in the metaverse. These will then be transferred to the real world. In this context, the metaverse is not a virtual match for reality, but an active workplace. In it, all the necessary resources and equipment are to be made available. It is important to simulate the actual properties and conditions of devices and materials in the virtual world. For this purpose, a connection to real devices is imaginable.

Currently, a multi-user application is being developed for the metaverse. This first step deals with virtual collaboration using data glasses.

Acting together via multi-user application

A multi-user application with multiple users allows them to work together in the virtual environment. The prerequisite for this is that both the participant and the user have the same scene view. The use of augmented reality data glasses enables an overlay of virtual information with reality. With existing CAD data, models of machines or devices can be prepared for the virtual world and enhanced with application-specific animations and interactions. Image 1 shows an example of this in the form of a model of a rail testing device in a laboratory. In connection with real components as well as an integrated gesture control in the data glasses, a real handling can be simulated in the virtual environment. In this way, test results can be projected locally onto three-dimensional objects (image 2).

For the current application, only one PC can be used as well. Image 3 shows that the participants are represented by a sphere in the virtual environment. The position is based on the camera position of the terminal device. The start location is used for orientation or positioning in the room during shared use. This is clearly defined in the application and is identical for all participants.

For the current version of the application, it is defined that the first user as master controls the main activities. This includes the manipulation of objects via gesture control and moving them around the room. The operation of buttons is possible for all participants. With this, additional information can be accessed and/or exploratory displays selected. Each of these actions of the master or participant is visible for all others and allows a detailed explanation or discussion.

Communication in the metaverse

Communication in the virtual environment is currently enabled exclusively by a chat function. On the one hand, the participants can use a predefined text field with the virtual keyboard and leave comments for the others (image 4). On the other hand, markings can be placed in the room as 3D writing or characters. After the multi-user application, further iterative steps towards the metaverse follow. It will be investigated to what extent avatars will be developed (how important is the representation of the body or arms) and which further communication channels must be found to allow natural collaboration. Furthermore, the focus will be more and more on the integration and connection between real and virtual devices to promote the development of new components.

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New raw materials and energy resources for a green industry

Dr. Matthias Jahn, Prof. Martin Gräbner

Carbon is a central raw material of countless products of our daily lives. Until now, the industry has relied on fossil raw material sources such as oil, natural gas or coal. During the production of these raw materials as well as at the end of the product life during combustion, large amounts of CO_2 are released. Germany alone incinerates around 47 million metric tons of these carbon-containing wastes in thermal waste treatment and combustion plants every year. Through precisely coordinated process combinations of chemical recycling, Fraunhofer IKTS and its new workgroup "Circular Carbon Technologies" want to recycle up to 100 % of these wastes in the future and make them usable for new products. Waste thus becomes a valuable source of raw materials, for example for basic substances in the chemical industry.

Large-scale testing of chemical recycling processes

At the new IKTS site in Freiberg, chemical recycling processes, such as pyrolysis or gasification, are optimized and tested on a large industrial scale. Plastics that are not mechanically recyclable, biomass or fossil mixed waste are broken down into smaller molecules so that they can be reused as synthesis gases, monomers or other intermediates in the chemical industry. For this purpose, IKTS operate a pyrolysis platform and – in cooperation with the TU Bergakademie Freiberg – systems for gasification in order to investigate various issues: Which waste fractions can be converted into which type of raw materials? How must the processes be operated in order to avoid corrosion or caking or to achieve a certain purity of the products? No less important is the question of cost-effectiveness. For industrial partners, various technologies can be adapted, evaluated and transferred into customer-specific solutions for the closure of carbon cycles.

Combining carbon recycling and power-to-X technologies

These competencies are to be expanded in the future. Regenerative electricity must form the basis of all substance conversion, e.g. for the production of green hydrogen. If the recycling processes mentioned above are combined with electrochemical conversion processes, such as high-temperature electrolysis, or synthesis processes, such as Fischer-Tropsch synthesis, higher-quality products, such as synthetic kerosene, can be produced on the one hand, and high efficiencies can be achieved on the other.

A holistic view of material, energy and heat flows

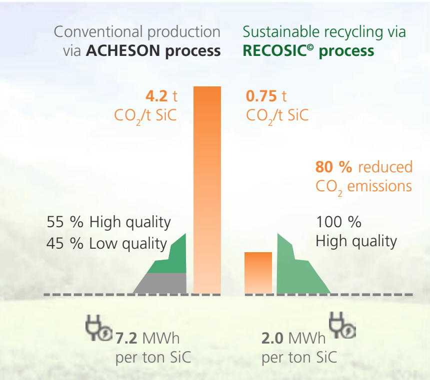
Only by coupling material, energy and heat flows in total is it possible to develop process concepts that offer a clear added value compared to previous approaches. Fraunhofer IKTS has many years of experience with technologies for hydrogen production and use. High-temperature electrolysis and Fischer-Tropsch synthesis are key technologies in this regard. With our expanded expertise in carbon recycling technologies, we are now able to provide new raw material and energy resources for a green industry.

STAATSMINISTERIUM FÜR WISSENSCHAFT KULTUR UND TOURISMUS | Freistaat SACHSEN

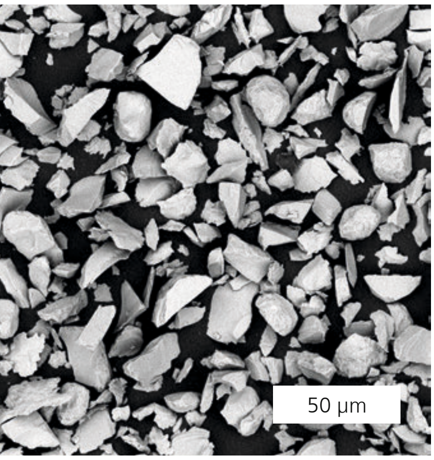
Circular Carbon Technologies complement the electrolysis, hydrogen and power-to-X technologies at IKTS and open up sustainable carbon sources for the circular economy. (Source: TU Bergakademie Freiberg)

Complex mixtures of organic compounds, such as synthetic fuels or pyrolysis oils from plastics, are analyzed using comprehensive gas chromatography mass spectrometry.

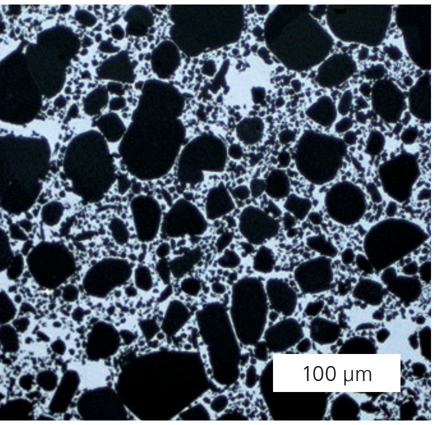
A pyrolysis rotary kiln is used for the upscaling of pyrolysis processes. The liquid products, containing the valuable chemical compounds, are obtained in a condensation unit.



Energy consumption, CO_2 footprint and yield of conventional SiC production (left) compared with the RECOSiC process (right).



Example of a RECOSiC E-ABRASIC F600 abrasive (ESK-SiC GmbH), identical with a conventional abrasive agent.



Microstructure of a SiSiC material made from rounded RECOSiC specialized powder.

RECOSiC – recycling of silicon carbide

Dipl.-Krist. Jörg Adler, Dipl.-Ing. Jan Räthel, Dr. Hans-Peter Martin, Dipl.-Ing. Axel Bales, Dipl.-Ing. Heike Heymer, Dipl.-Ing. Matthias Hausmann[2], Dr. Stefan Wild[2], M. Sc. Yvonne Wolff[2], Dipl.-Ing. (FH) Jörg Deutmarg[2] ([2] ESK-SiC GmbH)

Raw silicon carbide (SiC) has been produced for more than 100 years through the energy-intensive Acheson process – the carbothermal reduction of SiO_2. Global production has reached approx. 1 million metric tons annually. Every ton produced requires approx. 7.15 MWh of electricity and causes approx. 4.2 metric tons in CO_2 emissions. 2.4 tons of these emissions come directly from the reaction, while the remaining 1.8 tons are caused by the production of the required energy (based on the European electricity mix). However, as 70 to 80 % of worldwide production takes place in China, global emissions are even significantly higher than that. Additionally, large quantities of low-grade material accumulate when manufacturing the raw material and refining it to obtain specialized products for the ceramics, refractory and abrasives industries (image 1, left).

This is where a research team of ESK-SiC GmbH and Fraunhofer IKTS came in. They developed and patented the RECOSiC process, which allows to convert low-quality raw materials and byproducts thermally to obtain SiC powder with over 98 % SiC content and a grain size distribution suited to the subsequent target products, with the yield coming close to 100 %. The reusable materials thus obtained subsequently undergo well-established powder treatment processes. After these steps, all material characteristics are identical with, or even improved upon, those of products commonly available on the market (image 2). The RECOSiC process improves the CO_2 footprint of SiC production significantly, with less than one metric ton of CO_2 produced for every recycled ton of SiC. Moreover, the bottom line with regard to raw material consumption is much improved, since the novel process requires almost no primary raw materials (image 1, right). Through sophisticated RECOSiC process management, characteristics, such as grain size and shape, doping and polytype content can be tailored to suit the targeted final product, significantly bettering once again the yield of special products compared with conventional processes. In some cases, it is even possible to achieve properties (such as grain shape) that were hitherto unavailable. For the production of SiC ceramics, this opens up whole new options regarding the optimization of processes and properties, e.g. when it comes to more corrosion-resistant refractory products or additive manufacturing (image 3).

An early RECOSiC test plant, with an annual capacity of a few metric tons, is located at the Fraunhofer IKTS site. ESK-SiC GmbH is currently planning a first processing line with 12,000 tons annual capacity. It is set to make its first steps to becoming fully operational within the first half of 2024. Further development stages are already being planned.

It is expected that in the future waste materials from the SiC ceramics industry (such as green products, sinter scrap) can be introduced into the RECOSiC process as well. Assuming suitable logistics for acquisition, even selected SiC products that have reached their end of life could be introduced into a true circular economy.

Services offered

- Investigations of the recyclability of SiC waste materials
- Optimization of SiC materials for specific applications

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Highly thermally conductive silicon nitride ceramics for power electronics

Dr. Eveline Zschippang, M.Sc. Lea Schmidtner, Dr. Mathias Herrmann

Silicon nitride (Si_3N_4) materials are characterized by excellent mechanical and tribological properties even at high temperatures. In addition, the thermal conductivity of Si_3N_4 can be increased to up to 100 W/(m·K) by adjusting the chemical composition and micro-structure. This combination of high strength and good thermal conductivity is unique and leads to a very high thermal cycling stability and long working life of Si_3N_4-based substrates. Fraunhofer IKTS uses these properties combined with the high electrical resistance and the voltage stability of the material in the BMWK project CuSiN (FKZ 3ETE025), which aims to develop active metal-brazed copper silicon nitride composites (AMB substrates) for use as reliable circuit carriers in power electronics.

The effect of the type and quantity of oxide additives as well as of Si_3N_4 powder qualities was investigated by adapting the materials on the laboratory scale. Materials with thermal conductivities of > 90 W/(m·K) could be realized from cost-efficient Si_3N_4 powders with low oxygen content and reduced aluminum impurities.

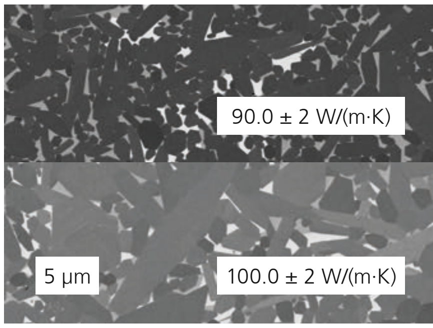
The granule composition developed on the laboratory scale was transferred to pilot scale (10 kg scale). The researchers used the granules, which have good pressing ability, to produce blocks through uniaxial or cold isostatic pressing with dimensions of 320 x 230 x 45 mm and 265 x 195 x 60 mm. The sintering of large blocks requires that temperature gradients which occur during heating and cooling be taken into account. Using modeling, it was possible to estimate critical stresses during the sintering process and optimize sintering. Fraunhofer CSP Halle produced 7.5 x 5.5 inch substrates from the sintered blocks through multi-wire sawing. The substrates thus obtained are of low roughness and high flatness; they do not require any mechanical post-processing of the substrate surface and allow for precise adjustment of the substrate thickness from e.g. 320 µm down to 100–150 µm.

In addition to developing the AMB technology, the team also qualified the methods for characterizing the substrates in terms of micro-structure, thermal, mechanical, electrical, and dielectric properties (see Steinborn et al., p. 62 and Gnauck et al., p. 59).

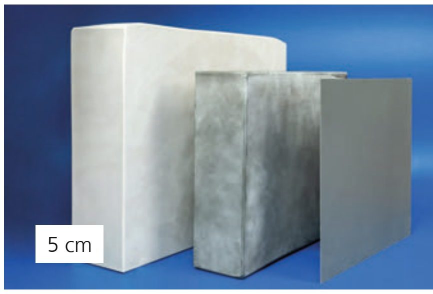
Further optimization of the material and the sintering regime will put thermal conductivities of > 100 W/(m·K) within reach.

Services offered

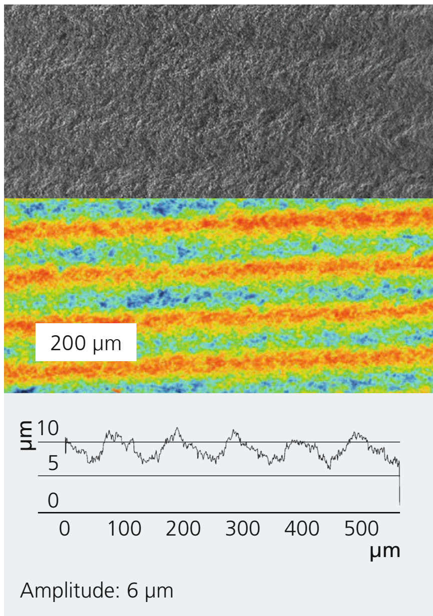
- Application-oriented development of nitride materials
- Characterization of substrates with regard to mechanical, thermal and electrical properties



Microstructure before (left) and after (right) optimization of the sinter process.



Green and sintered bodies made of Si_3N_4 and 320 µm substrate produced from them through multi-wire sawing.



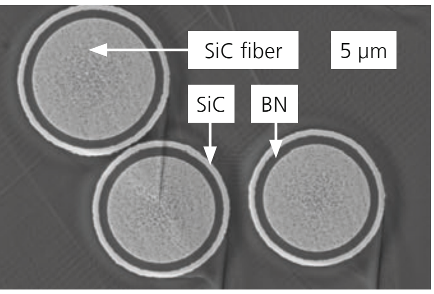
Laser scanning microscope image (left) and FESEM image (right) of the Si_3N_4 substrate surface after sawing.

Roll-to-roll CVD coating system for continuous fiber coating.

Continuous fiber coating for composite materials

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

Winding unit with processed endless fiber roving.



SEM image of a double layer of SiC and BN on a SiC fiber.

Fiber-reinforced composites are used in many areas of industry because of their diverse properties and varied design possibilities. The fibers perform different functions depending on the application. Regardless of the type of composite, the fiber-matrix interface plays a crucial role in adjusting the composite's properties. Defined fiber coatings open up a wide range of possibilities for adjusting properties, and therefore functions. Coatings can be applied to increase the strength of the fiber's bond to the matrix material, and protection from chemical interactions during infiltration with the matrix material can be achieved. The combination of continuous fibers, e.g. those made of glass or carbon, with a ductile matrix, e.g. from plastics or metals, serves mainly to improve the strength and stiffness of these materials. In contrast to this, Fraunhofer IKTS focuses its research on ceramic fiber composites with high fracture toughness and damage tolerance.

For this purpose, a coating system for chemical vapor deposition (CVD) has been set up at IKTS, with which manifold coating technologies and coating variants can be realized, using a 2-chamber reactor system in a roll-to-roll process (image 1 and 2). Both CVD coating chambers can be operated independently of each other with variable precursors at deposition temperatures of up to 1100 °C and coating pressures of up to 100 mbar in the CVD process. During the coating process, a fiber roving consisting of many individual filaments is continuously moving through both coating chambers using the roll-to-roll winding system.

CVD coating for fibers in ceramic composites

Ceramic matrix composites (CMC), which are used e.g. as lightweight materials or in high-temperature processes, require fiber coatings that ensure in particular (in addition to reliable oxidation and corrosion protection of the fibers) the composite's damage-tolerant behavior. The fiber reinforcement helps to avoid the brittle material behavior that is typical for ceramic materials, thanks to crack deflection and fiber pull-out. For non-oxide composites, layers of boron nitride with a hexagonal layer structure (h-BN) are normally used, since they provide favorable pull-out conditions. However, these layers are not sufficiently stable at high temperatures (oxidation resistance at temperatures > 1000 °C) in air. For this reason, Fraunhofer IKTS has developed double layers consisting of an h-BN layer with a protective layer of silicon carbide (SiC) on top (image 3). These double layers can be applied in one single run together with the h-BN layer using the two-coating-chambers setup (single pass processing). Single fiber push-out tests show the desired weak bonding of the coated fibers to the matrix material.

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Gelcasting – shape variability for ceramics

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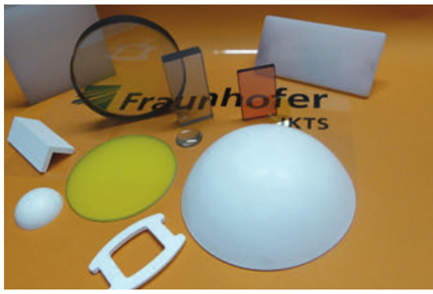
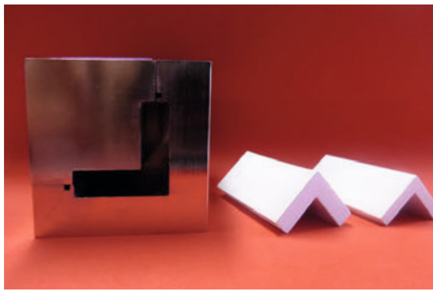
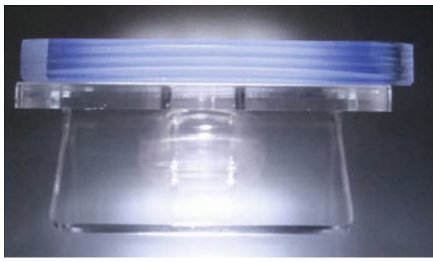


Ceramic parts with high shape variability produced by gelcasting.



Near-net shape technology: mold (left), component after sintering (center) and component after finish treatment (right).

Complex curved $MgAl_2O_4$ ceramic with different wall thicknesses (left) and curved Al_2O_3 ceramic (right).



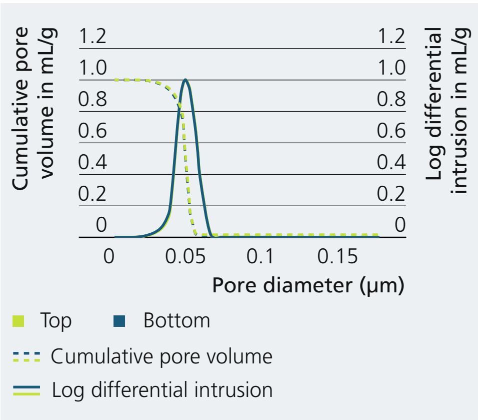
Multilayer gelcasting ($MgAl_2O_4$) of transparent ceramics with alternating doping with and without cobalt.

Gelcasting is a versatile shaping method for fabricating dense ceramic parts with a broad variety of geometries at a very low defect level and with high quality. Homogeneous green bodies of all shapes with a high green density between 50 and 65 % and a narrow pore size distribution can be achieved (figure).

A stable suspension with high densification and homogeneity is a prerequisite for gelcasting. This is achieved with an adequate powder/additive combination and tailored powder processing. A suitable monomer system is added to the suspension to polymerize around the particles and absorb the solvent. In the next step this suspension is cast in molds and consolidated by polymerization. The "gel body" is then demolded and must be dried slowly to prevent cracks. The drying stage is followed by heat treatment. The organic parts are burned out first. With pressureless sintering, a theoretical density of up to 99.5 % is achievable, while pressure-assisted sintering puts 100 % within reach.

Shape variability by bulk and multilayer processing

At Fraunhofer IKTS, we have extensive know-how regarding suitable gelcasting suspensions and appropriate molds. This allows to cast ceramic components, which need less finishing treatment after sintering (image 1). By considering shrinkage, molds can be constructed in near-net shape. It is possible to cast a variety of geometries, such as large blanks, geometries with cavities, sharp edges, and angles (image 2–3), as well as small or thin planar components. By tailoring the polymerization process, it is also possible to perform additive gelcasting layer by layer and introduce different elements for doping or varying concentrations. By increasing the concentration of coloring agents or dopants, an individually tailored color gradient can be achieved. This special gelcasting technique is suitable for manufacturing opaque and transparent ceramics. Image 4 shows an example of alternatingly doped $MgAl_2O_4$. Gelcasting by layers requires a strong cohesion between individual layers, which is realized though adapted process management.



