Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Defense and security research at Fraunhofer IKTS

Portfolio

Outline

1. Fraunhofer IKTS in profile
2. Defense and security research application – overview
3. Energy
4. Electronics and microsystems
5. Protective ceramics and structural ceramics
6. Environmental and process engineering
7. Monitoring of infrastructures
8. Contact

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01

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Facts & Figures

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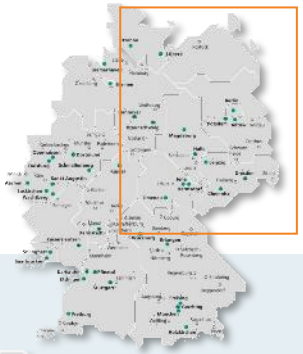
Facts and figures

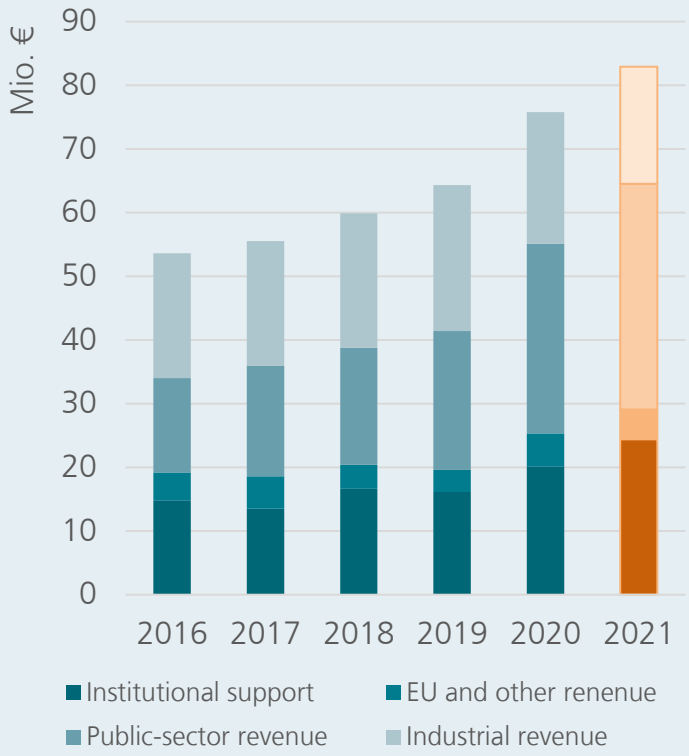


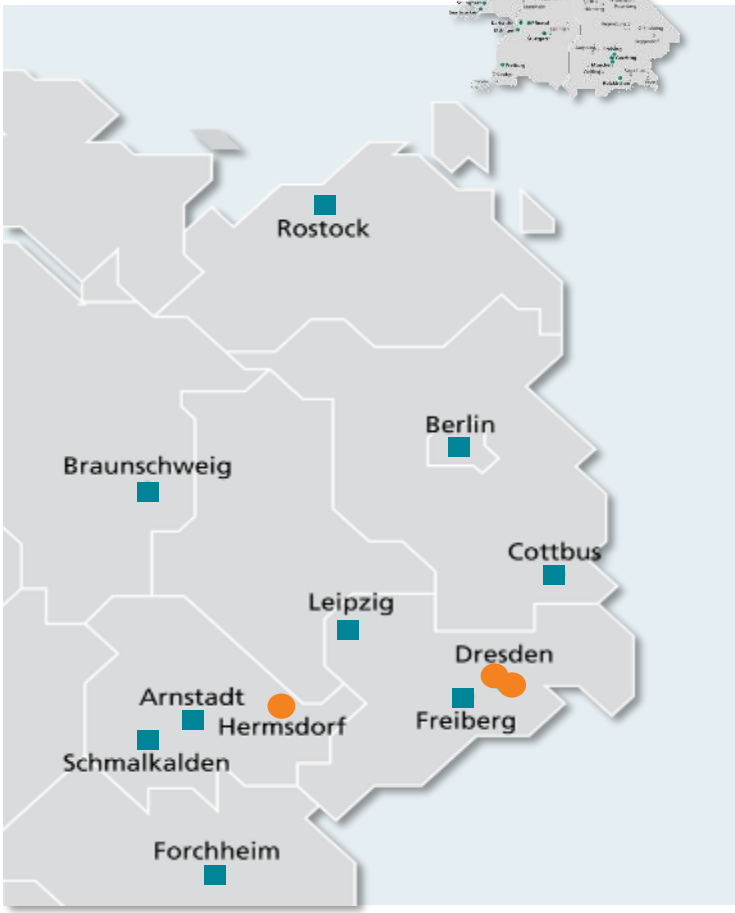
Service provider for applied research on the field of high-performance ceramic materials and technologies

Nearly **800** employees

3 IKTS main sites (•),
further external groups (■)

Fraunhofer IKTS overall revenue





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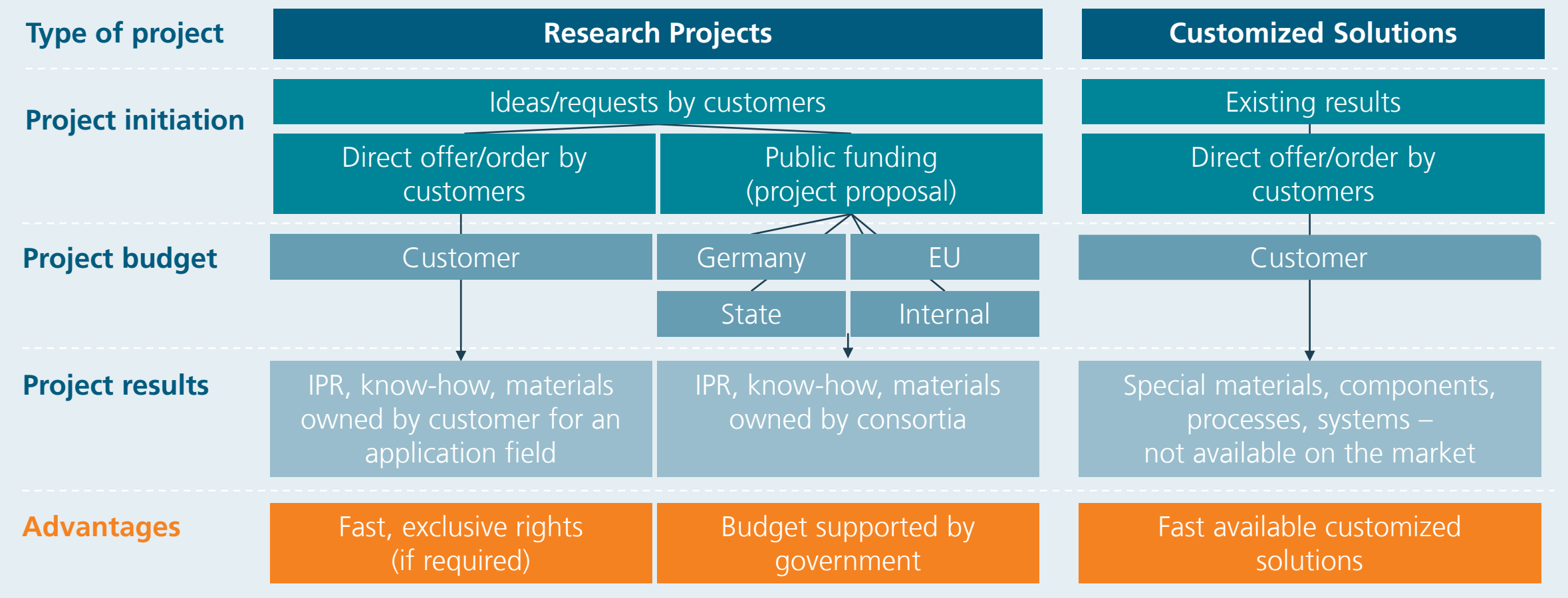
Our business model – service provider for applied research



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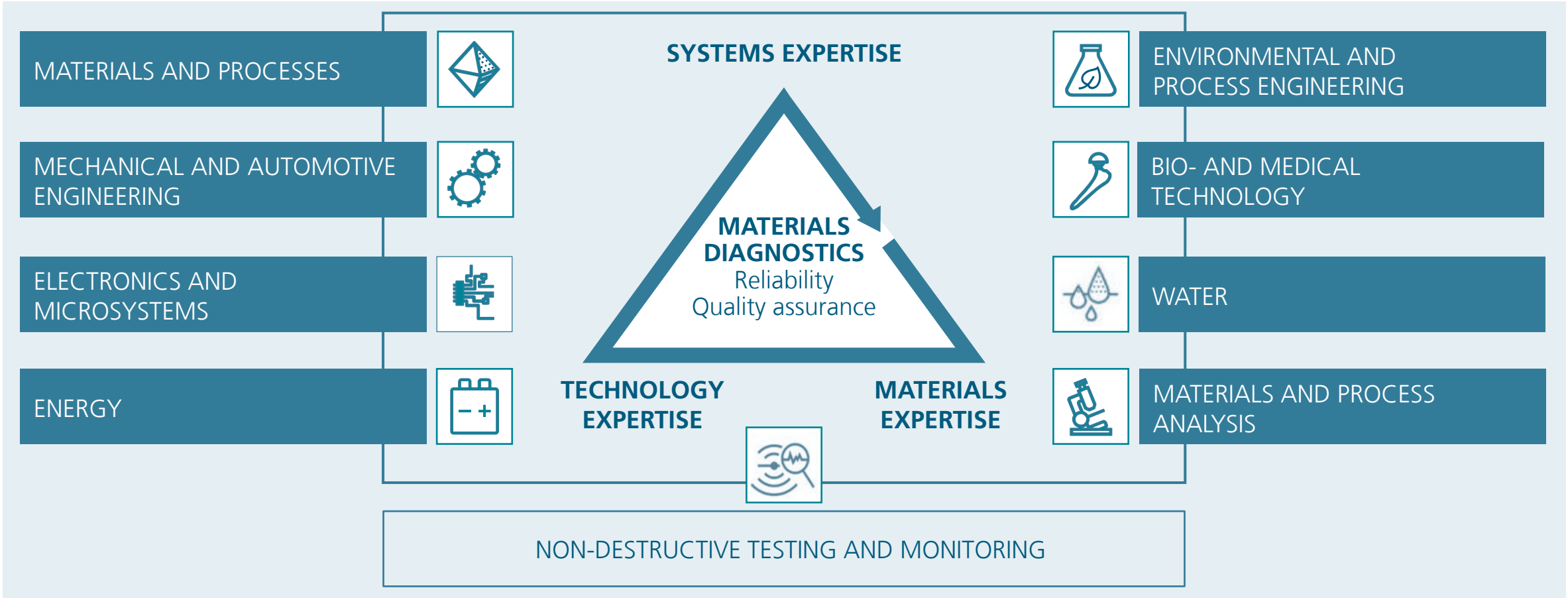
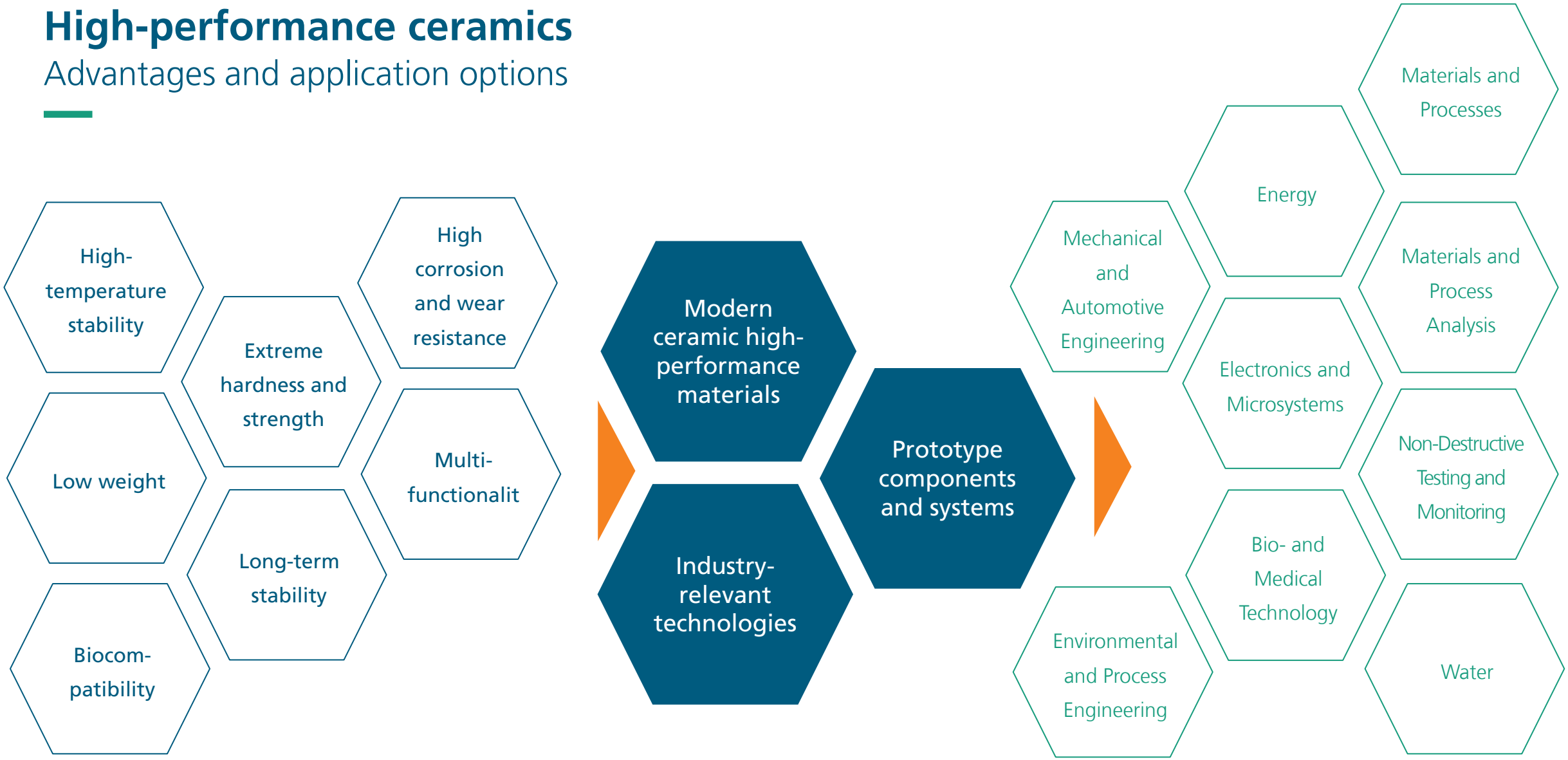
Business divisions