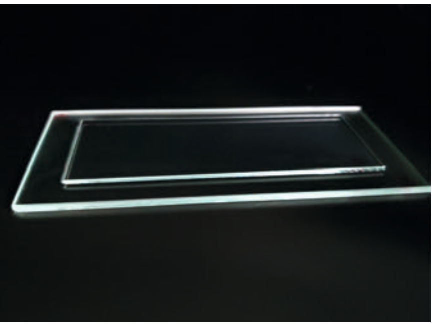
Results of Hg porosimetry of a cylindrical ceramic green body at different positions of the sample (top and bottom section, very homogeneous distribution).

Services offered

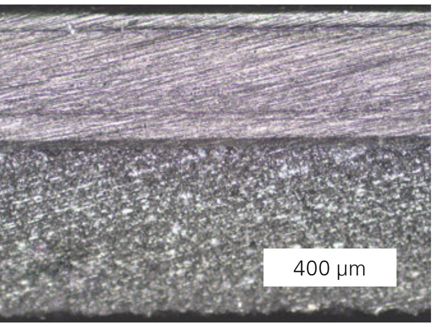
- Suspension development for different raw materials for liquid shaping
- Process optimization for near-net-shape geometries of high-density (opaque and transparent) ceramics
- Development of high-density ceramics with property gradients

Defect-free joining of composite laminates with transparent ceramics

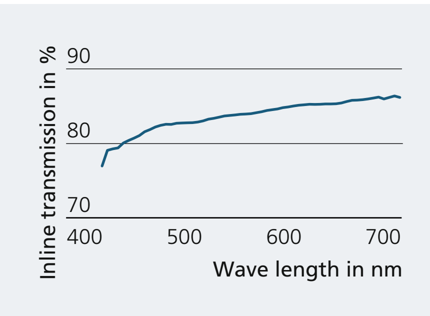
B. Eng. Thomas Grau, Dipl.-Chem. Ralph Schubert



Acrylate-joined composite laminate of transparent spinel ceramic (top) and borofloat glass.



Joint gap of an acrylate-joined composite laminate of transparent spinel ceramic (top) and PET.



Transmission spectrum of transparent spinel ceramics (plate thickness 10 mm).

In the field of modern surface applications, transparent spinel ceramics represent a wear- and corrosion-resistant alternative to commercially available materials such as polycarbonate and hardened or unhardened glass. Even with their polycrystalline structure, they have a comparable optical transparency in the wavelength range of visible light. Various applications such as optical scanners, telephone displays or optical sensors require laminating transparent spinel ceramics with functional components in optical quality. For this purpose, Fraunhofer IKTS has developed technologies for laminating transparent ceramics with thicknesses from 0.2 to 5 mm with glass, such as borofloat glass, or plastics, such as PET or PVC, using acrylate and epoxy adhesives. To avoid dust inclusions, lamination takes place in partially enclosed glass boxes with a supply of filtered air with slight overpressure in a specially insulated clean room.

The technological process consists of the following steps: To clean and activate the surfaces to be joined, all components must be treated in an oxygen microwave plasma. Depending on the chemical stability of the materials, the plasma treatment is preceded by additional cleaning steps, such as treatment in an ultrasonic water bath and with organic solvents.

In the next process step, a dispenser will apply the adhesives. The researchers developed defined coating patterns, which are dependent on the size of the surface to be joined. They enable complete and bubble-free wetting without adhesive transfer to the edges of the laminate structure. Systematic investigations have shown that the lowest error rates and best reproducibility can be achieved with bonding layer thicknesses between 50 and 100 µm.

After applying the adhesive, the components have so far been assembled manually. This process step has proven to be very prone to uneven adhesive distribution and carries the risk of bubbles being trapped in the joining gap. For defect-free and reproducible lamination results, there are plans for the development of a plant concept for the mechanical lamination of components of different sizes and the construction of a laboratory system.

The final technological step includes the curing of the adhesive. If acrylate adhesive is used, this is done through irradiation with UV light. If two-component epoxy resins are used, especially when joining with plastics, curing at room temperature is preferable to thermal curing at 60–80 °C, so as to avoid distortion of the composite laminates.

The favorable mechanical properties of the composites, such as adhesive strength, tensile shear strength and transverse rupture strength, were shown through characterization in accordance with the relevant test standards.

The research and development work was carried out in cooperation with the Materials Engineering department at Ernst Abbe Hochschule Jena, University of Applied Sciences.

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CerAMfacturing: electrically conductive and insulating Si_3N_4-SiC-$MoSi_2$ multi-material parts

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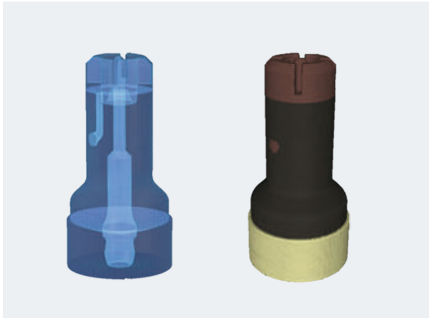
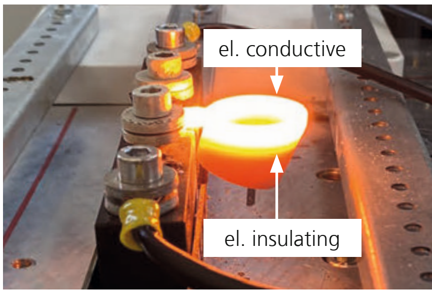


CAD of ceramic igniter for aerospike engines.

Ceramic igniter printed by CerAM MMJ: co-sintered (left); in use (right).



Ceramic heater in use, printed by CerAM FFF (partners: Poly-Merge GmbH, 3D Ceram Sinto Tiwari).

Additive manufacturing (AM) of functional components

In order to meet the ever-increasing demands for the functionalization and miniaturization of components, it is necessary to combine different materials in components with highly complex geometries. Property combinations such as dense/porous or electrically or thermally conductive and insulating in additively manufactured components enable the production of parts with previously unattained properties. AM technologies based on thermoplastic binder systems, in which the materials are applied only at the points at which they are needed, are particularly suitable for the production of multi-material components. These AM technologies also offer the chance to process an almost unlimited materials portfolio.

Electrically conductive and insulating properties in one component

Electrically conductive silicon nitride is a high-temperature-stable mixed ceramic. It consists of silicon nitride (Si_3N_4), an oxide grain boundary phase and one or more electrically conductive components. These can be TiN, SiC and various metal silicides. Because of the special nature of the material structure, even minor changes in composition are enough to make a material conductive or non-conductive. The combination of Si_3N_4-SiC-$MoSi_2$ makes it possible to realize complex ceramic sensors, heaters, and igniters, within one manufacturing step, which can be used at temperatures above 1000 °C (Figures 1–3). At Fraunhofer IKTS, various AM technologies are available for this.

Process diversity at Fraunhofer IKTS

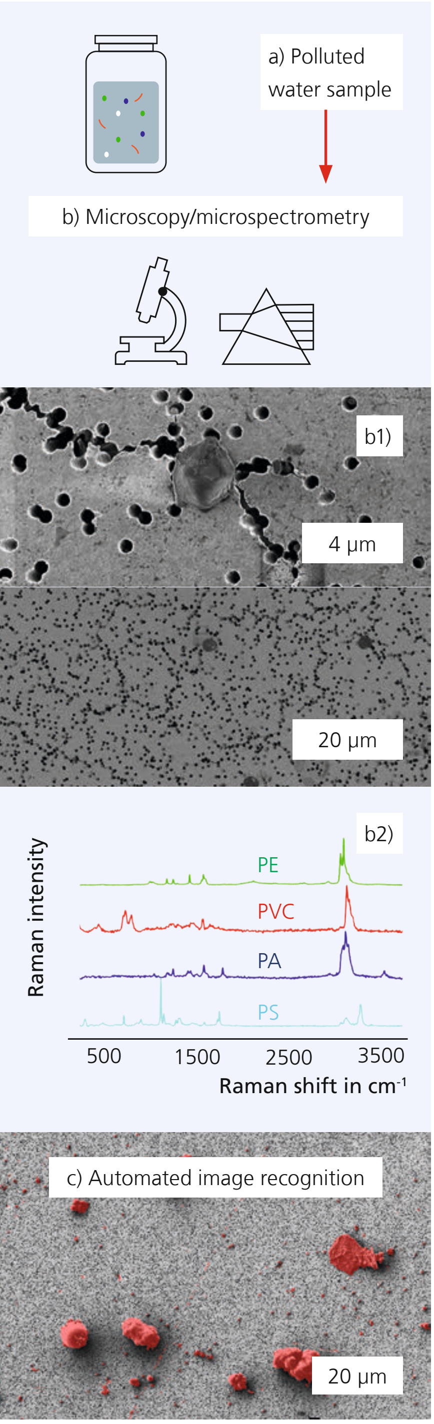
Multi Material Jetting (CerAM MMJ) is a droplet-based AM technology developed at IKTS that enables the manufacturing of components from one or more materials simultaneously by fusing individual thermoplastic droplets. Highly particle-filled thermoplastic feedstocks are deposited in the molten state. The technology is currently being commercialized in the form of an Fraunhofer IKTS spin-off within the framework of an Exist research grant project (03EFQSN180) of the BMWK. Starting 2023, the spin-off – AMAREA Technology GmbH – will enter the market as system provider for MMJ 3D printers and associated printing materials and services.

Fused Filament Fabrication (CerAM FFF) relies on line-based material application. The material is fed in the form of continuous filaments (developed at IKTS) with a wide variety of sintered materials used for particle filling. The existing system technology has a dual print head and thus also offers the possibility of manufacturing multi-functional components.

Services offered

- Component development (design and shaping based on different AM technologies and materials
- Customized filament development and distribution for CerAM FFF

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag



Workflow for water analysis from sampling (a) to filtering (b1) and microscopic (b1) as well as spectroscopic (b2) analysis including automated image recognition using machine learning methods (c).

High-resolution microscopic and spectroscopic methods for water analysis

Dr. George Sarau, Dr. Sabrina Pechmann, Prof. Silke Christiansen

Water pollution with plastics leads to health hazards worldwide. Macroscopic plastic parts weather in the environment to form micro- and nanoparticles (MNPs), which enter our food chain via plants and animals. The continuous monitoring of the extent of these hazards requires standardized reproducible, artefact-free and ideally automated high-resolution microscopic and spectroscopic methods (Figure a, b). This includes appropriate sample preparation. At Fraunhofer IKTS, these methods are established multimodally and across scales. IKTS has successfully validated its methodology in an international round robin study with 22 laboratories led by the Southern California Water Research Project (SCCWRP) [1]. An important factor for this study was the automated evaluation of the plastic MNPs, e.g. in electron microscopic images based on the training of a U-Net for automated particle detection [2,3] (Figure c). Whether these are plastic MNPs or other types of particles (inorganic, organic) must be determined through additional molecular fingerprinting, e.g. by Raman spectroscopy or infrared spectroscopy (FTIR). Different types of polymers (e.g. PE, PS, PA, PVC, PET and others) can be differentiated in this way as well. Using nanoGPS technology [4], high-resolution microscopy (Figure b1) and spectrometry (Figure b2) can be performed on identical particles with a lateral resolution of ~10 µm (FTIR) or ~1 µm (Raman). The analytical workflow established at Fraunhofer IKTS includes a regulation for water filtration in laminar flow boxes with sieves with mesh sizes from macro to nano scales. This is followed by light microscopy for rapid imaging of entire filters and automated counting and classification of particles up to ~1 µm in size, as well as data correlation with sub-1 µm resolution. Spectral matching with standardized reference libraries (commercial/open source) enables reliable mapping of measured particles.

Recommendations for analyses

Using optical spectroscopy (infrared spectroscopy FTIR) and Raman spectroscopy (Figure b1), particles down to ~1 µm can be recorded automatically with measurement times of < 3 min per particle. Workflows for the analysis of plastic MNPs are also established in complex matrices such as tissues at Fraunhofer IKTS.

Services offered

- Standardized water monitoring and high-resolution microscopic and spectroscopic characterization of plastic MNP residues
- Development of customer-specific preparative and analytical workflows for plastic MNP diagnostics in water samples and more complex matrices, e.g. tissues
- Automated segmentation of plastic MNPs using machine learning

Literature

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Decomposition of plastics in real conditions at river mouths

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

Reducing plastic discharge into the sea

The discharge of plastic waste from inland areas via rivers into the sea is the main cause of increasing plastics concentrations in many of the world's oceans. If other measures to prevent plastic emission are not effective, the separation of macroplastics before they reach the river mouth can contribute to the reduction of plastic input.

To design such treatment systems, the plastic load needs to be quantified. Additionally, information on its distribution on the water surface, in the water body, and in the sediment is important. Particle size, shape and density are the determining parameters for this.

Time-dependent properties of plastics

As plastic waste is being transported from its source to the river mouth, the material undergoes constant changes, which any model needs to take into account: the mechanical energy of the water and contact with the sediment accelerate the decomposition of macro- into microplastics. The growth of biofilm influences, among other things, the density. Because of this, plastics that previously floated near the surface may then sink. Previous studies on biofilm formation focused on the (specific) composition of the biofilm, not on the kinetics of mass increase.

Quantifying biofilm growth

In order to close this gap, Fraunhofer IKTS in Rostock is investigating the behavior of plastics in water bodies under real and permanently monitored conditions. Plastic plates are fixed in the Warnow, near the river mouth, and the change of surface and bulk of the material is analyzed at regular intervals while additionally monitoring temperature, pH value, salinity and other parameters of the water.

Polyethylene terephthalate as a case study

Polyethylene terephthalate (PET), a typical plastic that is discharged into rivers as waste in the form of bottles, was deposited for 8 weeks during winter and 8 weeks during summer. The influence of solar radiation was taken into account by fixing the samples at different depths below the water surface. In addition to the increase in mass due to biofilm growth, the change in polymer properties was analyzed using spectroscopic methods and contact angle measurements.

During the same period, a 50-fold increase in mass was detected during summer compared with winter, with the biofilm growth being stronger near the surface than near the sediment.

With the available experimental set-up, plastics and other materials can be tested for their durability under real and constantly monitored conditions.

We would like to thank the German Federal Ministry of Economics and Climate Protection BMWK for the project funding of "DeMARC" (grant no. 03SX556B).

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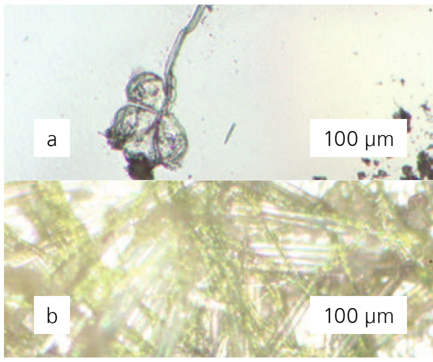
Underwater robot for photo documentation (source: Fraunhofer IGD).

Sample holder at the beginning of depositing.

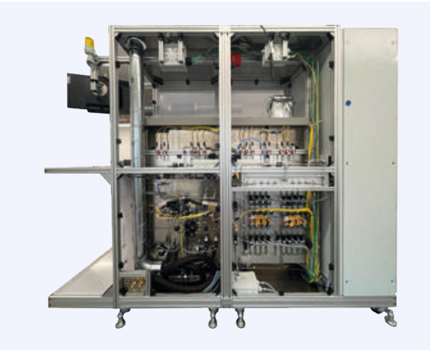


Microscopic image of the biofilm in winter after two (a) and eight weeks (b) near the water surface.

PET samples after 8 weeks near the water surface (winter/summer).

IKTS field test filtration system.

Gas separation system, for external use.



Multifunctional gas phase system (operation at up to 650 °C), under construction, for external use.

CE-compliant membrane filtration plants for applied research

Dipl.-Umweltwiss. Christian Pflieger, Dr. Marcus Weyd

In applied research, it is necessary to develop, build and operate devices or systems. Fraunhofer IKTS often implements complex technical solutions that go beyond standard solutions. It is then a particular challenge to meet the existing legal rules for product and operational safety.

Legal background

When devices or systems are developed and built for own use and for use in a research project, the builder is initially considered the manufacturer. Looking at the applicable legal framework, the Product Safety Act (ProdSG) and its ordinances apply in such cases. According to the Machine Ordinance (9^{th} ProdSV), the researcher, now deemed a manufacturer, must accept what is known as the responsibility for conformity. Operation of these systems requires compliance with the Occupational Health and Safety Act and the Ordinance on Industrial Safety and Health (BetrSichV).

Consequences for the researchers

Research projects and corresponding system developments usually take place continuously and over longer periods of time. The safety of the research operation is ensured at all times in accordance with the occupational safety and accident prevention regulations or by observing the operational safety regulations; a declaration of conformity within the meaning of the ProdSG is therefore not initially required.

However, if the developed technology is used either for routine tasks, or as part of research activities over more than three years, or if it is handed over to an external project partner, a conformity assessment procedure (CE) is necessary to ensure the minimum safety of the product placed on the market. In the field of devices and systems for research purposes, this can only be achieved if everyone involved has this topic in mind and acts responsibly along tried and tested procedures (risk assessment) before the build, i.e. right at the start of development of a prototype.

Established CE conformity at IKTS

Against this background, Fraunhofer IKTS has established a system for carrying out a CE conformity assessment procedure and has successfully applied it several times to sophisticated plant technology, including the characterization of and process development with filtration membranes. Consistent and prudent implementation of the process allows for the safe use of the developed systems, e.g. in the field of membrane-supported liquid and gas filtration, pervaporation, vapor and gas permeation. With this important competence, IKTS continues to establish itself as a reliable partner for prototype systems for solving practical research tasks in the academic environment and in industry.

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Ceramic stack systems for simultaneous filtration and photocatalytic oxidation

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Persistent organic pollutants, such as veterinary and human pharmaceuticals, pesticides and industrial chemicals, typically accumulate in aquatic environments. Conventional water treatment processes are hardly able to remove them completely and without residues, which means a new generation of highly adaptable and versatile, energy- and material-efficient technologies and processes is needed to solve the issue. Such technologies must themselves rely on high-performing materials and material compounds.

Functionally hybrid treatment systems

With this in mind, Fraunhofer IKTS – together with its cooperation partners from Saxony, WTA Vogtland GmbH, Rhode + Wagner Anlagenbau GmbH, and Innotas Elektronik GmbH – is working within the project "MemPhOx" to develop functionally hybrid filtration-photocatalysis-material compound systems that can be combined into stacks. The project combines

- ceramic microfiltration membranes in planar and tubular design,
- cellular ceramic structures with photocatalytically highly effective titanium dioxide coating, and
- energy-efficient, durable and environmentally friendly UV LEDs to stimulate catalytic reactions

into stacks, which are then integrated into continuously operated treatment plants. The compact systems work completely without chemicals. They are self-cleaning and enable the separation of pollutants bound to particulates with concurrent sterile filtration. Organic trace substances are fully eliminated thanks to the oxidation taking place downstream, in the photocatalytic zone.

Energy-efficient UV LEDs

In contrast to conventional UV lamps, UV LEDs provide targeted irradiation within the defined wave range, making it possible to tailor the eliminating effect to suit the needs of the respective application. By integrating the LEDs on thermally highly conductive and long-term stable ceramic plates, the researchers managed to develop a scalable stack system that can be hermetically sealed for immersion applications.

Lab tests with model waters and municipal wastewater have confirmed that the stack system is ideal for eliminating pharmaceutical agents and pathogenic microorganisms. The modular system can be used both at the point of use, as the final treatment step before consumption, and at the point of emission, treating organically contaminated municipal and industrial wastewaters.

Services offered

- Development and characterization of highly porous/cellular ceramic materials and membranes
- Development of ceramic, hermetically sealable LED arrays for LED applications
- Application-specific process design and prototype development
- Process trials under real-life conditions, process assessment

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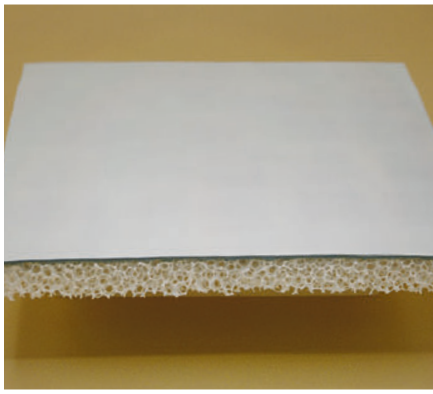
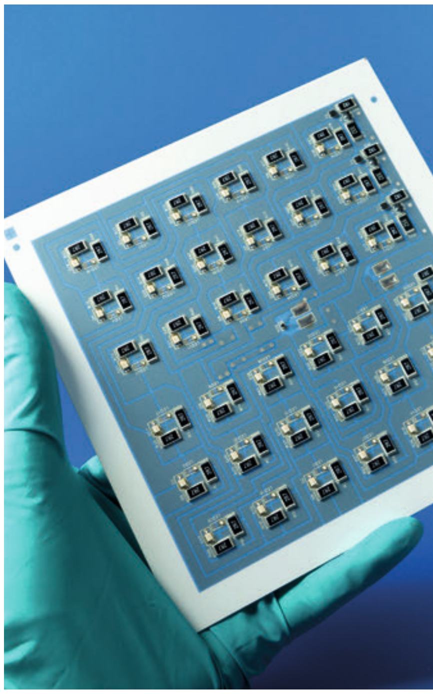
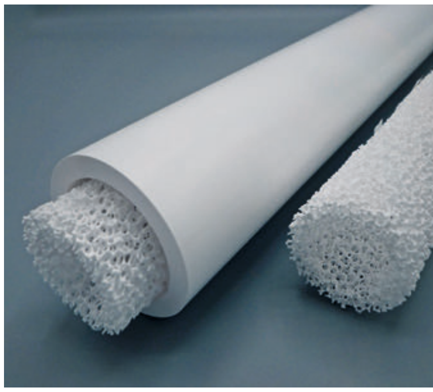
European Union
Europe funds Saxony EFRE European Regional Development Fund



Foam ceramics membrane compound in planar design.