High-performance ceramics

Advantages and application options



02

Defense and security research application

Overview

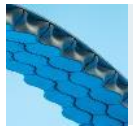
IKTS technologies

High-performance systems for challenging conditions

Offgrid-Power and micro CHP with flexible fuels (Fuel cells)

High-frequency and sensor systems for harsh environments

Stationary energy storage



Protective ceramic (transparent / non-transparent)

Materials for protective masks

Monitoring of critical systems / infrastructures

Oxygen Supply with Air separation O_2 generator

Compact **water treatment** and purification systems

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Defense and security research application – energy

Fuel cell technologies

- Fuel cells – development and test from component to system
- Flexible Offgrid-power from 1kW to MW range

Material solutions for Li-ion batterie

- Li- and post-Li-technologies
- From powder to pilot scale production

Stationary energy storage

- cerenergy® – Na/$NiCl_2$ battery system for stationary storage
- Container solutions for PV-hybrid systems

SOEC-Stacks for hydrogen generation

- Prototype production of SOFC/SOEC stacks (capacity of 1–10 MW/year) with mPower GmbH

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Defense and security research application – enviromental and process engineering

On-site O_2 generator

- High-temperature oxygen separation with mixed-conducting ceramic membranes.

Power-to-X

- Synthetic fuels and valuable products from renewable energy (biogas, wind, solar)

(On-site) Treatment of process and waste waters

- Self-sufficient and scalable systems for:
  - Disinfection
  - Breakdown of anthropo-genic substances
  - Treatment of mining water
  - Treatment of radioactive waste water

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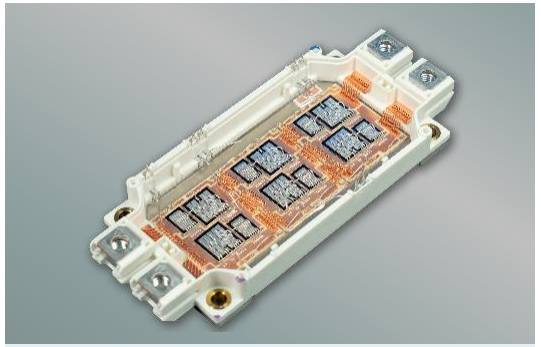
Defense and security research application – electronics / microsystem technnology

Sensors for extreme harsh environment

- Ceramic multilayer-technology based on printed sensors for high temperature, aggressive chemical media etc.