LED array.



Foam ceramics membrane compound in tubular design.

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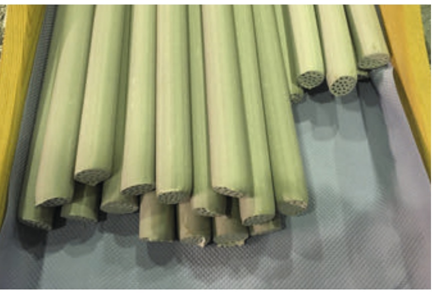
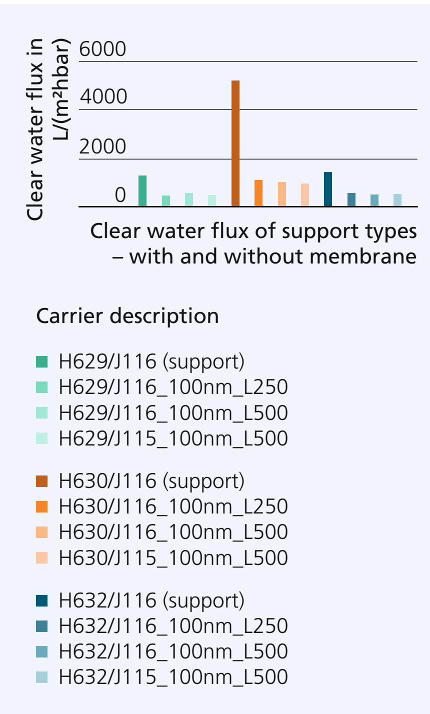
Extrusion tool for the shaping of the green bodies.



19-channel tubular extrudates – "green compacts".



Clear water flux of different support types – with and without a membrane.

KeraMOL – cost-efficient ceramic membranes for drinking water supply

Dipl.-Umweltwiss. Christian Pflieger, Dipl.-Ing. Birgit Köhler, Dipl.-Chem. Gundula Fischer

River mill for drinking water

As part of the KeraMOL project, funded by the German Federal Ministry for Economic Affairs and Climate Action (BMWK), mobile drinking water treatment plants shall, in future, supply small and remote locations in Asia, Africa and Central America with water from surface waters. The planned system types are based on the concept of the river mill, where the system itself floats on the water and energy for water treatment and transport is extracted from the river. The system should guarantee a long service life for the filters used and largely do without electronics and chemicals. To meet these requirements, the project combined cost-effectively produced ceramic membranes and a mineral-metal catalyst (MOL®LIK catalyst), which minimizes scaling and fouling effects.

Goal: cost-reduction for energy and materials

Within the KeraMOL project, Fraunhofer IKTS is developing the membrane support and the membrane synthesis for ceramic filter elements. Previous developments were mostly carried out with a view to particularly aggressive operating conditions, which also led to higher unit costs. For the task at hand, the costs for materials and energy needed to be significantly decreased. The costs for membrane support elements (the porous extruded tube) are mainly due to raw materials and sintering. This is what the new development focused on while also bearing in mind that future elements should also be applicable to micro-, ultra- and nanofiltration.

Development steps

To begin with, a support element was developed based on a tubular single-channel geometry (DA/DI = 10/7 mm). Following the successful development of a low-sintering, coatable support with suitable porosity and high strength, the process was scaled up using the best material system. A 19-channel geometry, an industry-relevant size for tubular filtration elements, was selected for this (outer diameter 25 mm, channel diameter 3.5 mm). Subsequent development steps and the selection of suitable sintering aids finally allowed for a decrease of the firing temperature from 1700 °C to 1430 °C while maintaining surface properties suitable for coating steps. The open porosity is around 30 % and the average pore size (d_{50}) is 3 µm. An Al_2O_3 membrane layer with an average pore size of 100 nm was synthesized on the support elements. The characterization, which used bubble point, ultrapure water flux and COD retention measurements among others, showed positive filtration qualities. The preferred carrier type in the form of complete filter elements is currently being examined regarding chemical stability. Additionally, project partners are running application tests with regard to operational capability.

The authors would like to thank the German Federal Ministry of Economic Affairs and Climate Action (BMWK) for its funding as part of the "Central Innovation Program for SMEs" (funding no.: ZF4076470SA9).

ZIM Zentrales Innovationsprogramm Mittelstand

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Reliable electronic circuit backends for automotive radar applications

Dr. André Clausner, Dr. Matthias Kraatz

The number of radar sensors in automobiles – not least because they are needed for autonomous driving capabilities – is increasing continuously. Therefore, the respective electronics in automobiles must be able to cope with high frequencies. The ARAMID project aims to qualify a semiconductor technology developed by GlobalFoundries for automobile radar applications. For this purpose, Fraunhofer IKTS is developing specific reliability tests for testing on-chip interconnects in the wiring layer (back end of line, BEoL) of semiconductor components.

Electromigration as the basis of reliability testing

Reliability testing of the BEoL in microelectronics typically consists of testing the behavior of electromigration (EM) and time-dependent dielectric breakdown (TDDB). The work in the ARAMID project focused on EM. EM is a transport process of metal ions in conductors. This process takes place at high current densities (~10 mA/µm²), which typically occur in on-chip conductors of microprocessors. The resulting pores (voids) can lead to the conductive path failing through interruption or short-circuiting. Standard EM behavior is tested with DC current, accelerated through elevated temperature and current. To qualify the technology for radar applications, the influence of radio frequency (RF) signals must be investigated additionally. For this purpose, an RF measuring station was set up (top figure). The measuring station consists of a wafer prober with hot plate, a network analyzer, and a combined source and measuring unit (SMU) for current measurement including superposition with DC voltage. Frequencies up to 90 GHz and a temperature up to 300 °C can be achieved with this setup.

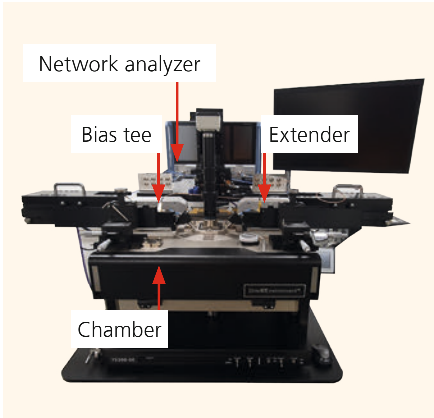
Evaluation of the experimental setup showed that for the temperatures, currents and time ranges used, no differences were initially observed between RF and non-RF. As expected, no resistance changes due to potential EM degradation occurred during the experimental period, which was comparatively shorter than typical long-term EM processes. That is why currents and temperatures are currently being increased.

Thermomechanical-electrical experiments

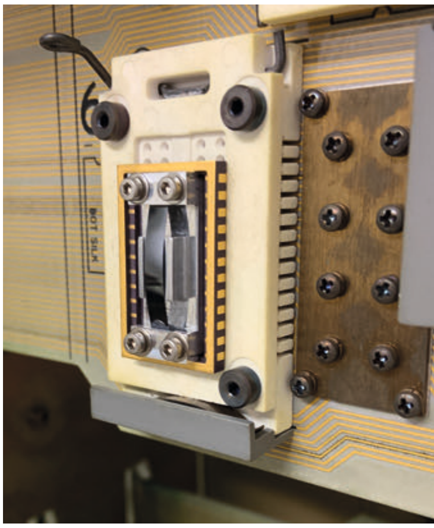
Mechanical stress is another factor influencing EM. It is increasing as more and more power electronics in automotive technology operate at a temperature of up to 250 °C and new usage behavior (car sharing) with more frequent starts and stops leads to a higher number of temperature cycles, which generate mechanical stresses and lead to material fatigue. Therefore, special bending stations (bottom image) are used at Fraunhofer IKTS to investigate how mechanical stresses affect EM behavior. In addition, material fatigue is tested in thermomechanical-electrical experiments under cyclic temperature loading in a climatic chamber.

These investigations contribute to increasing the service life of future microelectronic components for automotive technology and thus also to greater safety and sustainability. They also form the basis for further orders from the field of reliability for automotive electronics.

BOSCH SAB GlobalFoundries

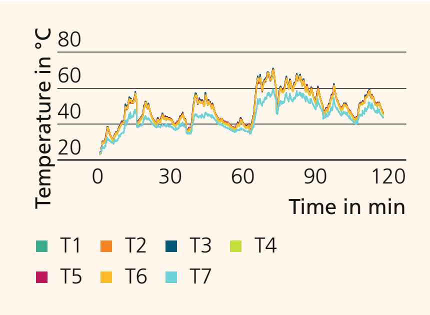


Wafer prober for testing chips on wafer basis.

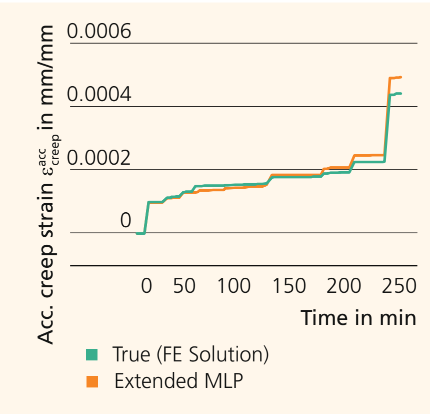


Bending station with bent silicon beam inside an EM oven; the wire-bonded EM chip is on the silicon beam.

E-bike for data collection in the field.



Mission profile data from the e-bike power module (example).



Damage prediction for the e-bike power module.

AI-assisted prognostics and condition management for electronics

M. Sc. Darshankumar Bhat, Dr. Stefan Münch, Dr. Mike Röllig

Not only since the rise of the Internet-of-Things (IoT), the demand for reliable, trustworthy and smart electronics has been steadily increasing. Prognostics and health monitoring (PHM) offers cost-efficient and fast electronic system monitoring and damage-based maintenance planning. Continuous monitoring of electronic systems generates a large amount of data. Ideally, this data should be evaluated without storing it permanently. Machine learning (ML) algorithms, an area of artificial intelligence, are suitable for this purpose.

New approach for real-time prognostics

The methodology we propose here has the potential of becoming a viable solution for online monitoring. As a test application, the power module of an electric bike was chosen (top image). The remaining service life was deduced directly from the thermal loads that occur during the ride (bottom figure).

A large dataset of synthetic temperature-time profiles was generated in order to perform the AI training. The damage of solder joints under these temperature loads was evaluated with finite element analysis (FEA), based on which a multilayer perceptron (MLP) model was trained. Temperature features and corresponding creep increments constitute a training dataset in this case. The accuracy of the trained model is further increased through transfer learning from field tests (mission profile). The remaining useful lifetime (RUL) of this discrete power electronics component under service is then estimated based on the determined lifetime model.

The key achievements of this method are: (1) the extraction of features from temperature-time data, which reduces the need for data storage, (2) efficient training using synthetic data and easy extension to limited real-world data, as well as (3) excellent forecasting capability in real time.

The graph below shows the impressively accurate forecast of creep of the MLP in comparison with the data from FEA. The average error as determined from the test data set is only 6.7 %.

Using the power electronics of the e-bike motor unit, we were able to demonstrate that this methodology is a significant step towards an intelligent PHM implementation. It provides a real-time forecast of the remaining service life – a feature that is critical in other safety-relevant applications, such as in the rail or automobility sectors.

European Union
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Special measuring methods for power electronics

Dr. Lars Rebenklau, Dr. Henry Barth, Dipl.-Ing. Johannes Drechsel, Dipl.-Ing. Mirko Kirchhoff

The range of applications for power electronic modules will continue to grow significantly in the coming years. This development is driven by the high demand in e-mobility and renewable energies. The use of ceramic substrates in power electronic modules is state of the art. This is due to the high electrical insulation strength of technical ceramics combined with their good thermal conductivity. With the use of fast-switching, wide bandgap power semiconductors, such as silicon carbide (SiC) and gallium nitride (GaN), the requirements on electrical insulation strength, mechanical stability, and heat dissipation capabilities of ceramic circuit carriers in power electronic modules are increasing. Application-specific measuring methods are refined at Fraunhofer IKTS to characterize the different assembly stages and components.

Partial discharge measurement

Partial discharge measurement is, as a non-destructive measurement method, well suited for the characterization of the metal-ceramic composite. Internal defects, such as delamination, conchoidal fractures or cavities, are revealed in the form of local partial breakdowns and thus as measurable current peaks in the supply power line. Since both recording and evaluation of the stochastic measurement data require a lot of time and computing effort, a highly automated measurement system is used. The data evaluation is developed further using machine learning based on the visualization methods currently used. The aim is to make the experience gained generally applicable in a data model. In addition to metal-ceramic or polymer substrates, future measurements will also focus on molding compounds and more complex structures.

Infrared thermography

Infrared thermography (IR thermography) is an effective non-destructive and non-contact measurement method. It enables recording heat distribution dynamically. For instance, particularly temperature-stressed areas can be identified locally and temperature gradients on ceramic circuit carriers equipped with bare dies can be recorded. At IKTS, there is extensive experience with ceramic circuit carriers, such as

- DCBs (direct copper bonding)
- AMBs (active metal brazing)
- Copper and silver thick-film substrates.

The measurements focus on thermal conductivity, efficiency and thermal capacity. The entire measurement system can be flexibly expanded. Additional temperature sensors can provide further information on the heat flow and thus enable comprehensive classification of the thermal behavior. A wide range of current sources is available for impressing electrical power into the sample structures and devices. The setup can be adapted to suit user-specific measurement requirements. The thermal power can be dissipated passively to the ambient air or actively via a cooling circuit with thermostat. Depending on the requirements, the thermostat can also be used as a heater.

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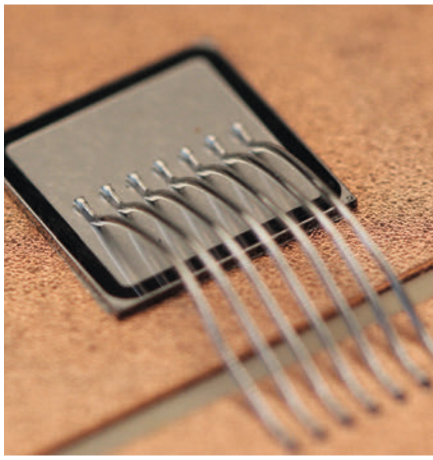
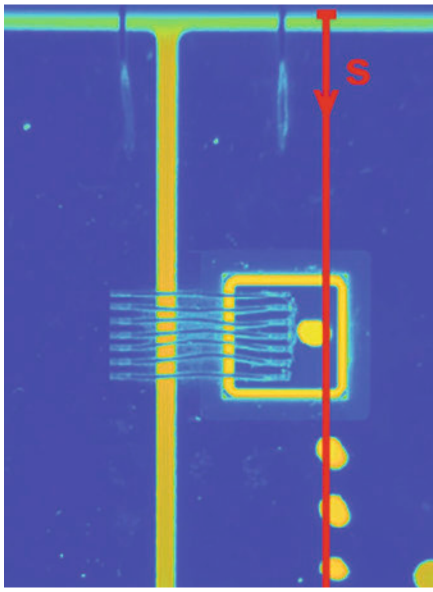
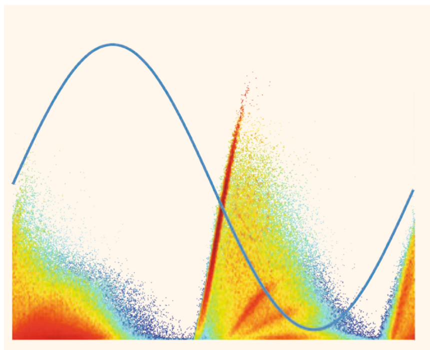


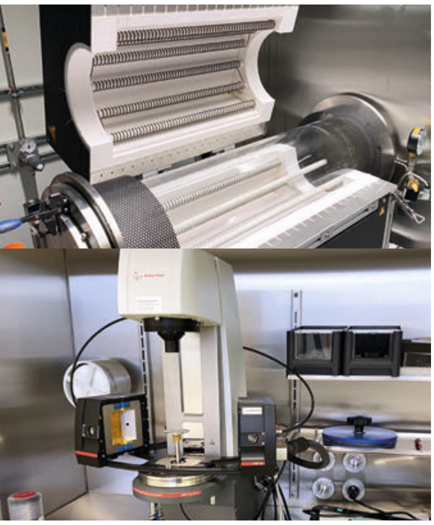
Bonded power diode on a DCB substrate.



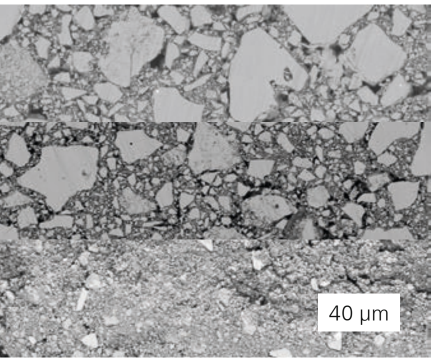
False-color representation of the infrared image of a wire-bonded power diode on a DCB substrate.



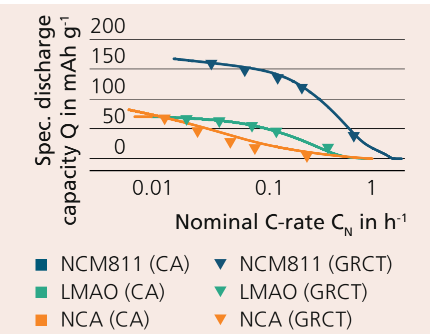
Time-dependent phase-resolved partial discharge pattern of DCB substrates.



Measuring samples sensitive to moisture and air. Top: Furnace integrated in Ar-Glovebox. Bottom: Rheometer integrated in Ar-Glovebox.



FESEM image of sulfidic electrolytes with varied particle sizes.



Capacity rate data from solid-state cells with sulfidic electrolytes vs. different cathode materials (absolute capacity vs. nominal C-rate, chronoamperometry (CA) galvanostatic (GRCT).

Battery development at the Fraunhofer Project Center ZESS

M.Sc. Matthias Seidel, M.Sc. Silian Yanev, Dr. Henry Auer, Dr. Kristian Nikolowski, Dr. Mareike Partsch

The Fraunhofer Project Center for Energy Storage and Systems ZESS is a joint research and transfer platform for the Fraunhofer Institutes IKTS, IST and IFAM, with four main areas of research: lithium solid-state batteries, stationary energy storage systems based on sodium-nickel chloride batteries, hydrogen technologies with high storage densities, and testing technology for quality assurance. The State of Lower Saxony has been supporting these activities since 2018.

For the research into solid-state batteries, new laboratories have been designed and equipped at the Braunschweig site. These provide the infrastructure for the synthesis of electrolytes under inert atmosphere, the manufacture of electrodes and for cell assembly. The processes are analyzed using the appropriate testing technologies. These include, for example, calorimetric and rheological measurements, as well as laser light diffraction. These methods allow for the examination of air and moisture-sensitive materials. In 2023, a new building is planned that will house chemical and technical laboratories, a drying room as well as office space for 100 employees. This makes it possible to bring up the processes tested in the project center to technical scale.

One research focus of Fraunhofer IKTS at ZESS is the development of sulfide-based electrolytes, including the testing of appropriate processing technologies and analytics. The evaluation of the electrodes serves to understand the connection between performance and material properties and thus the further development and optimization of the individual components. The crystal and particle properties must be adapted precisely to the requirements of the final composite. This makes it possible to match the electrochemical properties to the required properties of the solid-state cell. Furthermore, methods for the rapid characterization of these electrodes are being developed further. At ZESS, the method of chronoamperometry[1], optimized for the respective materials, is used. This allows for the components to be examined for their performance properties more quickly and without loss of information, leading to increased efficiency for the research process.

Fraunhofer IKTS contributes its comprehensive expertise in the area of materials and process development for ceramic energy carriers to the four research areas at ZESS. The field of competence covers materials development and the manufacturing of components, such as electrodes and separators, as well as the design and development of complete battery systems. The main focus is always on scaling up processes for industrial manufacturing.

Literature

[1] S. Yanev, H. Auer, C. Heubner, K. Nikolowski, M. Partsch, A. Michaelis, Rapid Determination of All-Solid-State Battery Performance via Chronoamperometry, J. Electrochem. Soc. 169 090519.