LTCC-based RF- and mmWave packaging

- High-frequency board for 77 GHz radar for driving assistance systems



Power electronics

- Ceramic solutions for power electronic packages: high performance, high suited, reliable

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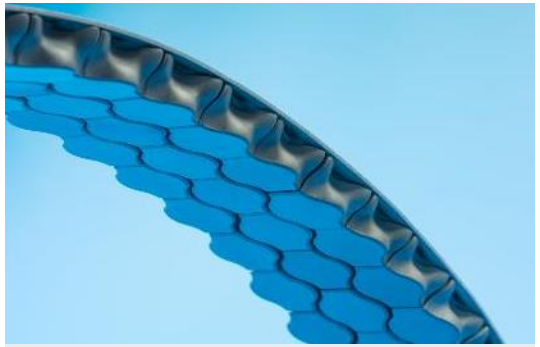
Defense and security research application – protective ceramics and structural ceramics

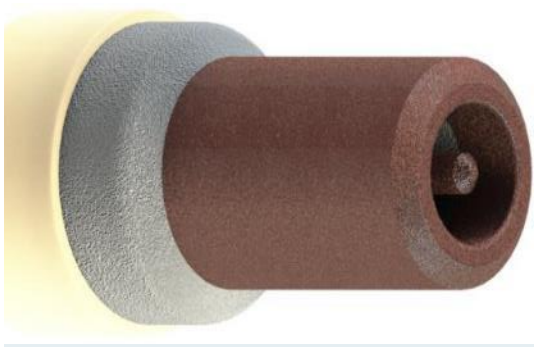
Transparent ceramics for ballistic protection

- Durable protection of optical and sensor systems in harsh environments
- Protective systems for civil / military vehicles



Modular 3D ceramic reinforcements for novel protection concepts – DuktAr

- Protective devices for centrifuges, rotors, recycling plants or for high-speed machining



Ceramic reactor for space application

- Next-gen multimaterial (conductive / non-conductive) for integrated devices

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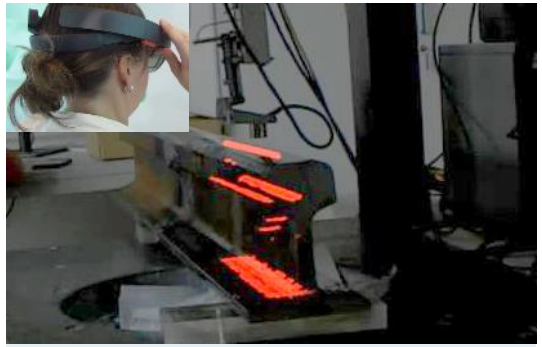
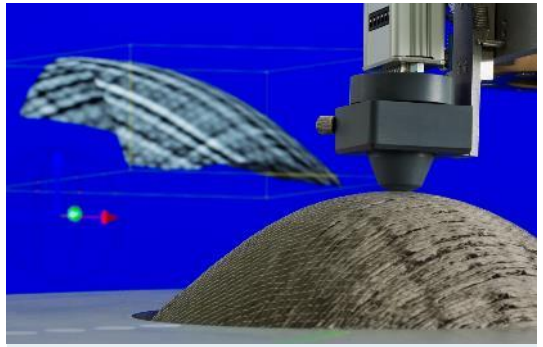
Defense and security research application – monitoring of critical systems and infrastructures



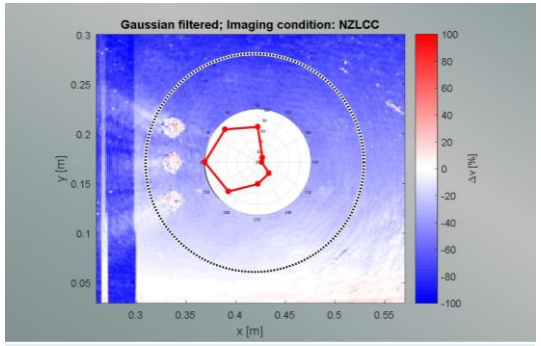
Software and digitalization

- In time visualization of complex 3D data by augmented reality
- Machine learning and KI for NDT data interpretation
- DICONDE and data fusion



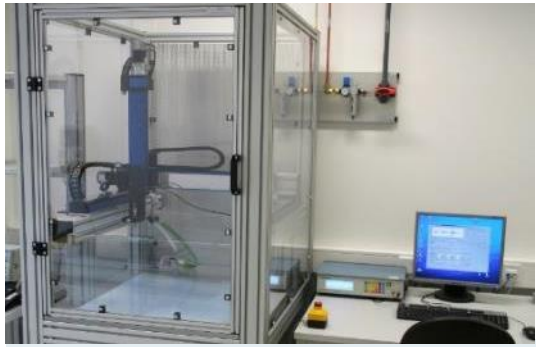
HF eddy current for CFRP

- Textural analysis of CFRPs
- NDT on damages / repairs
- Non-contact dielectric analysis (heat damages, aging, polymer degradation)
- Crack detection
- Monitoring of conductive coatings (on composites)



Special equipment for on-site material characterization and SHM

- SHM
- NDI for residual strain
- Small defect inspection
- Polymer and glue characterization
- Ultrasonic microsopy



Delivery of ultrasound NDT equipment

- Non-destructive detection of hidden, internal cracks on riveted plate structures
- Robot-based scanners for aircraft inspection

03

Energy

Defense and security research application

Energy
Full cells

Off-grid power supply military applications and catastrophic protection

Challenge

Every operation, whether short-, medium- or long-term, requires a reliable and flexible energy infrastructure for vehicles, surveillance and on-site supply.

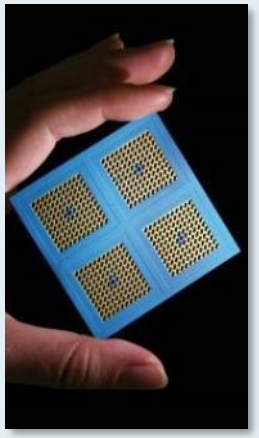
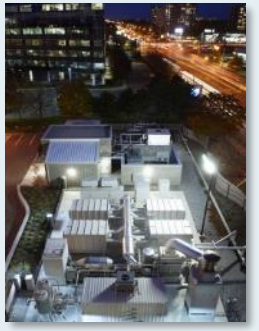
Solution

- Fuel Cells for from chemical to electrical energy and heat **direct and robust energy conversion**
- Various applications for **back-up power, off-grid power generation or co-generation** of heat and power
- **Weight and noise reduction**
- Highly **flexible fuel usage** (diesel, LPG, methanol, hydrogen, …)

Fuel cell and electrolysis technology @ IKTS

Customized system development from 1W to several MW

1 W – hand-held | **10 W** | **100 W** – portable | **1 kW** | **10 kW** – stationary | **1 MW**

Hydrogen	Butane	LPG	Natural Gas	Natural Gas	Biogas	NG / Biogas
PEFC	**SOFC**	**SOFC**	**SOFC**	**SOFC**	**SOFC**	**MCFC**
						
Ceramic Multilayer	Bundled Microtubes	Planar Mini-Stack	Integrated Stack Module	CFY / Integrated HotBox	CFY Stack Technology	DFC® Technology

Energy

Batteries for stationary & mobile energy storage systems

Battery technologies for military application

Challenge

- Critical challenges with Li-ion batteries:
  - Abundance and accessibility of (critical) materials
  - Safety
  - System complexity (climate control, energy demand)
  - Longevity

Solution

- cerenergy® – the high-temperature battery for stationary energy storage
  - Low cost local raw materials
  - Material cost < 30 $ kWh
  - High safety, because no spontaneous combustion can occur
  - Low system costs (no T-control / simple BMS)

Click for further information.