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Cold sintering of materials for solid-state battery applications

Dipl.-Ing. Christoph Baumgärtner, Dr. Mykola Vinnichenko, Alf Aurich, Dr. Katja Wätzig, M.Sc. Jean Philippe Beaupain, Dr. Dörte Wagner, M.Sc. Ansgar Lowack, Dr. Mathias Herrmann, Dr. Mihails Kusnezoff

The energy transition and electromobility are leading to a steadily increasing demand for power storage units with high energy and power densities. Currently, lithium-ion batteries with liquid electrolytes are mainly used for this purpose. Solid-state batteries are a promising alternative as they are also particularly safe. Fraunhofer IKTS is investigating innovative approaches, such as cold sintering for the production of components for lithium and sodium solid-state batteries.

Cold sintering

The cold sintering process has been attracting increasing attention in recent years as an energy-efficient sintering technique. In this process, materials are mixed with a liquid phase (water or solvent) and pressed at temperatures below 300 °C and pressures up to 700 MPa. The liquid phase causes dissolution and reprecipitation processes to take place in the microstructure. In this way, materials with densities comparable to those of conventionally sintered materials can be realized at a fraction of the conventional sintering temperature.

Solid electrolyte materials

The process parameters and solvents have been optimized for lithium ($Li_{1.3}Al_{0.3}Ti_{1.7}(PO_4)_3$, LATP) and sodium ion-conducting ($Na_{3.4}Zr_2Si_{2.4}P_{0.6}O_{12}$, NaSICON) solid electrolyte materials. Compared with dry-processed materials, the cold-sintered microstructures have significantly higher densities. After cold sintering at a maximum temperature of 200 °C, the electrolytes have relative densities of more than 90 %. However, scanning electron microscope studies show that amorphous secondary phases form at the particle contacts and between the electrolyte particles (top image). These reduce the ionic conductivity of the electrolyte materials. Thermal post-treatment reduced the secondary phases at the grain boundaries. As a result, ionic conductivities comparable to those of conventionally sintered electrolytes of 1.55×10^{-4} S/cm at 800 °C instead of 1080 °C for LATP [1], and 2.3×10^{-3} S/cm at 900 °C instead of 1300 °C for NaSICON (middle figure) were achieved.

Composite cathodes

Since solid-state batteries do not use liquid electrolytes, cathode composites of active and electrolyte materials have to be used for this purpose. At sintering temperatures such as those required for conventional sintering, the materials used react with each other and lose their electrochemical activity. Composite cathode tapes, developed at Fraunhofer IKTS, show reduced signs of these decomposition reactions after cold sintering at a maximum temperature of 200 °C. In addition, cold-sintered composites have significantly denser microstructures than conventional composites sintered at 750 °C (bottom image). Thus, cold sintering enables completely novel material combinations for the production of high-performance solid-state batteries.

Literature

[1] M. Vinnichenko et al, Nanomaterials 12, 3178 (2022)

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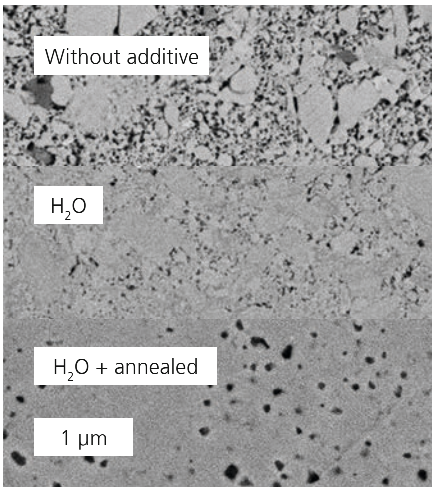
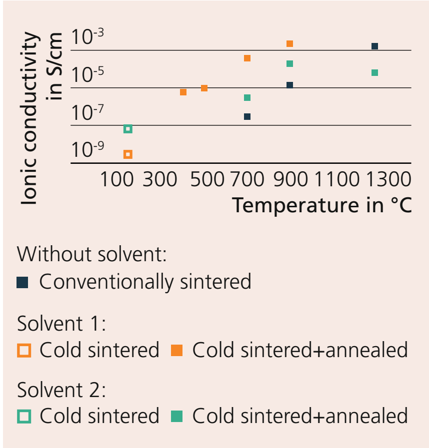
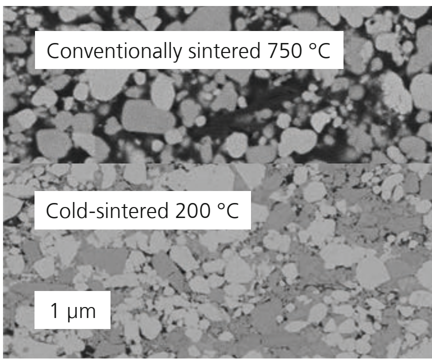


LATP microstructure after cold sintering with different solvents and thermal post-treatment.



Ionic conductivity of conventionally and cold-sintered NaSICON electrolytes.



FESEM images of conventionally and cold-sintered composite cathode tapes (dark = LATP; light = active material).

Fraunhofer Technology Center High Performance Materials THM.

Efficient recycling processes for lithium-ion batteries at Fraunhofer THM

Dr. Sandra Pavón, Prof. Martin Bertau, Dr. Burkhardt Faßauer, Dr. Mareike Partsch

Black mass of end-of-life batteries to be processed for the recovery of valuable metals.

Pilot plant for Li recovery using the COOL process.

The Fraunhofer Technology Center High Performance Materials THM in Freiberg/Saxony is a research and transfer platform of the Fraunhofer Institute for Integrated Systems and Device Technology IISB and the Fraunhofer Institute for Ceramic Technologies and Systems IKTS. Together, semiconductor materials as well as energetic materials and their applications are investigated, addressing the complete value chain, from synthesis to process development to recycling. Furthermore, Fraunhofer IKTS cooperates closely with the Institute of Chemical Technology at TU Bergakademie Freiberg (TUBAF).

One research focus of Fraunhofer IKTS in Freiberg is on the life cycle of lithium-ion batteries (LIBs) – from material to electrode production and assembly, and the future recycling of the materials. The work hones in on holistic and integrated solutions tailored to the requirements of the industry, for a closed battery production loop. The battery electrodes are developed using various pilot plants under lab and dry room conditions (TP -60 °C).

In order to provide the amounts of raw materials required to meet the increasing battery demand for e-mobility in the context of sustainability and the circular economy, environmentally friendly and efficient refurbishment and recycling processes for end-of-life batteries are indispensable. In the field of battery recycling, Fraunhofer IKTS therefore concentrates on concepts and technologies with which material and substance cycles can be closed and recovered material can be reused.

Together with the Institute of Chemical Technology of TUBAF, we are investigating how to scale up the alternative COOL process to recover Li selectively from black mass, as part of the project "EarLiMet – Early Stage Metal Recovery for Energy and Resource Efficient Recycling of Li-ion Batteries". These efforts have shown that 95 % of the lithium can be recovered after leaching with CO_2, forming Li_2CO_3, obtained as a main product in battery-grade quality. Afterwards, valuable raw materials such as cobalt, nickel, manganese and copper remain in the Li-free black mass.

The recovery of these valuable and critical raw materials from the cathode active material (CAM) was investigated within the BMBF project "EVanBatter – Development of a Resynthesis Route of Active Materials for LIBs that is Robust Against Impurities" (funding no. 03XP0340C). The purpose is to determine tolerable contaminant limits for CAM with aluminum and iron to reduce the purification steps within the entire recycling process, thus contributing not only to the reduction of chemicals but also to process efficiency.

In addition, IKTS is planning further infrastructure development at Fraunhofer THM in order to digitize battery production further and to automate recycling processes to a greater degree.

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aufgrund eines Beschlusses des Deutschen Bundestages

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High-temperature electrolysis for the production of green ammonia

Dr. Mihails Kusnezoff, Dr. Stefan Megel, Dipl.-Ing. Christian Eckart, Dr. Erik Reichelt, Dipl.-Ing. Michael Gallwitz, PD Dr. Matthias Jahn

Ammonia is considered a key chemical in a future sustainable energy and raw materials system. It is the most important basic chemical for fertilizer production and thus essential for feeding the growing world population. In the energy sector, ammonia is considered as a future carbon-free energy carrier with high energy density. The starting materials for the synthesis of this important chemical are nitrogen (N_2) and hydrogen (H_2). In the EU-project ARENHA as well as in the BMBF-funded project GreatSOC, Fraunhofer IKTS investigates ways to convert renewable energies into ammonia in the most efficient way.

High-temperature electrolysis

The supply of green (sustainably produced) hydrogen can only be achieved on a large scale via electrolysis. High-temperature electrolysis (SOE) operated at 700–850 °C has an outstanding role here, as it can produce hydrogen in a particularly energy-efficient manner through various heat integration options (electrical energy requirement: 3.2–3.5 kWh/Nm³ H_2). Cells, stacks and stack modules for this technology are being continuously developed and tested at Fraunhofer IKTS.

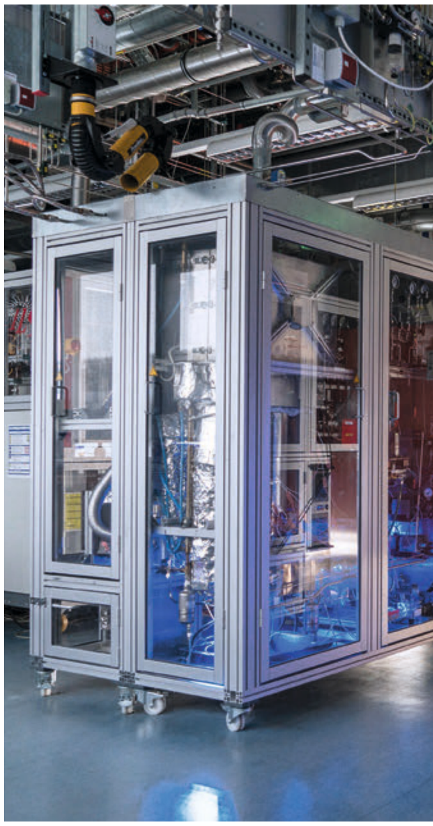
For ammonia synthesis, a reactant gas mixture of nitrogen and hydrogen in a ratio of 1:3 is required. The results presented in Figure 2 show that nitrogen admixture in electrolysis has no influence on the power required to supply hydrogen. This forms an important basis for innovative concepts for the supply of synthesis gas for ammonia synthesis via high-temperature electrolysis.

Sustainable concepts for the production of ammonia mostly focus on the production of the synthesis gas (N_2, H_2) for the downstream Haber-Bosch reactor, in which the actual conversion to ammonia takes place. When using low-temperature electrolyzers, air separation is required as an additional process step for the recovery of nitrogen from air. High-temperature electrolysis, on the other hand, allows the synthesis gas to be produced and supplied directly. For this, part of the hydrogen produced can be reacted with air to supply nitrogen. The resulting water can be converted back into hydrogen in the electrolyzer.

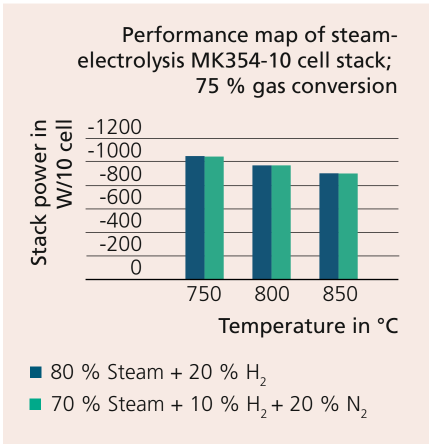
An additional advantage is that high-temperature electrolysis can use the waste heat from exothermic process steps, such as ammonia synthesis, to increase energy efficiency. This enables up to 10 % lower energy requirements for ammonia production compared to low-temperature electrolysis-based process concepts.

Unique core competencies of Fraunhofer IKTS, such as the simulation of individual process steps/reactors and their coupling with experimentally obtained operating data, allow an optimized process design up to demonstration.

We thank the European Union for funding the ARENHA project under the Horizon 2020 research and innovation program (funding no. 862482) and the German Federal Ministry of Education and Research BMBF for funding the GreatSOC project (funding no. 01DR22005A).



Demonstration plant for the coupling of high-temperature electrolysis and ammonia production.



Power requirements of SOE stack for hydrogen production at different operating temperatures and a current density of 600 mA/cm².

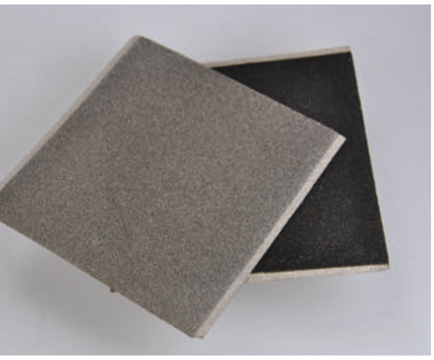
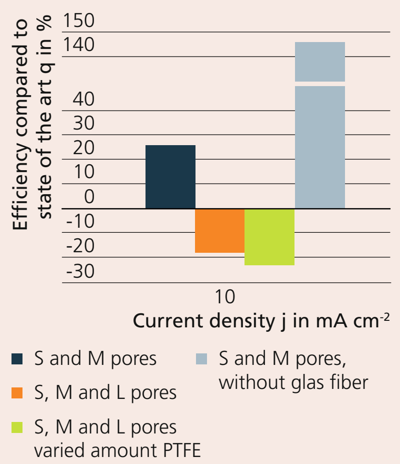
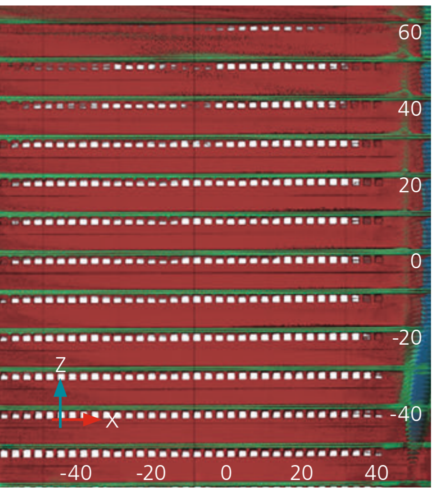


Image of ceramic-coated 3D electrodes for AWE.



Electrode performance vs. standard electrodes (GDE) for alkaline water electrolysis.



Computed tomography image of an externally placed stack.

Trends in alkaline and AEM water electrolysis for green hydrogen

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

The alkaline (AWE) and anion exchange membrane water electrolysis (AEMWE) will continue to produce the world's largest share of green hydrogen in the future. Fraunhofer IKTS is setting new trends on the materials and components side and supports the market ramp-up with development services.

The start – electrode architecture

IKTS developments of bi-functional electrodes for oxygen reduction and evolution make it possible to derive insights for an optimized electrode architecture. During electrolysis, the relevant physicochemical processes need to be harmonized: oxygen conversion, electron conduction and e.g. simultaneous transport management of liquid and gas phases. The latter in particular is much more demanding compared with purely gas-based systems, such as PEM or SOEC fuel cells. The results presented in the central figure show that an intelligent layer structure of 3D electrodes in a zero-gap design leads to improved transport or removal, respectively, of product gases, and in turn to increased electrolysis activity.

Methods for reducing CAPEX in alkaline and AEM water electrolysis

Installation costs (CAPEX) for hydrogen production by water electrolysis are evaluated in relation to the respective power consumption. Thus, increasing the amperage while keeping costs constant is an important lever for reducing CAPEX. Beside adapting electrode architectures, such increase can be achieved by varying the core components of the water electrolysis. Fraunhofer IKTS is developing ceramic coatings for electrodes, fully inorganic, scalable diaphragms and high-performance flowfields. In particular, the development of components for increasing temperature and pressure are promising tools for increasing performance. These merge into a production-ready stack design (electrochemical flow cell reactor in filter press design). With various possibilities for the post-mortem analysis of stacks (e.g. industrial computer tomography, impedance spectroscopy on components etc.) design decisions can be made based on a solid data base.

Development of electrolyzer systems and automated stack manufacturing

At the Fraunhofer IKTS site in Arnstadt, electrodes and stacks are being developed with a particular focus on digital processes. One core element of these efforts is the engineering of highly automated test stands with up to 10 kW or more for liquid electrolysis, from PEM to AEM to alkaline. In addition, test fields and containers are provided on open spaces, e.g. for 20 kW medium-temperature electrolysis. Automated stacking of large-area stacks for alkaline and AEM water electrolysis is another priority. A broad range of 6-axis industrial robots is available for this purpose. These are integrated into an automated, vision-based manufacturing concept for stacks in alkaline and AEM electrolyzers. The latter can have an active area of up to 6400 cm^2 or more with an end plate weight of up to 200 kg.

Freistaat Thüringen Ministerium für Wirtschaft, Wissenschaft und Digitale Gesellschaft
RLS Reiner Lemoine Stiftung

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A novel cell concept for sodium-based medium-temperature batteries

Micha Philip Fertig, Dr. Karl Skadell, Dr. Matthias Schulz, Prof. Michael Stelter

Measuring cell with sodium-beta alumina and transition metal oxide active material (Source: EL-CELL).

The Energy Transition requires batteries

Stationary electrochemical energy storage systems are essential for excess energy storage and to ensure secure energy supply. High-temperature batteries are already being used commercially for these purposes ("ZEBRA cell"). In contrast to Li-ion batteries, ZEBRA cells are operated without cobalt and lithium, which are rare elements, and therefore expensive. In the new cell system sodium acts as the negative electrode. The amount of sodium in the earth´s crust is a thousand times higher than the amount of lithium. Hence, it is cheap and available in almost unlimited supply. Another crucial component is the ceramic solid electrolyte: sodium-beta alumina. ZEBRA cells have been successfully improved by Fraunhofer IKTS and are currently being commercialized in cooperation with a business partner.

Sodium-beta alumina – the heart of the battery

Fraunhofer IKTS has engineered materials and processes for the production of sodium-beta alumina, achieving high phase purity and density. Therefore, the solid electrolyte exhibits outstanding chemical, electrochemical and mechanical stability and is ideal for use as an ion-conducting solid electrolyte in batteries. In contrast with conventional organic electrolytes, it is also non-toxic and non-flammable.

The success of transition metal oxides

Today´s Li-ion cells rely on transition metal oxides ("NMC"), which function as positive electrodes. Their high energy density and cost efficiency make them extremely successful – even gaining their discoverers a Nobel Prize in Chemistry in 2019. However, powerful sodium-based lithium analogs are also available, so these high-performance transition metals can be used in sodium-based cell systems as well.

A novel cell concept – combining powerful cell components

At Fraunhofer IKTS, sodium, sodium-beta alumina and transition metal oxides are combined in a novel cell concept, which is suitable for stationary energy storage.

Utilizing a special polymeric composite cathode creates a safe solid-state battery with high specific energy. By integrating the composite positive electrode, IKTS was able to reduce the operating temperature to only 80 °C. The disk-shaped sodium-beta alumina solid electrolyte is advantageous for production and battery pack construction.

Due to the active material´s phase transitions, the battery´s lifetime is still limited. However, improvements are being made, for example by introducing stabilizing agents into the crystal lattice ("doping"). Simultaneously, the cell resistance is optimized by producing even thinner sodium-beta alumina solid electrolytes. Fraunhofer IKTS's development goal is a commercial solid-state battery with high specific energy, which is sustainable and safe and can be utilized for stationary energy storage.

Disk-shaped solid state electrolyte made of sodium-beta alumina.

BATTERIE 2020

Supported by: Federal Ministry of Education and Research on the basis of a decision by the German Bundestag

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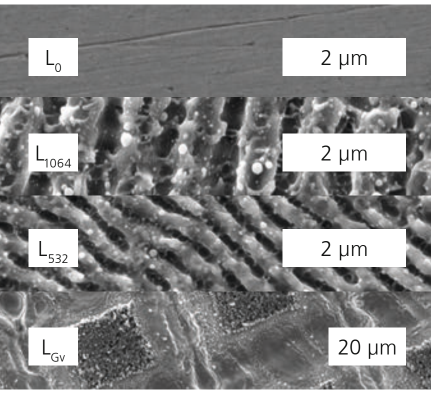
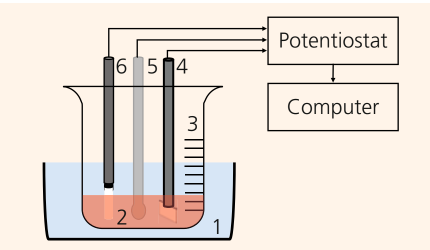


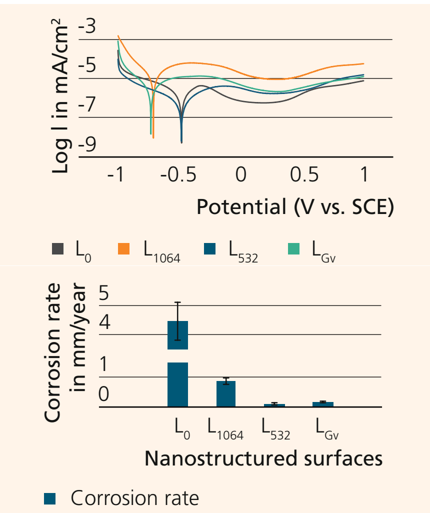
Surface morphology of untreated (Lo) and laser-treated stainless steel samples by picosecond laser system.