Energy
Oxygen generator

Portable O_2 generator for military operations and catastrophic protection

Challenge
Mobile oxygen generation in deployment scenarios, for example, in the event of a catastrophe or in military field camps

Application
Medical, disaster control or for military operations

Solution
- Highly purified, dry O_2 on-site
- Lowest energy demand (< 0.5 kWh/Nm³ O_2)
- Lowest CO_2 emissions, no O_2 transport
- Recycling of off-gas (O_3 destruction included)
- Wide scalability, recyclability
- Process simplification, small footprint
- Avoidance of supply bottlenecks and safety risks

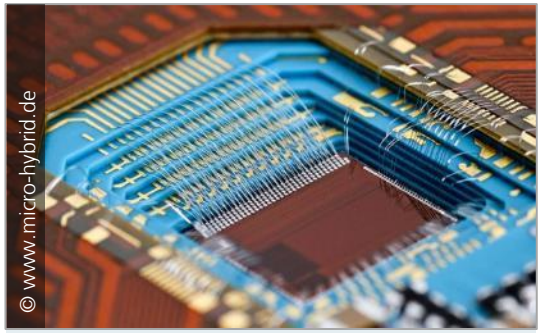
04

Electronics and microsystems

Defense and security research application

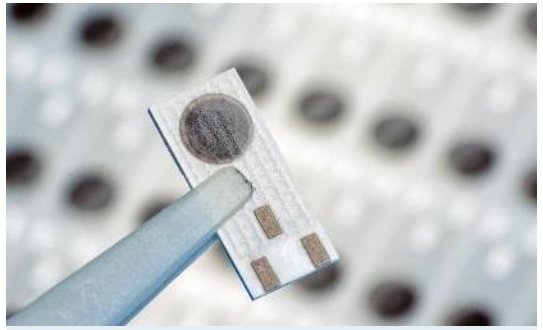
Electronics and microsystems

Applications for ceramic thick-film and multilayer based components



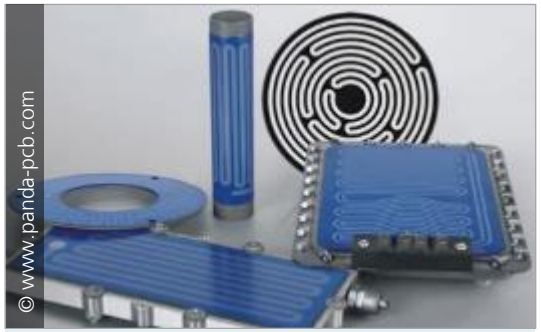
Ceramic PCB's

- **Standard thick-film**
- **Multilayer** (ULTCC, LTCC, HTCC)
- **Power electronics** (DCB, AMB)



Sensors for defense and aerospace

- **Mechanical** (p, F, a, level)
- **Thermal** (resistor type, thermocouples)
- **Chemical** (water)
- High accuracy and reliability
- Low weight and power requirements



Components

- **Multilayer integrated passives** (RLC), **multilayer varistors** (MLV)
- **Chip resistors**
- **Heaters**
- Ceramic **MEMS-packages**
- LED-, laser diodes packages
- LTCC-based actuators

Green energy

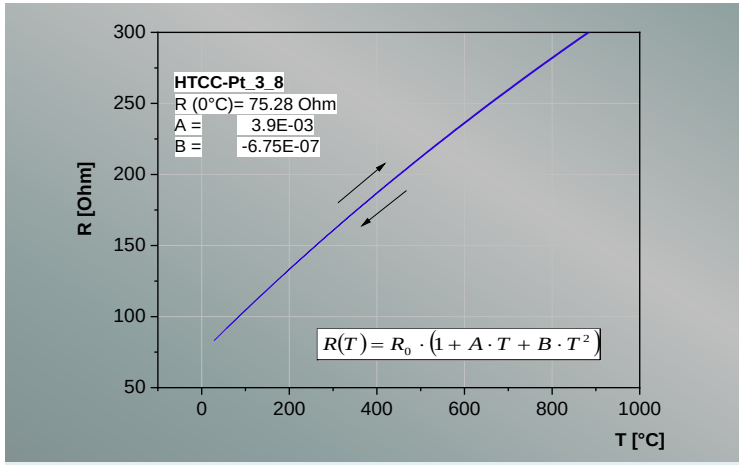
- **Solar cells** (crystalline, HJT)
- **Fuel cells** (µPEMFC)
- **Li-batteries** (printed 3D-electrodes, LLZO-separators
- Electrode materials for **Photo-Electro-Catalysis** cells (PEC)

Digitalization, IoT, Industry 4.0

Sensors for extreme harsh environment

Pressure sensors for turbines / jet engines

- Multilayer (**LTCC**, HTCC)
- T = 300 .. **500 °C**
- P = 50 .. **200 bar**



Temperature sensores

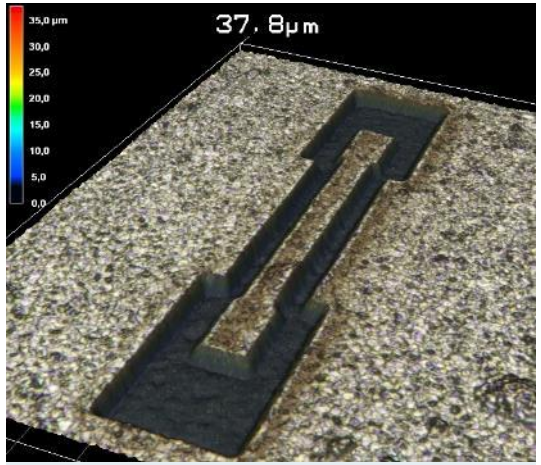
- Multilayer (**HTCC**)
- T = 200 .. **1000 °C**

MEMS based acceleration sensors

- **LTCC-based packages**
- Aerosol-Jet-printed wires / contacts
- a … **100.000 g**

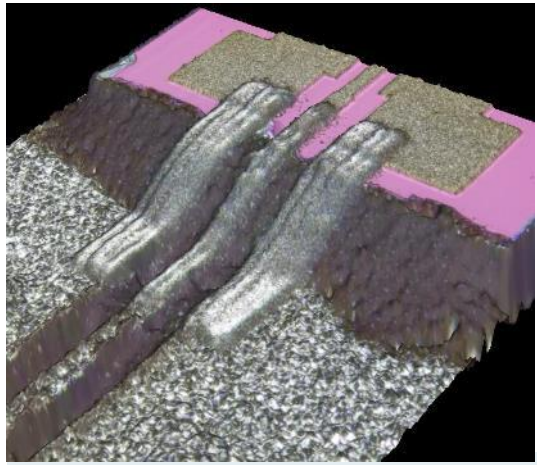
Electronics and microsystems

High frequency applications > 100 GHz



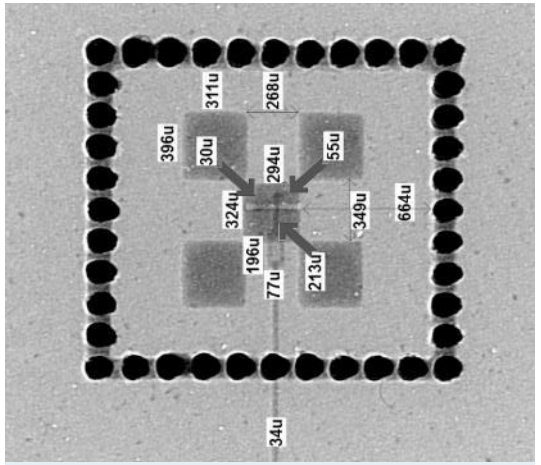
Characterization

- **Test (f = 0–220/320 GHz), structures (lines 35 µm)**
  - Aerosol Jet Printing
  - Laser ablation
  - Screen Printing
  - PI-Pastes



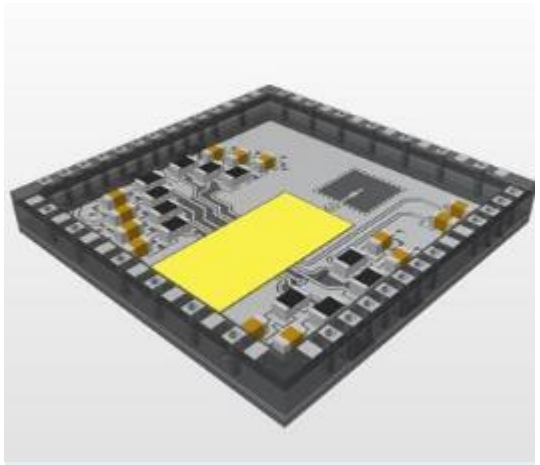
MMIC interconnections

- **Printing of HF Interconnections**
  - Test MMICs
  - f = 0–320 GHz



Antennas

- **Broadband antennas**
  - Vivaldi antenna (140 GHz)
  - Stacked Patch antenna (140 GHz)