Improved stent properties by laser-induced periodic surface structuring

Dr. Natalia Beshchasna, Dr. Muhammad Saqib, Dr. Joerg Opitz



*Experimental setup for electrochemical measurements on stents. 1. Circulating water bath 2. Hank's Balanced Salt Solution (HBSS) 3. Glass beaker 4. Counter electrode: platinum sheet (25*25 mm²), 5. Reference electrode: saturated calomel electrode (SCE) 6. Working electrode: TiON stent.*



Corrosion behavior of LIPSS surfaces: Tafel curves (top) and bar chart for corrosion rates (bottom).

For several decades, stents have been successfully applied to treat coronary artery disease. Despite this fact, the biocompatibility of stents still needs to be further improved, in particular with regard to antirestenosis, endothelialization and corrosion.

In collaboration with the University of Modena & Reggio Emilia (Italy), NanoPrime (Poland) and the University of Latvia, IKTS researchers investigated the influence of laser-induced periodic surface structuring (LIPSS) on stent properties. This is a promising surface modification technique to influence the migration and proliferation (growth) of cells as well as the corrosion rate of metallic stents.

Three test scenarios

For the tests, AISI 316L stainless steel plates (2 mm in thickness and 10 mm in diameter) were prepared through laser cutting and polishing and were subsequently treated by an EKSPLA Atlantic 5 picosecond laser (beamlines of 1064 nm and 532 nm wavelength). The focus was on three different laser treatments: two, L_{1064} and L_{532}, aimed to obtain a uniform distribution of LIPSS, while the third, L_{Gv}, was supposed to generate a grid of grooves 40 µm in spacing.

Biocompatibility was assessed using human umbilical cord mesenchymal steam cells. The morphology, wettability and structure of the surfaces were evaluated through scanning electron microscopy with energy dispersive X-ray analysis (SEM-EDX), contact angle measurements and laser profilometry.

All LIPSS samples showed increased roughness compared with the reference state and changes of wettability from the hydrophilic to the hydrophobic state. Electrochemical corrosion tests demonstrated the increased corrosion resistance of the laser-treated surfaces associated with their hydrophobic behavior. Among all LIPSS samples tested, the L_{532} specimen demonstrated the highest corrosion resistance and the highest cell attachment and proliferation with significant influence on cell shape and directional growth along the nanogrooves.

Promising results

The results of this study show that stent surface properties may be enhanced through the application of micro- or nanopatterned coatings or surface modifications. In addition, the treated surface has a positive effect on cell-material interaction by suppressing in-stent restenosis and promoting reendothelialization. Since LIPSS structures are capable of mimicking natural nano-properties of vascular tissue, there is great potential for biological transformation.

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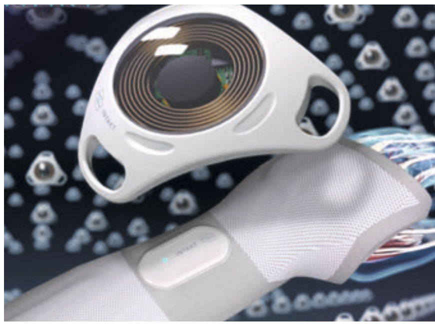
Implant housing with optical window made of transparent ceramics

Dipl.-Ing. Olaf Sandkuhl, Dr. Daniel Schumacher, Dr. Sabine Begand



INTAKT single implant design (Source: Wilddesign GmbH).

Within the INTAKT innovation cluster, partners from industry, science and medicine have worked on a unique research project with a focus on the therapeutic use of interactive micro-implants. Under the leadership of Fraunhofer IBMT, 18 partners have been working on the development of new digital medical products designed to provide the most beneficial solution to patients by establishing new technologies which ensure reliable, life-long use of implants. Three applications were addressed: tinnitus suppression, the restoration of grasping functions and the treatment of gastrointestinal dysfunctions.

The aim of the INTAKT research project was to develop a completely new generation of actively networked micro-implants which can provide forward-looking approaches for improved human-technology interaction. Networked single implants (image 1) communicate with the doctor or patient via external interfaces. In the future, such direct communication will allow physicians to obtain data-secure access to relevant information and to optimally tailor treatment to the patient by externally controlling parameters and stimulation modes.

With the acquisition of the transparent ceramics division of CeramTec-ETEC in April 2021, IKTS has continued the work in the sub-project addressing gastrointestinal dysfunctions.

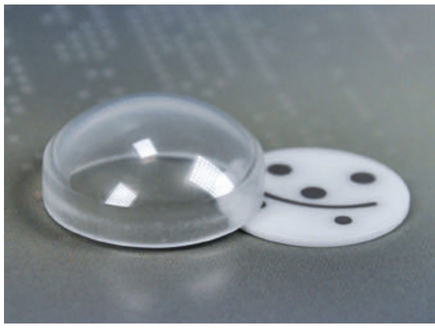
The task was to develop a rigid and hermetically sealed ceramic housing with sufficient break resistance and an optical window. For this purpose, the researchers selected the transparent ceramic magnesium-aluminum spinel. The requirements for the ceramic were biocompatibility, transparency in the IR range (λ = 1.07 µm) and sufficient fracture strength. An optical window was incorporated to enable signal transmission.

Two shaping technologies were tested: slip casting and manufacturing through hard machining from solid material.

CeramTec-ETEC produced first-generation housing demonstrators made of PERLUCOR® through hard machining from solid material. Fraunhofer IKTS produced the casing lid demonstrator through slip casting and thus also evaluated this technology for a monolithic casing lid. Once the final design was available, a further small series of the second-generation monolithic casing lids could be produced from spinel ceramic (image 2). Initial in-vitro tests with assembled implants (image 3) returned promising results. The sensor structure, the support plate and the power supply were developed by project partners. The Fraunhofer IKTS working group is certified for medical products according to ISO 13485, enabling further improved development and manufacturing of the prototype.

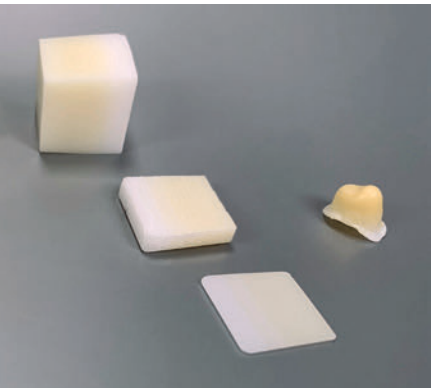
Spinel housing with support plate (Source: Wilddesign GmbH).

The 5-year project is initiated and funded by the German Federal Ministry of Education and Research (BMBF) within the research program "Bringing Technology to the People" under the project number FKZ 16SV7652.



Implant with sensor component.

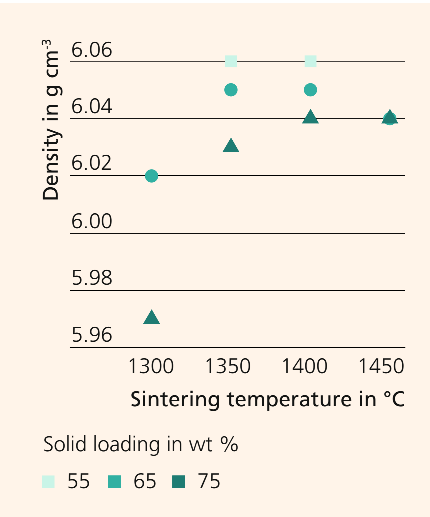
INTAKT



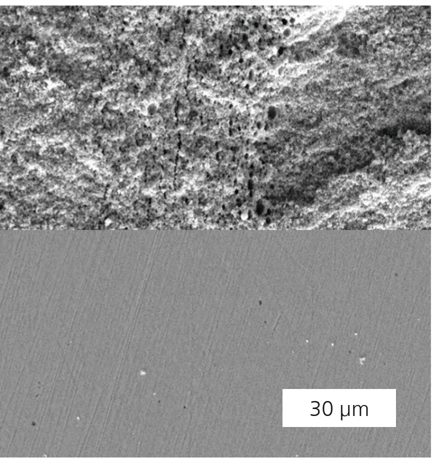
Pressure slip casting of multilayer blanks for dental restoration

Dr. Daniel Schumacher, Dr. Sabine Begand

Sintered multilayer blank and milled crown made from a multicolor blank.



Density as a function of solid loading and sintering temperature at a casting pressure of 15 bar.



SEM image of the interface, partially sintered (top) and sintered (bottom).

For more than two decades, zirconia has seen growing interest for applications in the dental market. The industry network Aegis Communications predicts an annual sales growth of up to 9.3 %. Patients place increasing importance on aesthetic aspects. This puts a strong focus on the development of cost-effective processes to adapt color and translucency. Zirconia offers several advantages over other materials: good biocompatibility, reduced plaque deposits and low thermal conductivity. Additionally, health risks from allergic reactions are unlikely.

Pressure slip casting

Pressure slip casting is used to produce technical ceramics on an industrial scale. For some years now, this technology has also been used in dental ceramics. In particular, the processing of slips with a small particle size is a major challenge. Small particle sizes are a crucial requirement for highly mechanically loaded components, e.g. in dental restoration.

Good aesthetics without veneering

IKTS scientists were able to manufacture multilayer blanks for dental restoration through pressure slip casting within a joint project with an industrial partner. Gradients in color and translucency of natural teeth were implemented as early as in the shaping process, whereas previously it had been necessary to veneer the material with glass or glass-ceramics in a complex subsequent step to meet aesthetic requirements. Two major concepts were vital to implement the process: the doping of zirconia offers a straightforward approach to alter color and translucency. Additionally, tailored mixing of slurries with different dopants allows for gradients without the formation of visible layers.

Color gradients with doped slurries

After selecting a suitable mold material, the researchers defined optimized process parameters for the preparation of the slurries by agitator bead mills. With a particle size of 0.18 µm, a specially designed pressure slip casting cell allowed for the generation of a homogeneous and dense microstructure with good mechanical properties. Subsequently, process dependencies such as the influence of solid loading (55–75 %) and casting pressure (15–25 bar) on density and microstructure were investigated. During the casting process, the precise addition of slurries with different dopings resulted in the generation of multicolored blanks with 20 mm height. These components meet the high standards set in terms of color gradient and translucency. At the interface of the differently doped slurries, no inhomogeneity was found after sintering. Besides aesthetics, these multicolor blanks also exhibit very good mechanical properties (biaxial strength of 1050 MPa). Final machining experiments with a dental milling machine confirmed the high suitability of the blanks for the manufacturing of multicolor restoration material.

For applications in the field of medical technology, we provide the customized development of oxide ceramic components and technologies as well as customized manufacturing of semi-finished products. For this scope, we are certified according to DIN EN ISO 13485.

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Full-volume quality control and online evaluation of carbon fiber fabrics

Prof. Henning Heuer, Dirk Hofmann, Martin Küttner, Jürgen Michauk, Martin Oemus, Christian Pilz, Matthias Pooch, Maren Rake, Scally Joyce Scharbow, Martin Schulze, Till Schulze, Nikolas Wohlgemuth

Multiaxial high-performance carbon fiber (NCF) cannot yet be fully inspected inline. The available optical methods do not allow a view of hidden layers and thus of invisible defects in the material. This concerns in particular the hidden 0°-orientated layers. Therefore, a multi-channel eddy current system was developed at Fraunhofer IKTS, which tests CF textiles non-destructively inline, at high speed and full production width.

Proven basis

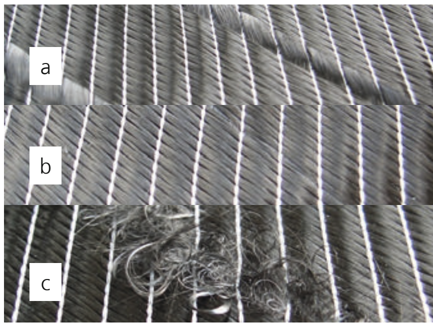
The industry-proven EddyCus® Pro-II measurement system by Fraunhofer IKTS is the cornerstone of this new technology. It enables the detection and evaluation of hidden carbon fiber layers inside a multiaxial layer structure. The modularly expandable sensor elements allow production widths of up to 101 inches to be inspected without blind pixels, inline and at production speeds of up to 5 m/s. The system can classify metallic contaminants and sewn-in carbon fiber fluffs clearly, in addition to automated gap detection, defect size evaluation and fiber orientation measurement. The inspection system records information of the conductivity state in real time while maintaining high lateral resolution – contactless without damaging the material. This is made possible by combining several eddy-current channels with sensor-integrated multiplexers and a powerful edge server for data analysis.

Applications

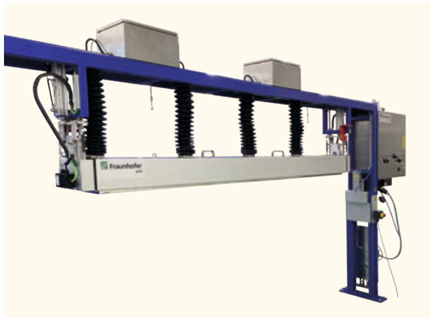
- Inline production monitoring of up to 101 inch width during the production of NCF plies (for gaps, undulations, ply build-up, inclusion of foreign material) especially in hidden and non-visible layers
- Inline inspection of layer and wall thicknesses and electrical layer resistance of high and low conductive layers on wafers, battery tapes, conductive coatings on glass and plastic in nanometer resolution

Properties of the test system

- Cascadable system with channel multiplex rate of up to 100 KS/s
- Consisting of 4 EddyCus® Pro-II devices and 12 array sensors
- Up to 25 MHz eddy-current excitation frequency with integrated multiplexer
- Maximum pixel resolution: 0.853 mm
- ATEX-compliant for zone 21 (IP 68)
- Temperature compensation
- Data analysis and system control through included edge server
- Optional Ethernet-based OPC-UA for smart factory applications
- Analog and digital I/O for communication with production line
- Algorithms for automated calibrations especially for inhomogeneous and anisotropic materials, such as NCF (non-crimp fabrics)

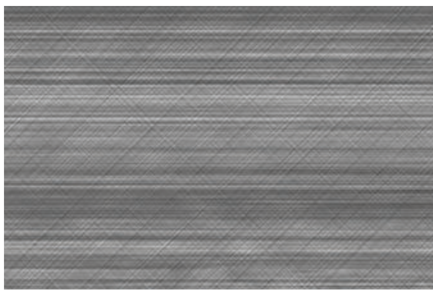


Potential defects during NCF production: a) gaps, b) overlapped tows, c) fringes.



Eddy-current inspection system.

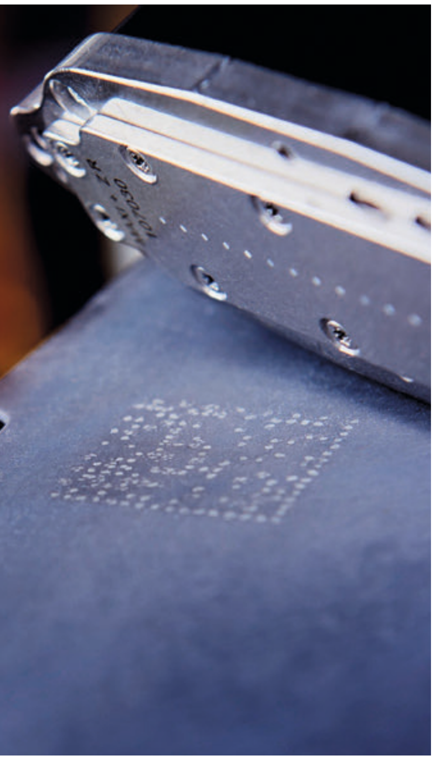
EddyCus® Pro-II ECA measurement bar for 101 inch inspection width, stacked sensor arrays.



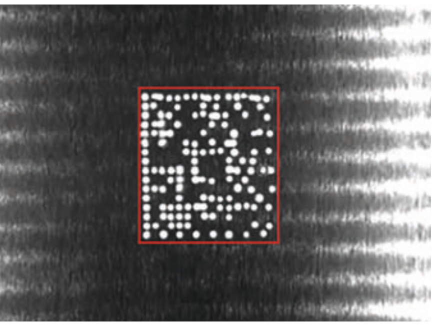
Eddy-current C-Scan, 101 inch wide.

Process digitization in the metal industry

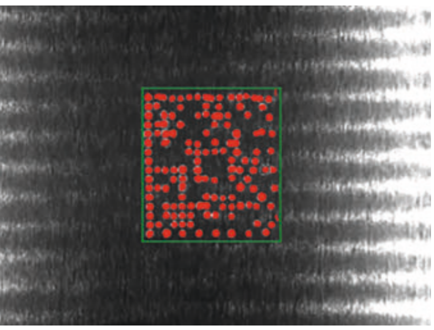
Peter Bischoff, Dr. Manuela Heymann, Dr. Christiane Schuster, Prof. Thomas Härtling



Data matrix code on hot-formed metal sheet, printed with an industrial printer.



Automatically detected region of interest for a data matrix code.



Detection of printed dots for detailed print image evaluation.

For the digitization of production processes, the individual identification of the manufactured components is a prerequisite as production parameters and component condition can only then be combined. Particular challenges arise in metal processing. While cold-manufactured metal components are being marked since a long time, high process temperatures of over 1000 °C prevent consistent marking of other components. The melting of surfaces, tarnishing, scaling and potentially occurring corrosion make conventional marking methods impossible in many cases.

The Ceracode® technology

For these difficult applications, Fraunhofer IKTS has therefore successfully developed the high-temperature Ceracode® ink, which is marketed by the IKTS spin-off Senodis Technologies GmbH. This ink is used to print markings (such as data matrix codes) on metal components using standard industrial printers, before these are further processed in high-temperature steps. The high temperature causes the ink components and the metal surface to bond, resulting in a permanent marking. The marking is already being used for press hardening in production lines at automotive manufacturers. This forming technology is used to produce high-strength crash-relevant body elements, like A, B, C pillars or battery boxes.

The marking process has passed the stage of technology development and is available as a product of the marketing partner. Against this background, Fraunhofer IKTS is now tackling new applications that go beyond the pure component identification (track-and-trace).

Opening up new applications in process digitization

In addition to recording the code content (e.g. serial production number), the identification allows process parameters (like furnace dwell times, press forces, tools used) to be assigned to individual components. Thus, the granularity of process digitization is increased and can be used for optimization via the digital twin of the production process. On the other hand, the marking process itself can be monitored and thus made highly reliable by automatically analyzing the print image immediately after printing.

Fraunhofer IKTS and Senodis are pursuing the latter together in the BMWK joint project "Ceracode Digital" (grant no. 16GP105802). Automated image segmentation (differentiation between print pattern and background) makes it possible to detect smallest individual deviations, e.g. print dots deviating from their target position. The characteristics of the print determined in this way allow print failures to be detected and prevented at an early stage. In addition, it can also be used to verify the authenticity of components, which will be of great relevance in the future, e.g. for recording component-specific CO_2 footprints.

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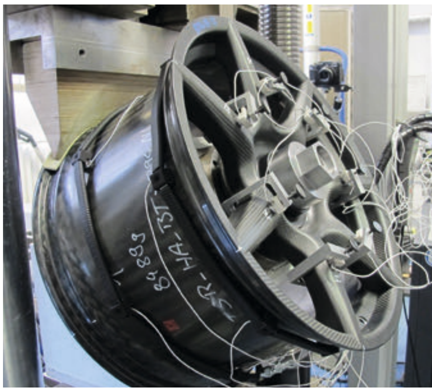
CoMoBase3 – new hardware platform for acoustic condition monitoring

Dr. Bianca Weihnacht, M.Sc. Thomas Klesse, Jörn Augustin, Sebastian Sonntag, Richard Kienitz, Dr. Lars Schubert



CfK rim testing with acoustic emission analysis.

The continuous acquisition of data enables online condition monitoring of infrastructure and comparison with digital twins. Collecting a wide range of data during operation, for example via acoustic condition monitoring, is therefore an important goal.

CoMoBase3

CoMoBase3, a hardware platform developed at Fraunhofer IKTS, will meet the high demands associated with this task. It is designed for autonomous, long-term monitoring of technical structures and facilities. This includes both active ultrasonic (acousto ultrasonic) and passive methods (acoustic emission analysis) in the frequency range from 1 kHz to 8 MHz.

The multi-channel acoustic measurement system is ready to use for acoustic sensor networks and suitable, for example, for the surveillance of pressure tanks or pipelines in industrial plants, with the option to synchronize the operating data directly with the measurement data. The piezoelectric sensors are applied either to hot spots or on a larger surface. With the help of online and offline analysis, damage indicators are defined and provide information about the condition of the structure. Another application is the monitoring of fatigue tests. Damage progression can be displayed as early as in the test phase.

The system has a modular design and can be equipped with up to 32 synchronous channels at 20 MS/s, depending on the monitoring task, and has a resolution of 16 bits.

Sensor solutions

The hardware can be combined with a wide range of sensor solutions for various surveillance tasks. These are available for different frequency ranges, but also for high-temperature applications as well as for measurements in ATEX zones.

Application areas

Typical areas of application for this measurement technology include fiber composites such as carbon fiber reinforced plastic (CFRP) and glass fiber reinforced plastic (GFRP), for example in pressure tanks, pipelines or rotor blades. But the hardware can also be used for metallic infrastructure components, such as tanks or pipes. The two measuring methods can be used to detect a wide range of corrosion damage, such as cracks, wall erosion or pitting. In addition, the hardware is also suitable for the non-permanent testing of components.