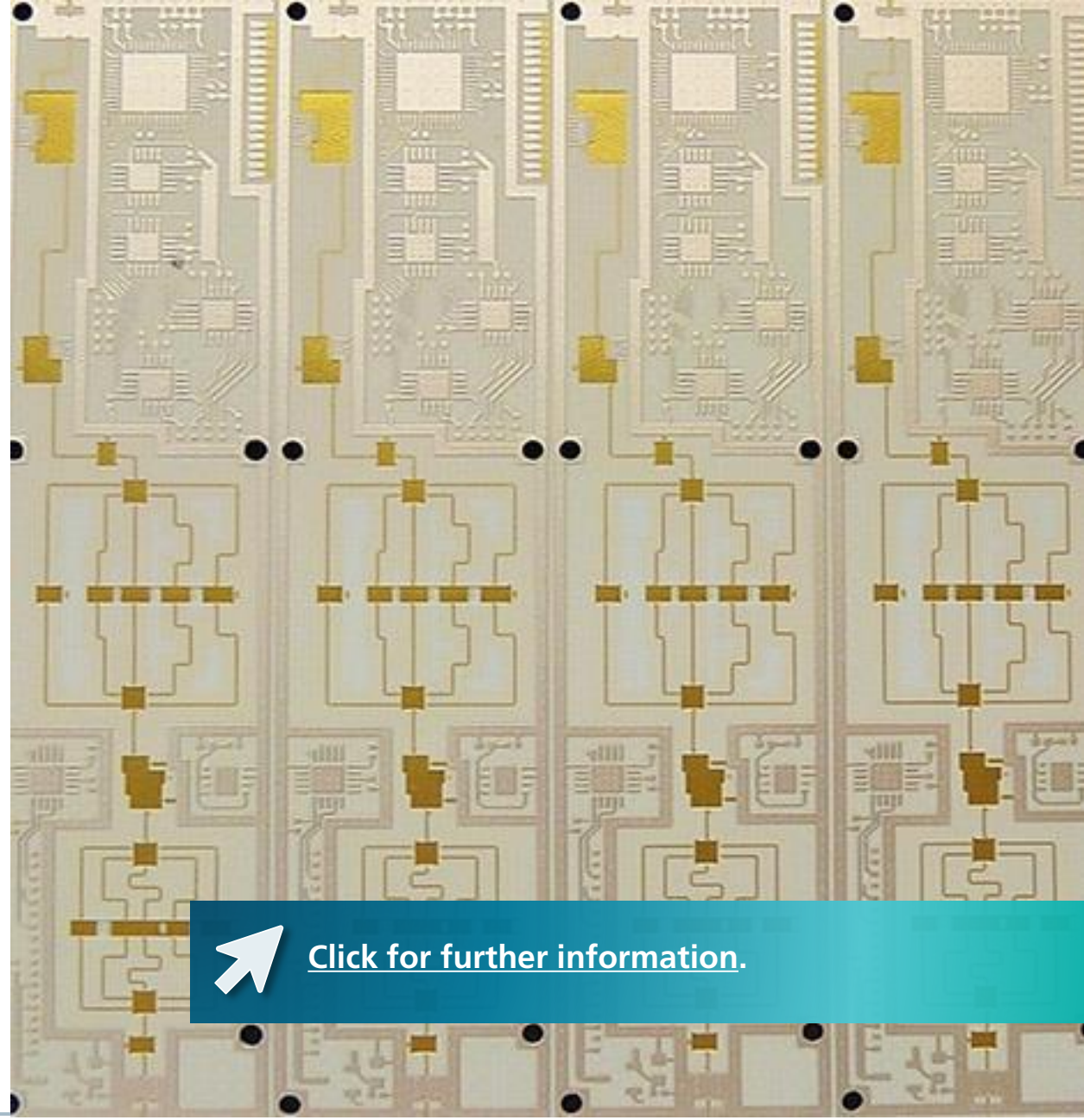
LTCC packaging

- **Full HF packaging**
  - MMIC
  - Stacked Patch antenna
  - BGA connection to next level

Electronics and microsystems

High frequency applications > 100 GHz

- Circuit for RF signal conditioning
- Low loss dielectric, 5 metallization layers
- Multi-printed board fabrication (6"x 6"), Automatic tape handling and stacking
- Excellent positioning accuracy, high edge quality of conductor lines
- Cavities with bonding pads for MMIC assembly
- High flatness for SMD soldering processes on top of circuit carrier
- Metallization frame for hermetic sealing



Click for further information.

Ceramic thick-film and multilayer technology

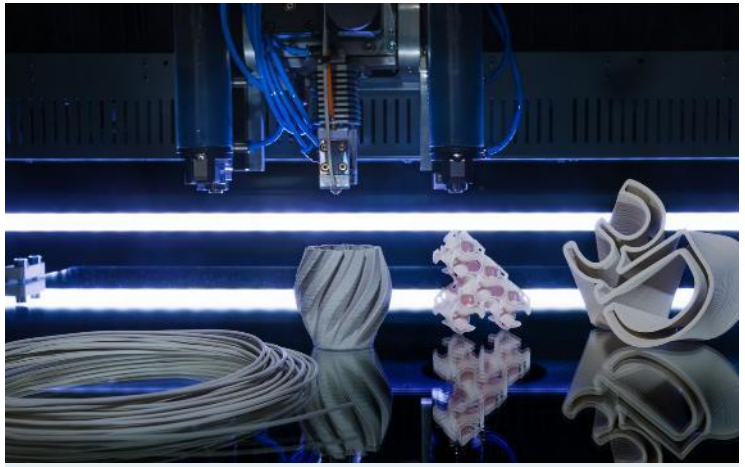
2D / 3D-printing technologies for functional film deposition

Screen- / stencil printing

- Mask- based (pastes)
- 2D / 3D (tubular)
- Max. resolution 25 µm

Ink-jet / aerosol-jet printing

- Digital, multi-material (5 inks)
- 2D / 3D, NovaCentrix Pulse Forge
- Max. resolution 10 µm



Additive manufacturing

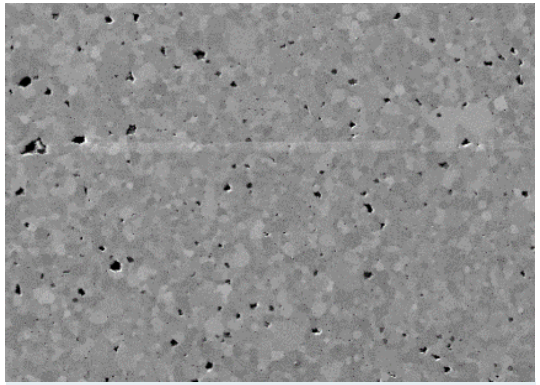
- A variety of ceramic components – manufactured using the additive manufacturing process FFF

Customized paste / ink formulations for different printing technologies available @ IKTS

- Adaption of solids (functionality, sintering behavior – PSD, specific surface)
- Adaption of binder system (type, viscous behavior, wetting, printing and burn out behavior)

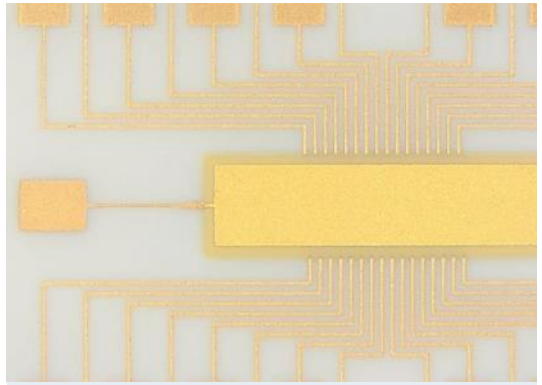
Electronics and microsystems

Electroceramic materials and integration technologies



Dielectric and piezoelectric materials

- **Anti-ferroelectric dielectrics** for high-energy power capacitors
- **Piezoceramic materials** for sensors and ultrasonic transducers; lead free and textured materials