Permanent monitoring of pressure tanks with guided waves.

Funding

The development was carried out in the project "QuantCarbon" funded by the Sächsische Aufbaubank under the application number 100393561.

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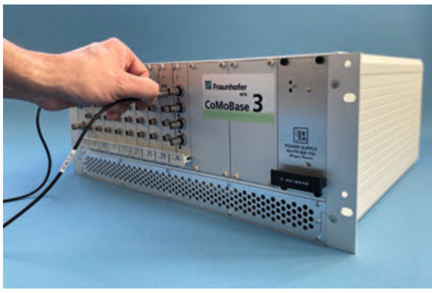

Acoustic measurement system with 32 channels.

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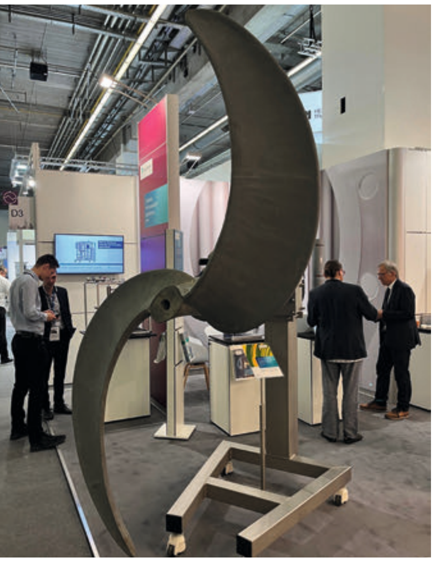
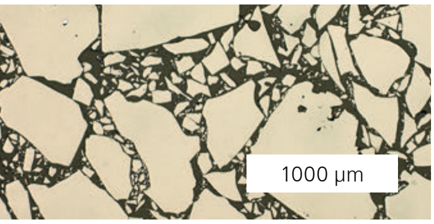
Pilot impeller during coating process (source: SiCcast GmbH).

Wear- and corrosion-resistant stirrer for fermenters in biogas plants

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



Pilot impeller on a trade fair stand after the two-year application test.



Typical material structure of the polymer-ceramic composite (source: SiCcast GmbH).

Propeller with (center) and without coating (right) after tribotests in the laboratory.

Due to the complex characteristics of the fermentation substrates, stirrers made of metallic materials, plastics or glass fiber reinforced polymers only achieve service lives of a few thousand operating hours. In addition to the increased maintenance effort, it is problematic that the wear and corrosion of the stirrer, which already sets in after a short operating time, negatively affects the mixing process in the fermenters. The main requirements for stirrers are determined by the chemical (pH value, heat of reaction, high salt content, H_2S), mechanical and tribological conditions in the fermenter.

As part of the joint project "MaRüFerm", Fraunhofer IKTS, together with the agitator manufacturer RTO GmbH and the mineral casting specialist SiCcast GmbH, developed a wear-resistant coating for fermentation stirrers. It consists mainly of a cold-curing polymer-ceramic composite that can be applied in variable layer thicknesses to metallic, ceramic and polymer materials. This coating technology allows not only new stirrers to be reinforced, but also already worn agitator equipment to be refurbished in a time-efficient and cost-effective manner.

The polymer-ceramic composite has a very high media stability and no fouling tendency. Thanks to its strong damping properties, it is damage-tolerant and insensitive to impacts despite its high ceramic content. In a tribotest on scaled impellers, the reinforcement showed a wear rate lower by a factor of 5 compared with stirrers made of polyamide 12.

Technological testing took place in a two-year long-term test of a reinforced industrial pilot stirrer (Ø 2500 mm, speeds of up to 60 rpm) in a biogas plant.

The impeller showed extremely low wear over the course of this period and confirmed the tests in the laboratory scale. The results indicate that such reinforced fermenter stirrers can be used in continuous operation in biogas plants for more than 10 years without any significant loss of stirring performance.

Image 4 shows scaled impellers after the tribotests. Stirrer (PA 12) in its initial state (left), stirrer (PA 12) after the high wear test (right), stirrer coated with the developed reinforcement after the wear test (center).

Services offered

- Characterization, development and optimization of agitators
- Material development of ceramic-based wear protection coatings
- Characterization of tribological and corrosive effects
- Manufacture of sample components

Supported by: Federal Ministry of Education and Research on the basis of a decision by the German Bundestag

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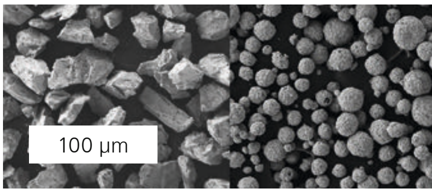
Novel hard materials for the development of wear-resistant brake discs

Dr. Johannes Pötschke, Dr. Susan Conze, Dr. Lutz-Michael Berger



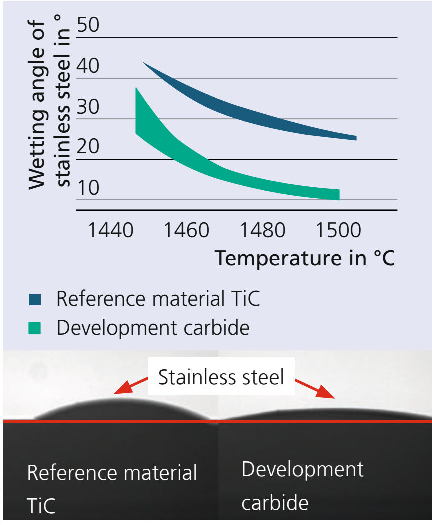
s&c (left) and a&s (right) feedstock powder.

The new mobility concepts of the 21st century require technical adaptation of all components. Brakes are the central safety system of every vehicle and in their current conventional form, they no longer meet technical, ecological and legal requirements. For this reason, Fraunhofer IKTS works on innovative material solutions for laser and surface technology for a new generation of brake discs. The aim is to ensure the required braking performance, the active and passive safety of vehicles, passengers and road users, and a drastic reduction in particulate emissions for millions of these components.

As part of the SAB project BremsCLAD, IKTS develops carbide materials embedded in a metal matrix and optimized in terms of their function. The project partners C4 Laser Technology GmbH and Fraunhofer IWS apply these materials to the cast iron brake disc base body through high-performance laser cladding. In this process, the carbide and metal powders are mixed by a customized powder nozzle system and applied to the rotating brake disc via a laser beam.

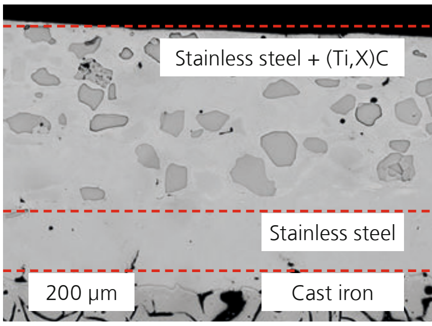
The new carbide materials developed at IKTS are produced using industrial processes, such as sintering and crushing (s&c) and agglomeration and sintering (a&s). The latter are also suitable for the production of pre-compacted carbide metal powders. The development carbides (Ti,X)C show a comparable or superior hardness of up to 2530 HV0.1 compared with the reference material TiC with 2420 HV0.1. Likewise, increased density in the range of 6 g/cm³ (TiC: 4.9 g/cm³) allows for improved flowability and a smaller particle size, which in turn enables reducing the coating thickness.

For a low-defect coating of carbide material and metal matrix, the carbide material was further optimized with respect to the wetting behavior of the metal matrix. Wetting angle measurements show that, depending on the chemical composition, the wetting angle can be halved compared with TiC (Figure 2). This leads to a homogeneous and dense coating produced with less laser power and thus lower energy consumption. Alternatively, the production of binder-containing carbide powder (carbide metal powder) was investigated in order to achieve improved wetting with the metal matrix during laser processing.



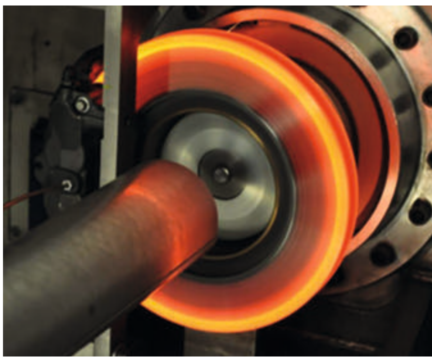
Wetting behavior compared to stainless steel.

With optimized developing carbides, it is possible to realize a material-efficient and cost-effective coating with lower coating thickness and reduced hard material content. At the same time, the faster heat transfer to the cast-base body reduces the thermal load of the coating in use. Currently, the brake discs coated with the development carbides are being tested with the project partner, C4 Laser Technology GmbH



Coating system on cast iron.

The SAB project BremsCLAD (funding no. 100552819) is financially supported by the EU and the Free State of Saxony from funds of the European Regional Development Fund (EFRE).



Brake disc during a test program.

CAD rendering of the reactor – cross-section of substrate (left), overall structure including heater structure (right).

Ceramic reactor for more eco-friendly satellite propulsion systems

Dr. Uwe Scheithauer, Dr. Lars Rebenklau, Dr. Henry Barth, Dipl.-Ing. Eric Schwarzer-Fischer, Dipl.-Ing. Leon Berger

Reactor including electrical contacting.

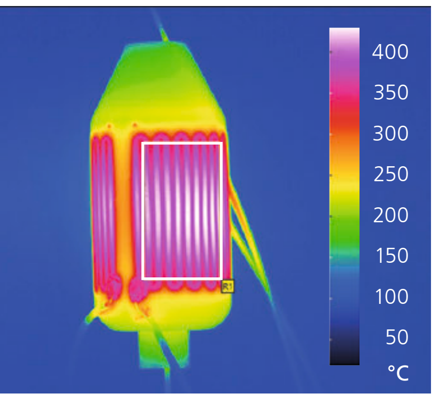


Image taken with an IR camera during heating.

Satellite thrusters are used for attitude control and orbit transfer, as well as end-of-life de-orbiting to avoid space debris. These engines are mostly powered by highly toxic and expensive propellants, such as hydrazine, which are increasingly being replaced by more environmentally friendly alternatives, such as hydrogen peroxide (H_2O_2).

The induction of the necessary decomposition of H_2O_2 into water and oxygen (oxidizing agent in the combustion process) is currently carried out catalytically. Silver nets or granules coated with platinum or MnO_2 are used for this purpose. Apart from its high costs, the fact that the process is not very dynamic causes problems, as satellite engines must work in finely tuned pulses to achieve the required accuracy.

Thermally induced decomposition of H_2O_2 as a green alternative

As an alternative to the catalytically induced decomposition of H_2O_2, thermal induction of the strongly exothermic reaction (T > 1000 °C) is also possible; the reaction then continues to proceed in a stable manner without further energy input. This requires temperatures above 150 °C, but no catalytically active materials.

Additively manufactured and functionalized ceramic components offer a promising approach. The reactor developed at Fraunhofer IKTS (image 2) combines several properties that offer significant advantages for the application scenario. The applied heater structure enables a high-performing induction of the decomposition reaction. The Al_2O_3 used for the substrate is superior to metallic materials in terms of chemical and thermal resistance and also has a low density. The complex component geometry (image 1) results in a directed fluid flow, which ensures very good mixing and prevents overheating of the externally applied heater structures despite the high reaction temperatures inside.

Combining unique IKTS competences

The manufacturing of the reactor relied on a combination of unique competences of Fraunhofer IKTS. The Al_2O_3 substrate is manufactured additively through the CerAM VPP technology followed by sintering at 1650 °C. Subsequently, the heater structure including the insulation layer and contact pads was applied by means of rotary screen printing in a thick-film process. The functional materials used for this were then sintered at 850 °C in a second thermal processing step. Finally, wires for electrical contacting were joined by means of adapted micro-welding processes and the assembly points were covered in a thermally stable manner.

Reliable operation up to 400 °C has already been demonstrated in the laboratory. Extensive real-life tests are planned for the spring of 2023. Additionally, an expansion of the material portfolio to Si_3N_4 and AlN is in progress.

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Study on the kinetics of flexibly operated iron ore direct reduction

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

The steel industry causes approx. 7 % of global anthropogenic CO_2 emissions and is therefore currently one of the biggest emitters of CO_2. The direct reduction process, as an alternative route to conventional steel production, offers enormous potential for CO_2 reduction, especially as it ideally facilitates the changeover to sustainable power generation and can be implemented relatively shortterm.

In direct reduction, pelletized iron ores are converted into sponge iron using gaseous reducing agents, instead of coal and coke as in the conventional blast furnace process. Natural gas can be used but regeneratively produced reducing gases, such as hydrogen or syngas, are also suitable. The flexible operation of direct reduction plants with dynamic changes in the raw material base can offer enormous advantages compared with stationary operation. It is conceivable to control production for grid-connected services while making optimal use of volatile renewable energy sources, and to increase economic efficiency and resilience to changes in the energy market.

To evaluate the potential of the process, knowledge of the reaction kinetics of flexible direct reduction is essential. As part of the BMBF-funded project "BeWiSe", a direct reduction plant was implemented on a laboratory scale, which makes it possible to investigate the reaction kinetics on individual iron ore pellets at different process gas compositions and reaction conditions up to 1000 °C and 8 bar. In addition, the system is equipped with an automated conveyor unit, which allows the reactor to be filled and emptied while it is still hot, thus ensuring that experiments are carried out in a time-efficient manner.

Based on the experimental work, a comprehensive kinetic model is currently being developed in which the influence of each significant parameter is considered. The necessary quantification of the reaction rate constant is very complex due to the many different mechanisms involved. For the heterogeneous gas-solid reaction, the kinetic regime can be determined through the pore diffusion of the gases within the pellet, solid-state diffusion of Fe^{2+} and O^{2-} ions or by nucleation and growth during the phase transition. In the presence of carbon-containing components in the process gas, the formation of carbidic phases, the deposition of pure carbon and the water gas shift reaction also occur.

The model developed will be used to simulate the transition conditions that occur in the flexible operation of the direct reduction process in order to be able to predict energy demand, the degree of metallization and other process parameters.

In addition to the direct reduction of iron ore, the plant, which is unique at Fraunhofer IKTS, can be used for a variety of other applications in the field of pressure-loaded high-temperature processes.

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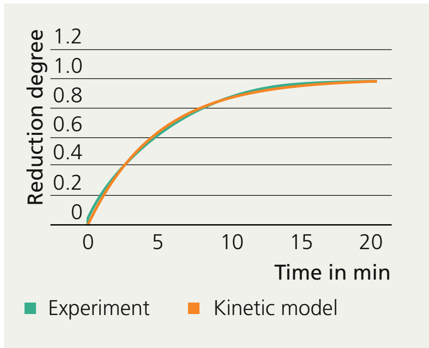
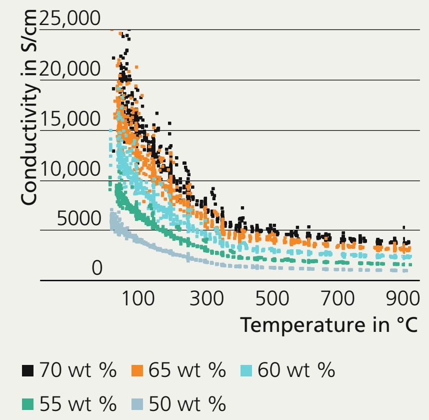
Lab-scale direct reduction plant.

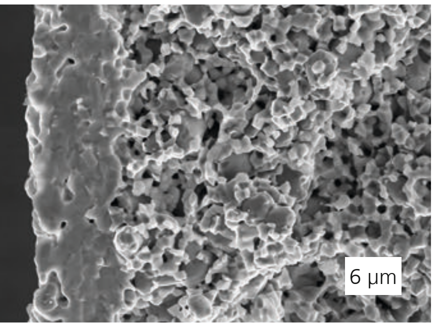
Pelletized iron ore.



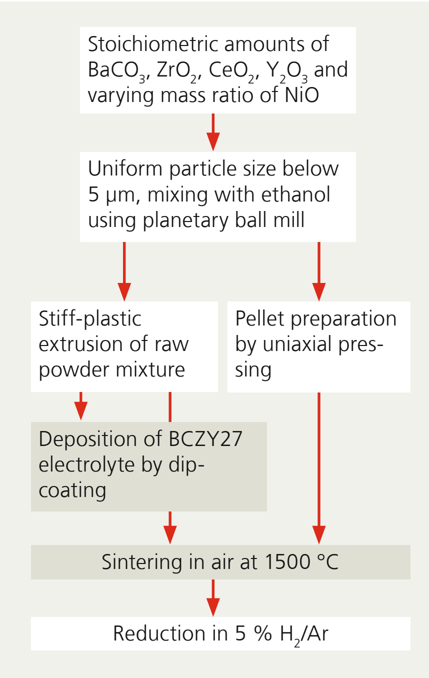
Reduction curve of a direct reduction pellet in H_2 and comparison to kinetic model.



Electrical conductivity of Ni-BCZY27 by varying Ni content.



SEM of a dense BCZY27 electrolyte layer on Ni-BCZY27 support.



Manufacturing route of the ceramic supports.

Tubular membrane-electrode assembly for solid-state ammonia synthesis

Dr. Olga Ravkina, Dr. Robert Hoffmann, Dr. Ralf Kriegel

The desired conversion to a low-emission economy requires the development of innovative CO_2-free processes for energy conversion and the adaptation of existing industrial processes. In addition to methanol, ammonia plays a major role as a completely carbon-free energy source for that transition process. Compared with hydrogen, ammonia has a significantly higher energy density and can be stored and transported more efficiently and cost-effectively as a liquid.

Ammonia is already one of the most important and most-produced basic chemicals worldwide. However, the current state of the art – ammonia synthesis using the Haber-Bosch process – is one of the largest sources of CO_2 emissions and is responsible for up to three percent of global fossil fuel consumption. The development of alternative synthesis routes for green ammonia will therefore become a major challenge of the next decade.

Solid-state ammonia synthesis

A possible solution is being pursued as part of the joint project CAMPFIRE 04 with partners from the Leibniz Institute for Plasma Science and Technology (INP), the Hydrogen and Fuel Cell Center (ZBT) and the Leibniz Institute for Catalysis (LIKAT). The investigations focus on decentralized solid-state ammonia synthesis (SSAS) based on thin-layer-based membrane-electrode assemblies, using renewable energies (power-to-ammonia). The SSAS is an electrochemical ammonia synthesis route, in which a direct conversion of atmospheric nitrogen and water evolves in a membrane reactor. On the anode side, water is decomposed into oxygen and protons. The protons are transported to the cathode via a proton-conducting membrane to the cathode, where they react directly with atmospheric nitrogen.

The heart of the membrane reactor, the tubular porous composite support (metal/ceramic) for the hydrogen-conducting electrolyte was developed at Fraunhofer IKTS. The tubular design is crucial for the pressure stability of the membrane reactor. The open-pored support also enables rapid gas-phase transport thanks to its fine pore structure.

The optimized percolation structure consisting of metallic nickel and ceramic proton conductor ($BaCe_{0.2}Zr_{0.7}Y_{0.1}O_3$) is the prerequisite for the high electric conductivity of the membrane support.

Fraunhofer IKTS developed the recipe for the stiff-plastic extrusion of raw powder of the support composition and adapted it to the requirements of the final component strength. Values of 86 MPa were measured for tubes with an outer diameter of 10 mm, which represents a satisfactory pressure stability.

Services offered

- Customer-specific support and membrane development for the SSAS
- Plastification of ceramic starting powders and extrusion of tubes and honeycombs of different geometries

Supported by: Federal Ministry of Education and Research on the basis of a decision by the German Bundestag

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Zeolite membranes for the energy-efficient separation of CO_2 from biogas

M. Sc. Alireza Taherizadeh, Dr. Adrian Simon, Dr. Hannes Richter

Membrane technology is ideally suited for the energy-efficient removal of CO_2 from biogas. Inorganic membranes are suitable candidates for CO_2 separation because they have a high hydro-mechanochemical stability and good permeation properties. Zeolites, for example, have special properties, such as an intrinsic molecular sieving capacity, which means they can separate molecules of different sizes. Additionally, they are capable of preferential adsorption of certain gases. Chabasite (CHA) zeolites were chosen to fabricate membranes that separate CO_2 from biogas (CH_4). Pore size in the CHA framework is similar to CH_4 molecules but larger than CO_2. In this research project, ultrahigh-flux CHA membranes with a high Si/Al ratio (SSZ-13) were produced for CO_2/CH_4 separation.

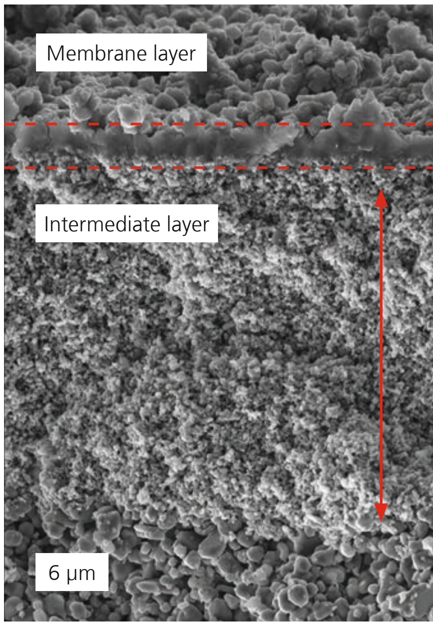
Asymmetric porous Al_2O_3 monotubular supports (10 mm outer diameter, 7 mm inner diameter, 200 nm average pore size in the separation layer, and a membrane surface area of ~17 cm²) were chosen for the zeolite membrane (top image).

To evaluate the separation properties of the membrane, the permeation of single gases (middle figure) and the more complex permeation of binary gases (bottom figure) were analyzed. The single gas permeation of SSZ-13 membranes was tested at room temperature (here the dominant separation mechanism is adsorption) and at 150 °C (diffusion). In both cases, CO_2 has the highest permeance of the tested gases. The ideal CO_2/CH_4 permselectivity reaches up to 112 with a CO_2 permeance of around 11 m³/(m²hbar).

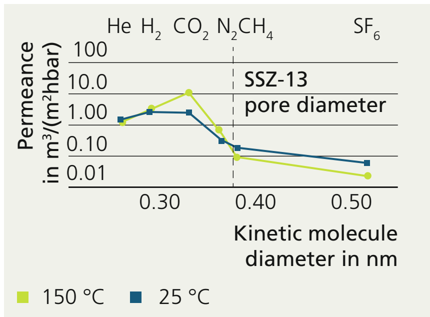
During the mixed gas permeation measurements, a gas mixture of 50 vol % CO_2 and CH_4 each was evaluated at room temperature with two different feed pressures. At the feed pressure of 2.55 bar, the CO_2 permeance is high at ~5 m³/(m²hbar) and the permeance of CH_4 is around 0.033 m³/(m²hbar). Accordingly, a CO_2/CH_4 selectivity of > 150 was achieved. An increase of feed pressure to 6.05 bar led to a decrease of the CO_2 permeance down to ~2.5 m³/(m²hbar) and an increase of the permeance of CH_4 to ~0.045 m³/(m²hbar). The CO_2/CH_4 selectivity of the SSZ-13 membranes decreased at higher pressure, but still reached a satisfactory value of ~57.

The results show that the novel zeolite membranes provide excellent separation performance – both in terms of CO_2/CH_4 selectivity and CO_2 permeance. These membranes thus offer, for the first time, the possibility of separating highly concentrated CO_2 from biogas in an energy-efficient manner in just a single membrane stage. The next step is now to upscale the membranes with partners from industry while maintaining the same separation performance.

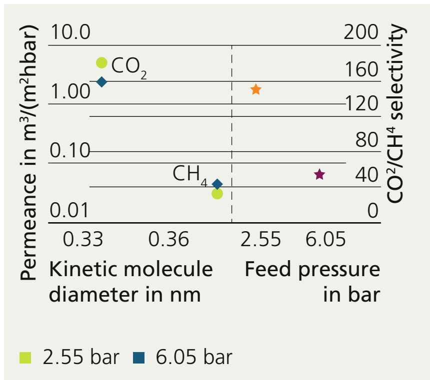
We gratefully acknowledge the financial support of the European Union through the project "INNOMEM" (grant no. 862330–INNOMEM–H2O2–NMBP–TO–IND–2010–2020/H2O2–NMBP–HUBS–2019).



Cross-section view of the support, intermediate layers and formed SSZ-13 membrane.



Single gas permeation measurement of SSZ-13 membrane at 25 °C and 150 °C.



Binary gas permeation measurement of SSZ-13 membrane at 2.55 bar and 6.05 bar feed pressure.

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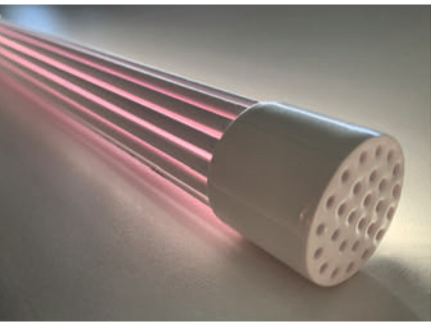
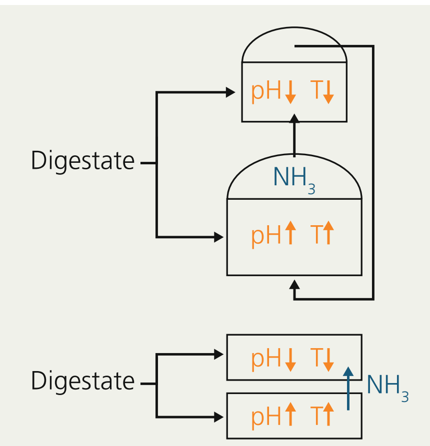
Efficient fertilization: adapted nitrogen contents in fertilizers

Dipl.-Ing. Björn Schwarz, Dr. Marcus Weyd

Test system for circulation stripping.



Hydrophobic ceramic capillary bundle for the membrane contactor.



Schematic of circulation stripping (top) and membrane contactor (bottom).

Nitrogen: valuable and problematic

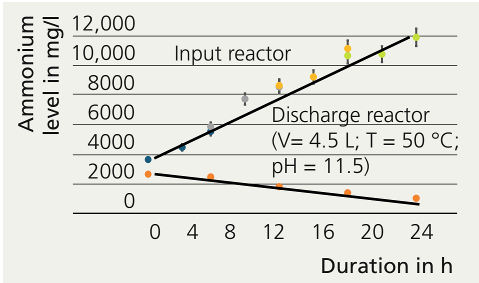
Nitrogen is an essential plant nutrient for agriculture. Manure and fermentation products from biogas plants are important sources of nitrogen. However, high production volumes, as they occur along with intensive livestock farming, cannot be applied to fields throughout the year. Thus, the nitrogen volume from autumn must be stored until the following spring. Low nitrogen concentrations require large slurry storages. With the beginning of plant growth in spring, large nutrient quantities have to be applied in a very short time, which means a lot of stress for the soil and strains the machinery.

Changing the nitrogen concentration

In the "N-Shift" project, two methods were tested to influence the nitrogen content in fermentation products in such a way that optimized autumn and spring fertilization becomes possible. Ammonia was transferred from one part of the fermentation product to another part by means of circular stripping or membrane contactor processes. The solubility of the ammonia and thus the driving force for the mass transfer were specifically influenced by varying temperature and pH value.

Circulation stripping

During circulation stripping, an active exchange of stripping gas takes place between two reactors in a closed loop. In the basic discharge reactor, the stripping gas absorbs ammonia from the fermentation product. In the acidic feed reactor, ammonia from the stripping gas is dissolved as ammonium in the fermentation product. Depending on the set milieu conditions and intensity of stripping, up to 3.2 % of the ammonia load could be transferred per hour.



Result of circulation stripping.

Membrane contactor

In the membrane contactor, both fermentation product phases are separated by a hydrophobic ceramic membrane, which must not be wetted by liquid and only allow the gaseous transport of ammonia. The membranes developed showed stable hydrophobic properties and prevented effectively any mixing of the liquid phases. Ammonia concentrations in the receiving phase were 3 times higher than in the discharging phase.

Advantages for fertilization

The autumn fertilizer produced in the project is characterized by very low nitrogen contents (especially NH_3), phosphorus fixation and alkaline properties (lime substitute). The spring fertilizer contains high concentrations of available nitrogen and phosphorus. This means that more mass can be applied in autumn, which saves storage capacity. Overall, nitrogen losses are significantly reduced and the plants are fertilized in a targeted manner.

With support from
Federal Ministry of Food and Agriculture
by decision of the German Bundestag

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Large-area target preparation through correlative work with laser/FIB in FESEM

Dipl.-Ing. Kerstin Gnauck, Dipl.-Ing. Lea Schmidtner, Dr. Sören Höhn, Dr. habil. Mathias Herrmann

High-performance ceramics for structural and functional applications have specially developed microstructures to achieve dedicated properties. To realize this, flawless structures are essential. Errors that occur must therefore be localized, uncovered and characterized quickly.

The new correlative preparation and analysis technique of field emission scanning electron microscopy (FESEM), laser cutting and focused ion beam cutting (FIB) at Fraunhofer IKTS enables fast and accurate preparation, as well as artefact-free microstructure documentation and characterization of the material. Elemental analysis using energy-dispersive X-ray analysis (EDX) also provides exact information about the chemical composition of the microstructure. Other analysis methods, such as computed tomographic (CT) measurements, can be integrated into the analysis process.

The sample is placed once on a holder for preparation and the subsequent analysis steps. All analysis steps are carried out in the FESEM in a correlative, contamination-free manner, without repeated contact with atmospheric oxygen.

The sample point to be examined is localized in the FESEM, documented and saved with its coordinates. The laser module creates cross-sections in the microstructure at the stored coordinates. Cutting lengths of up to one millimeter are possible. Using the integrated FIB technology, selected structural areas are finely polished and therefore accessible for high-resolution microanalysis.

The potential of the method is demonstrated by characterizing electrical breakdowns in Si_3N_4 substrates.

As part of the BMWK project CuSiN (see Zschippang et al., p. 27), a Si_3N_4 material with thermal conductivity > 85 W/(mK) was developed at Fraunhofer IKTS for applications in power electronics. Dielectric strengths > 40 kV/mm were determined on the substrates. The breakdown channels from such measurements were examined more closely using CT and correlative FESEM/laser-FIB technology to gain a better understanding of the processes taking place. The cut was made through the breakdown channel (Figures 1–4). A cross-sectional area of approx. 1000 µm x 300 µm was prepared with laser coarse and fine cuts and then characterized by scanning electron microscopy. The analysis shows that decomposition of the material occurs only in a relatively narrow zone (< 50 µm) around the channel (Figure 5).

Great potential for error analysis

The correlative target preparation using laser and FIB is characterized by excellent target accuracy and the effective and damage-free preparation of cross-sections. In many cases, the established mechanical target preparation can be replaced.

We thank the German Federal Ministry of Economics and Climate Protection (BMWK) for funding the CuSiN project (grant no.: 03ETE025A).

Supported by:
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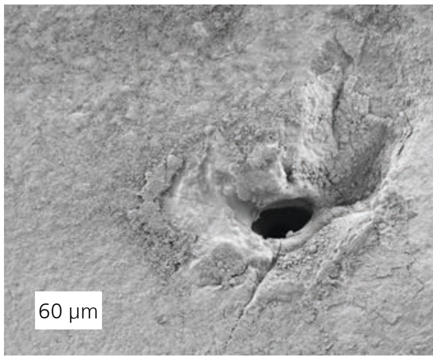
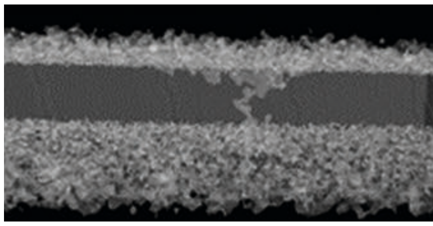
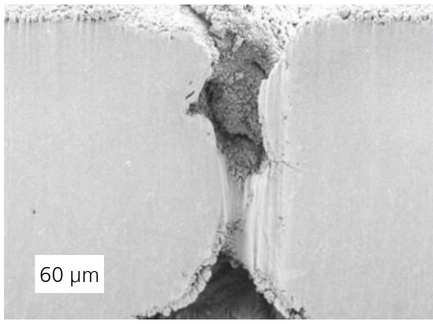


SE surface image of the breakdown in an Si_3N_4 plate.

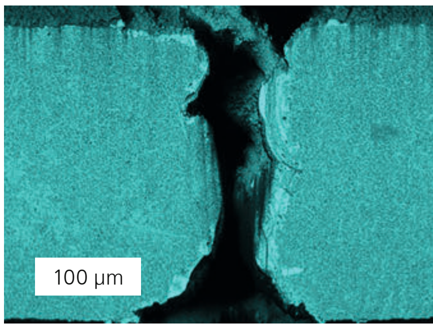


CT image of the breakdown.

Laser fine cut, view from top.



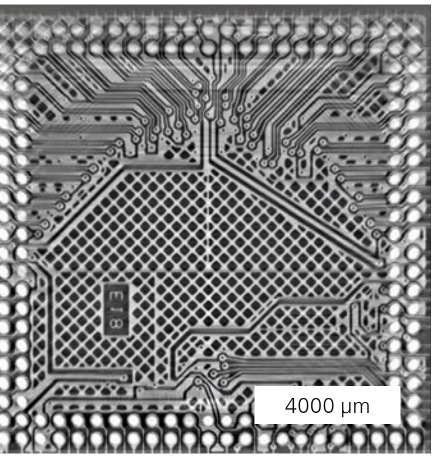
Laser cross-cut.



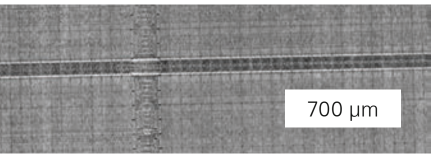
Si element distribution.

Multiscale 3D analytics, data correlation and preparation in semiconductor development

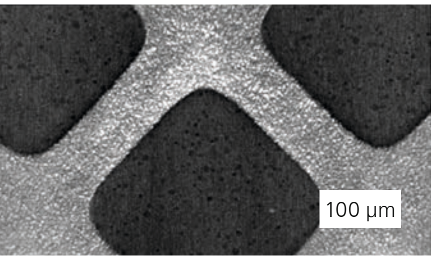
Prof. Silke Christiansen, Dr. Sabrina Pechmann, Ph.D. Tommaso Fontanot, Dr. George Sarau



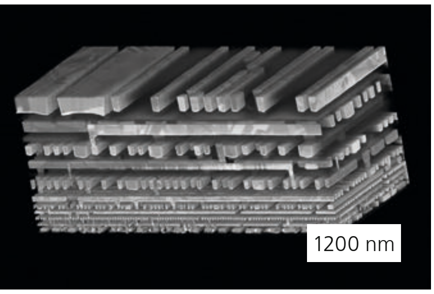
X-ray microscopy on a DRAM chip; overview scan with 8.6 µm voxel size.



Zoomed-in detail from top image.



Detailed scan with 0.6 µm voxel size.



Detailed 3D view of a CPU chip with nm voxel size from a tomography generated with the focused Ga-ion beam in an electron microscope.

Fraunhofer IKTS offers analytical and preparative workflows for cross-scale, multimodal analysis to support the development of materials, components and devices of micro- and power electronics, with the aim of accelerated optimization. Preparation can be inert and cooled (by liquid nitrogen) as required. The analytics provided includes microscopes (2D), which use electrons to image ions and light (including X-rays), as well as X-ray computer tomographs (3D). These devices are equipped with operando modules for mechanical testing (e.g. tension/pressure, bending, adhesion). All data generated in this way is stored according to FAIR (findable, accessible, interoperable, reachable) principles and is used for correlative, quantitative and statistical evaluation, including methods of machine learning, and made available to the customer.

Non-destructive volume analysis

Integrated semiconductor devices (semiconductor chip, image 1–4) can be tomographically examined using X-ray microscopy (XRM). Various such devices are available; they work with 3D volume pixels (so-called voxels) ranging from a few nanometers to a few 10 µm resolution. In contrast, the highly absorbent metallic traces and vertical contacts in particular become visible. Any defects such as damaged metallization can be identified and located in the volume. A target preparation for the defects can then be carried out and examined further through subsequent analysis.

Sample target preparation

Micro- and nanoanalysis usually requires dedicated sample target preparation, which is fully available at Fraunhofer IKTS and supports the analytics along the process chain. By means of laser ablation, mechanical polishing (TXP) and ion etching (TIC3X), encapsulations of components can be removed and internal surfaces can be gently exposed. Final preparation, accurate to the nanometer, takes place in the dual-beam scanning electron ion microscope (FIB-SEM), for which gallium, helium and neon ions are available.

Cross-scale, multi-modal and correlative analysis and data correlation

Analytical microscopy (composition determination with energy dispersive X-ray analysis – EDX) and spectroscopy (e.g. molecular fingerprinting with Raman spectroscopy and time-of-flight mass spectroscopy – TOF-MS with ion beam material removal in FIB-SEM) can provide a comprehensive picture of the morphology and multi-physical properties of samples. As part of the reliability analysis, IKTS can combine analytical microscopy in FIB-SEMs, including element and crystal analysis and electrical fault analysis using scanning probe methods, with mechanical testing (in FIB-SEM and XRM). Thanks to nanoGPS technology [1], it is possible to achieve relocation with µm accuracy of identical sample sites in the various measurement modalities. The complex, very large data sets (for XRM e.g. > 15 GB per data set) are automated, quantitatively and statistically evaluated using AI-based methods.

Literature

[1] O. Acher et al., Meas. Sci. Technol. 32, 045402 (2021).

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New approaches for in-situ analytics in microelectronics

Dr. André Clausner, Dr. Birgit Jost, Jendrik Silomon, Dr. Juliane Posseckardt, Stefan Weitz

3D nano-X-ray tomography of µ-cracks in wiring stacks on microchips

On-chip interconnect stacks (Back-End of Line BEoL) of microelectronic technologies consist of increasingly fine structures of various materials like copper or nano-porous dieletrics. This leads to higher demands on their mechanical stability and therefore their reliability under various loads, such as chip package interaction (CPI). New methods for the study of these fine structures are X-ray microscopy and based on that 3D nano-X-ray tomography (nanoXCT). The latter with its resolution of 50 nm is perfectly suitable for in-situ nanoXCT microcrack experiments for the analysis of mechanically weak spots in the BEoL.

Image 1 shows a complex lever-based push-to-pull sample geometry manufactured by plasmaFIB, which introduces a crack in tensile mode into the region of interest (ROI) in the BEoL. During the micromechanical experiment, the crack propagation in the ROI can be observed in high resolution in 2D and 3D and understood. On the basis of such complex micromechanical in-situ nanoXCT workflows, more mechanically stable microchip technologies for demanding applications like automotive electronics can emerge in the future.

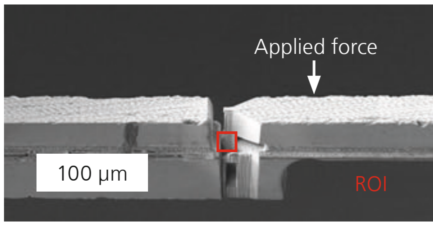
Crack identification in Back-End of Line (BEoL) stacks

In the industry, the investigation of the stability of solder bumps and copper pillar geometries is already established. However, there is no comparable standard for the underlying crack-prone BEoL stacks. At Fraunhofer IKTS, a method was adapted to observe crack initiation and propagation in copper pillar/BEoL systems.

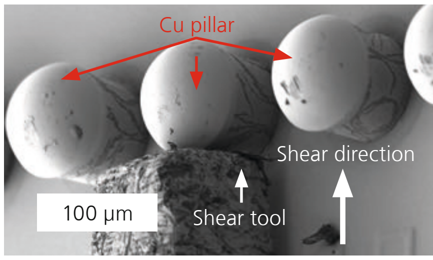
First, external forces are applied to the copper pillar to evaluate the mechanical stability of BEoL stacks. This is done by shear loading with an in-situ (image 2) or ex-situ nanoindenter system (image 3a). An acoustic emission (AE) detection sensor, attached to the sample, identifies and measures acoustic waves indicative of damage during the shear experiment (figure). The much higher temporal resolution of the AE measurements compared to the piezo sensors of the indenter allows a more accurate insight into the damage process. Subsequently, the resulting damages are further investigated with nanoanalytics methods, such as nano-X-ray computed tomography (nanoXCT, image 3b, c) and scanning electron microscopy (SEM, image 2).

The results allow for a better understanding of the origin and propagation of damage in the BEoL stack. The nanoXCT damage analysis of the example depicted in the images shows that the BEoL stack not only delaminates locally, but that cracks can also propagate horizontally along the layers, which are not detectable with other optical measurement methods. Additional in-situ shear tests on copper pillars in the nanoXCT and SEM offer a more precise insight into crack formation.

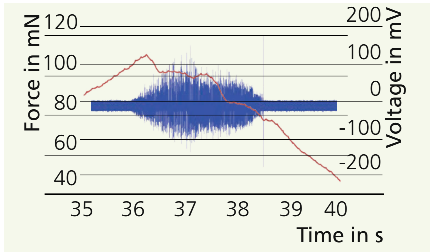
In the future, these investigations will complement the analysis of BEoL structures and characterize crack propagation more precisely. This will bring decisive advantages for reliability assessment.



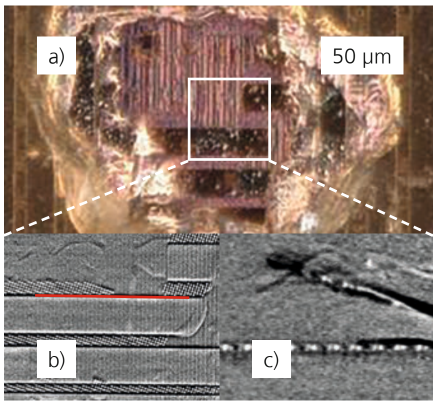
Push-to-pull sample for in-situ nanoXCT nano-mechanical testing of BEoL structures (prepared using plasma-FIB).



In-situ SEM shear experiment setup.



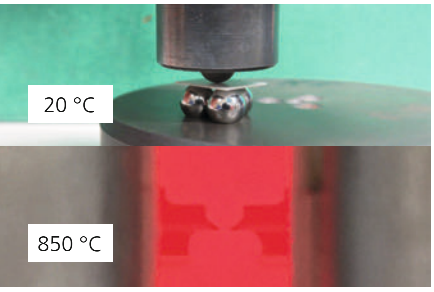
Force progression curve (red) with piezo voltage of AE signal (blue) of SnAg cap shear and image of resulting damage.



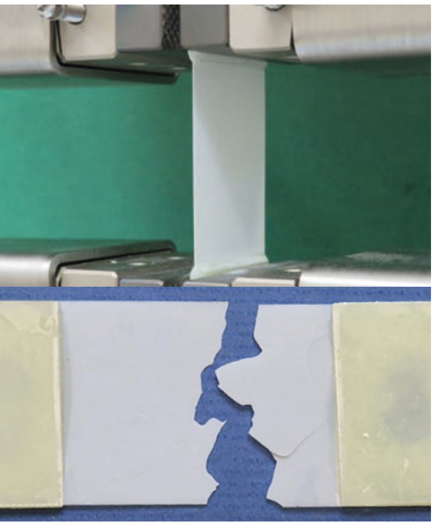
nanoXCT damage analysis: Optical microscopy overview image (a), details with sub-surface crack location (b), and virtual cross section with side view of the crack (c).

Determining the strength and fracture toughness of thin ceramic substrates

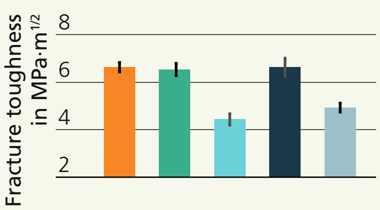
Dr. Clemens Steinborn, Dr. Wieland Beckert



B3B test at 20 °C and 850 °C.



Determination of the strength of 90 µm thick 3YSZ substrate in a tensile test.



- SEVNB sample 6.6 ± 0.20 MPa·m$^{1/2}$
- Substrate with V-notch 6.5 ± 0.26 MPa·m$^{1/2}$
- Anstis* 4.4 ± 0.24 MPa·m$^{1/2}$
- Niihara (half penny crack)* 6.6 ± 0.38 MPa·m$^{1/2}$
- Niihara (Palmquist crack)* 4.9 ± 0.19 MPa·m$^{1/2}$

* determined from the crack length of Vickers hardness indentations

Fracture toughness comparison, measured at notched beam (SEVNB), notched substrate (250 µm), by assessing the fracture length of Vickers hardness indentations.

More and more power electronics components and SO(F)Cs rely on substrates made from Si_3N_4, AlN and ZrO_2 materials. In addition to thermal conductivity, mechanical stability under thermal load cycles is an important prerequisite for the systems' long service life and the miniaturization of circuits and assemblies. The assessment and quality assurance of these systems therefore focuses on characteristic values such as strength, fracture toughness and the scattering of these values. When it comes to thin substrates (d < 0.4 mm), any analysis of the results from the standardized 4-point bending test for strength assessment is only possible with extensive corrections due to strong deflection. Alternative methods, such as ring-on-ring or B3B strength testing, offer a lot of flexibility with regard to the sample size. Moreover, the results are not affected by the quality of the sample edge. The downside of these latter methods, however, is that the volume under load is low and represents merely a fraction of the sample, which tends to lead to exaggerated strength values. Calculating strength requires an FEM analysis to determine the stress distribution within the sample. Another way of determining the strength of substrates is a tensile test, which uses a greater sample volume (image 2). The quality of the values measured in such a test depends largely on how well the samples are prepared and mounted in the testing machine. A comparison of tensile testing with B3B testing yielded consistent results considering the volumes tested. This means that both methods are suitable for testing thin substrates. By integrating the B3B test setup into a universal testing machine with a furnace, it is even possible to test the strength of 3YSZ substrates at high operating temperatures of up to 1000 °C (image 1). The fracture toughness value describes how well the substrates can tolerate defects in the material. This value is determined using samples with a V-notch, representing a crack that is critical for the material. Fraunhofer IKTS has developed a method that allows producing notches in substrate samples as thin as 90 µm. After measuring the notch using stereomicroscopy, the thin samples underwent a bending test. Fracture toughness was determined based on the geometric data and the breaking force as detected in the test. A comparison of the fracture toughness of thermally conductive Si_3N_4 ceramics, performed by IKTS and measured on notched substrate samples (d = 250 µm, ISO 21113) and 3 x 4 x 45 mm notched bending bars (SEVNB in accordance with DIN EN ISO 23146) showed that the measured results were in high agreement. Determining fracture toughness via hardness indentations is possible only if the crack geometry and the applicable assessment formula are known (bottom figure). The comparisons performed point toward new options of determining mechanical characteristic values of substrates. With the testing methods developed at Fraunhofer IKTS and specially adapted for ceramic substrates, manufacturers and users are enabled to assess the quality of ceramic substrates by simple and effective means.

Services offered

- Development of new testing concepts, validation of test setups and load regimes through accompanying simulation
- Determination of the strength, fracture toughness and hardness of substrates
- Fractographic examination of defects leading to fracture
- Determination of thermophysical, electrical and dielectrical characteristic values

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Cooperation and memberships

Scientists at Fraunhofer IKTS are active in numerous thematically oriented networks, alliances and groups. This enables us to offer our customers a joint and coordinated range of services and to take up new topics.

Memberships

AGENT-3D

AMA Association for Sensors and Measurement

American Ceramic Society (ACerS)

Arbeitsgemeinschaft industrieller Forschungseinrichtungen "Otto von Guericke" e. V. / German Federation of Industrial Research Associations

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

Association for Manufacturing Technology and Development (GFE)

Association of Electrochemical Research Institutes (AGEF)

Association of German Engineers (VDI)

Association of Thermal Spraying (GTS)

Automotive Thuringia

BfR Commission for Risk Research and Risk Perception (RISKOM)

biosaxony e. V.

Carbon Composites e. V. (CCeV)

Ceramics Applications

Ceramics Meeting Point

CiS Forschungsinstitut für Mikrosensorik GmbH

CO_2 Value Europe AiSBL

Competence Center for Nano Evaluation nanoeva®

Competence Network on Optical Technologies (Optonet)

COMPOSITES UNITED e. V.

Cool Silicon e. V.

DECHEMA – Society for Chemical Engineering and Biotechnology

DeepSea Mining Alliance e. V.

Deutsche Glastechnische Gesellschaft e. V. (DGG)

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

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

DIN Standards Committee Precision Mechanics and Optics (NAFuO)

DRESDEN-concept e. V.

Dresden Fraunhofer Cluster Nanoanalysis

Dresdner Gesprächskreis der Wirtschaft und der Wissenschaft e. V.

ECPE European Cluster for Power Electronics

EIT Health

Energy Saxony e. V.

European Powder Metallurgy Association (EPMA)

European Research Association for Sheet Metal Working (EFB)

European Society of Thin Films (EFDS)

Expert Group on Ceramic Injection Molding in the German Ceramic Society (DKG)

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

Fachverband Pulvermetallurgie

Fördergemeinschaft für das Süddeutsche Kunststoff-Zentrum e. V.

Fördergesellschaft Erneuerbare Energien (FEE)

Fraunhofer Adaptronics Alliance

Fraunhofer Battery Alliance

Fraunhofer Big Data and Artificial Intelligence Alliance

Fraunhofer Chemistry Alliance

Fraunhofer Competence Field Additive Manufacturing

Fraunhofer Energy Alliance

Fraunhofer Group for Materials and Components – MATERIALS

Fraunhofer Nanotechnology Network FNT

Fraunhofer Numerical Simulation of Products and Processes Network

Fraunhofer Research Field Lightweight Construction

Fraunhofer Water Systems Alliance (SysWasser)

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

German Association of University Professors and Lecturers (DHV)

German Biogas Association

German Chemical Society (GDCh)

German Electroplating and Surface Treatment Association (DGO)

German Energy Storage Association (BVES)

German Federation of Industrial Research Associations (AiF)

German Materials Society (DGM)

German Phosphor Plattform

German Physical Society

German Platform NanoBioMedizin

German Society for Crystallography (DGK)

German Society for Membrane Technology (DGMT)

German Society for Non-Destructive Testing (DGZfP)

German Thermoelectric Society (DTG)

Growth core smood® – smart neighborhood

HERMSDORF e. V.

HYPOS Hydrogen Power Storage & Solutions East Germany

HySON – Förderverein Institut für Angewandte Wasserstoffforschung Sonneberg e. V.

InDeKo Innovationszentrum Deutschland Korea

InfectoGnostics Research Campus Jena

Initiative Erfurter Kreuz e. V.

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

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

Institut für Mikroelektronik- und Mechatronik-Systeme gGmbH

International Microelectronics and Packaging Society, IMAPS Deutschland

International SOS GmbH

International Zeolite Association

JenaVersum network

Joint Committee High Performance Ceramics of the German Materials Society (DGM) and the German Ceramic Society (DKG)

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

Materials Research Network Dresden (MFD)

medways e. V.

Meeting of Refractory Experts Freiberg (MORE)

microTEC Südwest

Nachhaltigkeitsabkommen Thüringen

NAFEMS UK

Organic Electronics Saxony

Ostthüringer Ausbildungsverbund e. V. Jena

ProcessNet – an initiative of DECHEMA and VDI-GVC

QBN Quantum Business Network

Rail.S e. V.

Regionale Aktionsgruppe Saale Holzland e. V.

Research Association for Diesel Emission Control Technologies (FAD)

Research Association Mechatronic Integrated Devices 3-D MID

Research Association of the German Ceramic Society (FDKG)

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

Silicon Saxony e. V.

smart³ e. V.

SmartTex Network

Society for Corrosion Protection (GfKORR)

Thüringer Erneuerbare Energien Netzwerk e. V. (ThEEN)

Thüringer Wasser-Innovationscluster

TITK Materials research institute for polymer functional and engineering materials

TRIDELTA CAMPUS HERMSDORF e. V.

TWI Innovation Network

VDMA Medical technology

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

Verein für Regional- und Technikgeschichte e. V. Hermsdorf

Wind Energy Network Rostock

Fraunhofer Group for Materials and Components – MATERIALS

The Fraunhofer Group for Materials, Components – MATERIALS stands for cross-scale materials expertise along industrial value chains. It applies its expertise from materials science fundamentals to materials engineering system solutions to create innovations for the markets of its customers and partners.

The Fraunhofer MATERIALS Group bundles the competencies of materials science and materials engineering in the Fraunhofer-Gesellschaft. This applies in particular to the development of new and improved materials, the application-specific (re)design of existing materials, the appropriate manufacturing processes and process technologies up to quasi-industrial scale, the characterization of material and component properties up to the evaluation of the system behavior of materials and components in products.

Numerical modeling and simulation techniques are used as well as state-of-the-art experimental investigations in laboratories and pilot plants. Both are carried out across all scales from molecules and components to complex systems and process technology. In parallel, the methods and tools used are constantly being developed to the highest standards. In terms of materials, the Fraunhofer MATERIALS Group covers the entire range of metallic, inorganic-non-metallic and polymeric materials, and materials produced from renewable raw materials, as well as semiconductor materials, hybrid and composite materials.

The scientists in the collaborative institutes apply their know-how and expertise primarily in the business areas of mobility, health, mechanical and plant engineering, construction and housing, microsystems technology, safety and security, and energy and the environment. They are well networked at national, European and international level and make a significant contribution to innovation processes at these levels.
At European level, for example, the Group is committed to strengthening Europe's technological sovereignty through excellent materials science and engineering as part of the Advanced Materials Initiative (AMI 2030).

In the view of the Fraunhofer MATERIALS Group, a key function lies in the digitization of materials research and materials technology throughout the entire value creation process, along the life cycle of materials. Digitization in this area is an essential prerequisite for the sustainable success of Industry 4.0, as well as for the realization of resource efficiency. Data generation and the development of digital material twins are therefore a particular focus of the Fraunhofer Group's projects.

Climate change, scarcity of resources and a simultaneous increase in demand for mobility, living space and comfort call for a general rethinking in product development. From the point of view of the Fraunhofer MATERIALS Group, hybrid lightweight system construction offers a high potential for solutions. The target parameter in the development process here is resource efficiency with a weight-optimized and at the same time function-optimized design of components. The Group sees lightweight construction as a holistic challenge and focuses on sustainable, recyclable materials, intelligent hybrid structure design and integrated material and component evaluations.

Renewable energies are gaining a dominant importance in the course of the energy transition. In order to generate, store, transport and convert them, a variety of materials will be used to a much greater extent than for classic energy supply systems, from copper, steel and concrete to rare earths. The Fraunhofer Group for Materials, Components – MATERIALS is working on this complex of issues in the context of sustainability, particularly with regard to resource efficiency, the development of new material flows and the creation of closed resource cycles.

Contact

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20 years of Treffpunkt Keramik in Dresden

Treffpunkt Keramik (Ceramics Meeting Point) remains an integral part of our institute's public relations activities. In total, more than 70 partners use this platform to present their range of services with exhibits and information material to new users in industry and research. The cooperation with the "Ceramic Applications" of publishers Göller Verlag is an effective combination of science and communication practice.

Because of the successful acquisition of large-scale projects, the previous area of Treffpunkt Keramik is needed as logistics space. Following an elaborate redesign of the circulation areas, the exhibition is now presented over three floors in the center of the institute. Combined with modern presentation technology, it is a highlight at all tours of the institute, seminars and conferences, as well as at employee talks. In future, coffee breaks will evolve into impromptu further training and forays into market research. Raw material suppliers are to be found there as well as suppliers of machine technology. However, the focus will continue to be on component manufacturers and the research highlights of Fraunhofer IKTS.

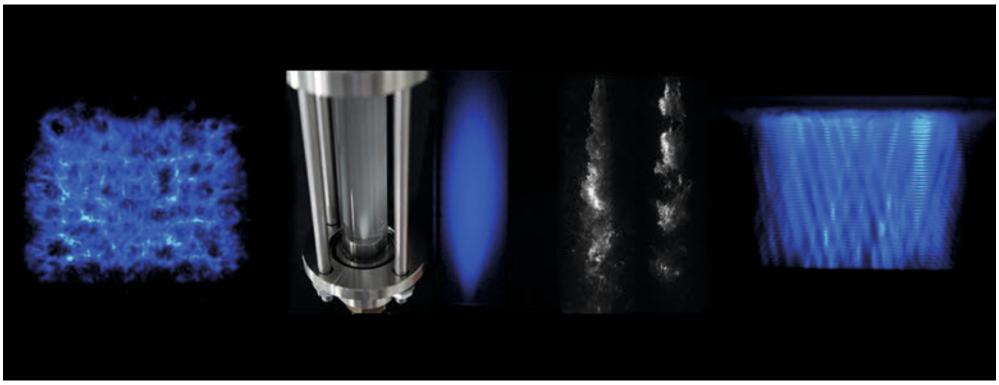
Additively manufactured components in oxide and non-oxide ceramics are presented next to material composites. If requested, this can be followed by a visit to the corresponding laboratories. Systems from more than 10 manufacturers are tested for the latest applications, from the jewelry industry to fusion technology.

Gigantic structural ceramic components made of silicon carbide and weighing more than 50 kg can be viewed in addition to complex, modular, brazed structures made of aluminum oxide and more than two meters high. Of course, there are also energy or hydrogen technology exhibits. Even after 20 years of Treffpunkt Keramik in Dresden, the material continues to fascinate visitors.

In 2023, there will once again be face-to-face seminar and training sessions of Fraunhofer IKTS, the German Ceramic Society (DKG) and the German Materials Society (DGM). In-house training at companies also remains an option.

Ceramics Meeting Point at Fraunhofer IKTS in Dresden-Gruna.

Center for Energy and Environmental Chemistry Jena (CEEC)



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

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

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

One focus of the collaboration is the "Technical Environmental Chemistry" chair, which is held by Prof. Michael Stelter. The working group is dedicated to water treatment, water purification, and water analysis using novel methods, such as ultrasound and hydrodynamic cavitation, electrochemistry, and ceramic membrane technology.

In 2019, new equipment for high-performance analytics, penetrating extremely low concentration ranges and providing data on pollutant degradation processes in automated high throughput, could be procured especially in the research area of trace substances. This technology opens the path for digitalization and sensors even in water treatment.

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

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

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CEEC JENA
Center for Energy and Environmental Chemistry Jena

Names, dates, events

Please find information on patents, publications and scientific engagement of IKTS employees in 2022 on the website

www.ikts.fraunhofer.de/en/dates2022

- **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 2023

You can find current dates on our websites.

Conferences and events

DKG Annual Meeting
March 27–29, 2023, Jena/Hermsdorf

Preschoolers discover condition monitoring (DE)
April 17, 2023, Dresden-Klotzsche

Girl's Day: "Become a physics and chemistry lab technician for one day!" (DE)
April 27, 2023, Hermsdorf and Dresden-Gruna

Junior doctor program: "Little detectives: Trouble-shooting with eddy current" (DE)
April 27 and May 25, 2023, Dresden-Klotzsche

NDT4INDUSTRY – Testing and monitoring of nuclear facilities – current NDT developments
May 3, 2023, Online seminar

SBS4 International Sodium Battery Symposium
September 4–5, 2023, Dresden-Gruna

NDT4INDUSTRY – Testing technology for biological materials
September 20, 2023, Online seminar

Dresden Battery Days
September 25–27, 2023, Dresden-Gruna

Training seminars and workshops

DGM training seminar: Ceramic materials – properties and industrial applications (DE)
May 3–4, 2023, Dresden-Gruna

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

Trade fairs and exhibitions

ICACC
January 22–27, 2023, Daytona

SPIE.PhotonicsWest
January 31–February 2, 2023, San Francisco
German Pavillon

FILTECH
February 14–16, 2023, Cologne

TOGC 2023 – Transportation Oil & Gas Congress
February 20–21, 2023, Istanbul

LOPEC
February 28–March 2, 2023, Munich
Joint booth OES e. V.

Rad&Schiene
March 1–3, 2023, Dresden

IDS
March 14–18, 2023, Cologne

Tausendwasser
March 15–16, 2023, Berlin

Schall 23
March 21–22, 2023, Wetzlar

Hannover Messe
April 17–21, 2023, Hannover
Joint booths "Das ist Thüringen" and "Research for the future"

Bonding
April 18–20, 2023, Dresden

JEC
April 25–27, 2023, Paris
Joint booth SAXONY!

Sensor und Test
May 9–11, 2023, Nuremberg

Control
May 9–12, 2023, Stuttgart
Joint booth Fraunhofer Business Unit Vision

Rapidtech
May 9–11, 2023, Erfurt
Joint booth Fraunhofer Competence Field Additive Manufacturing

DACH-Jahrestagung
May 15–17, 2023, Friedrichshafen

20. Tagung Schweißen in der maritimen Technik und im Ingenieurbau
May 24–25, 2023, Hamburg

ZfP im Eisenbahnwesen
tbd., Erfurt

GIFA
June 12–16, 2023, Dusseldorf
Joint booth BDG Bundesverband der Deutschen Gießerei-Industrie e. V.

EES Europe
June 14–16, 2023, Munich

Erfurter Energiespeichertage
June 20–21, 2023, Erfurt

DWA-Landesverbandstagung Sachsen/Thüringen
September 6, 2023, Radebeul

V2023
September 19–21, 2023, Dresden

EuroPM
October 1–4, 2023, Lisboa

Formnext
November 7–10, 2023, Frankfurt
Joint booth Fraunhofer Competence Field Additive Manufacturing

FAD-Konferenz
November 8–9, 2023, Dresden

Compamed
November 13–16, 2023, Dusseldorf
Joint booth Fraunhofer-Gesellschaft e. V.

Offshore Energy
November 28–29, 2023, Amsterdam

Hagener Symposium
November 30–December 1, 2023, Hagen

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

How to reach us at Fraunhofer IKTS

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

How to reach us in Dresden-Gruna

By car

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

By public transport

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

By plane

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

How to reach us in Dresden-Klotzsche

By car

- Highway A4: exit "Dresden-Flughafen" in direction "Hoyerswerda" along "H.-Reichelt-Straße" to "Grenzstraße"
- "Maria-Reiche-Straße" is the first road to the right after "Dörnichtweg"
- From Dresden city: B97 in direction "Hoyerswerda"
- "Grenzstraße" branches off to the left 400 m after the tram rails change from the middle of the street to the right side
- "Maria-Reiche-Straße" branches off to the left after approx. 500 m

By public transport

- Take tram 7 from Dresden city to stop "Arkonastraße"
- Turn left and cross the residential area diagonally to "Grenzstraße"
- Follow this road for about 10 min to the left and you will reach "Maria-Reiche-Straße"
- Take suburban train S2 (direction "Airport") to "Dresden-Grenzstraße"
- Walk back about 400 m along "Genzstraße"
- "Maria-Reiche-Straße" branches off to the right

By plane

- From Dresden-Klotzsche airport, take bus 80 (direction "Bf. Klotzsche") to "Grenzstraße", then walk back to "Grenzstraße", turn right there. After approx. 150 m "Maria-Reiche-Straße" turns right
- Or take the suburban train one stop to "Dresden-Grenzstraße", and after about 400 m turn right into "Maria-Reiche-Straße"

How to reach us in Hermsdorf

By car

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

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

By public transport

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

Editorial notes

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