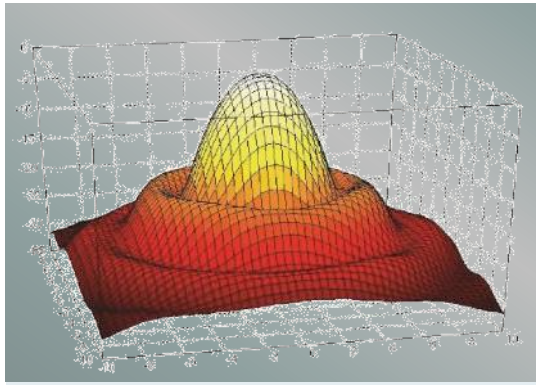


Printed sensors and transducers

- **Mechanical sensors** for force and force field
- **Ultrasonic transducers** for SHM, process control, level and distance control
- **Transducers** for mechanical energy harvesting

Piezoceramic components and piezoceramic-polymer composites

- **1-3 piezofiber composites** for ultrasonic transducers
- **SONAR transducers** in low and high frequency range

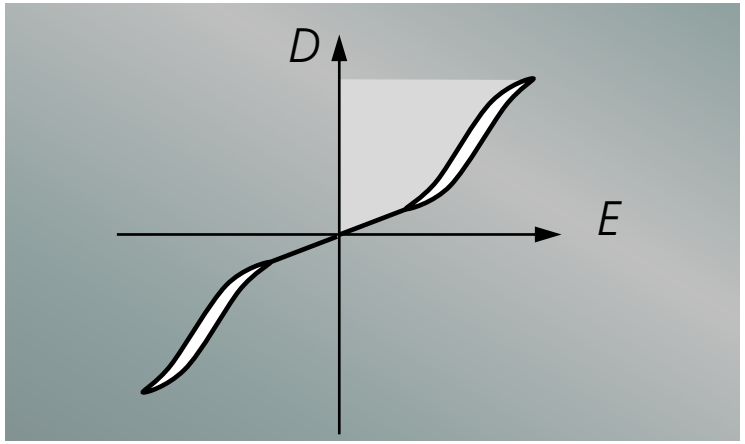


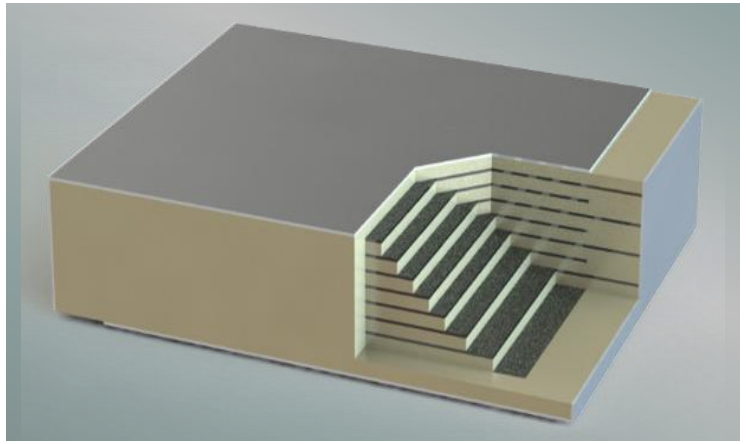
Complex characterization and modeling

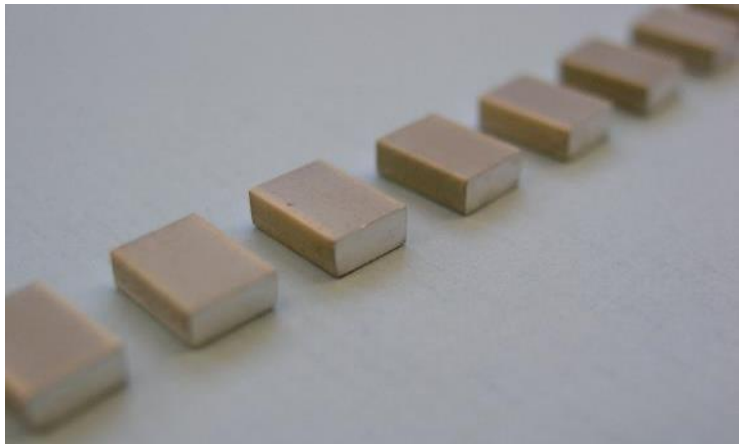
- Customer-specific complex electro-mechanical and characterization
- Material, component and system modeling, simulation
- Process modeling

Anti-ferroelectric capacitors

High energy density capacitors for power electronics







Advantage

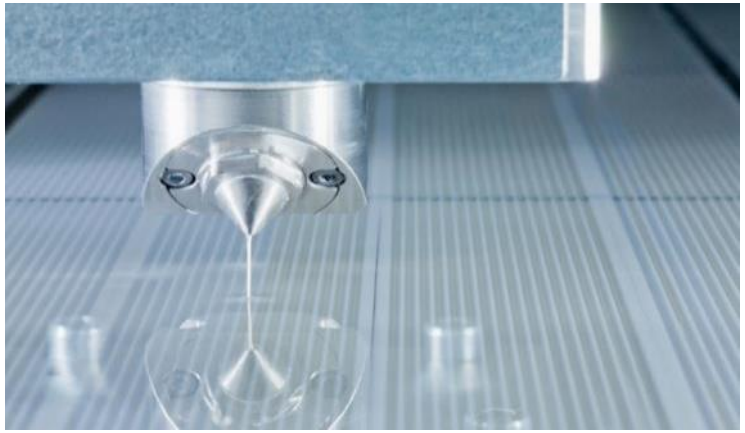
- Anti-ferroelectric dielectrics for high capacity and energy density (factor 3 compared to state of the art)
- Low leakage at elevated temperatures, low dielectric losses, high DC and thermal stability
- No thermal runaway due to permittivity characteristics
- Robust multilayer components with low parasitics for fast switching under high frequencies

Applications

- DC-link capacitors and snubbers in inverters
- Puls capacitors in detonators

Piezoceramic-polymer composites

1-3 composites for ultrasonic transducers



Advantage

- Enhanced electro-mechanical coupling of 1-3 piezocomposites compared to bulk piezoceramic materials
- Piezoceramic fibers of commercially available piezoceramic materials (PZT and lead-free); diameter 100–800 µm
- 1-3 piezofiber-polymer composites with regular or random fiber arrangement

Applications

- Ultrasonic transducers for Sonar (low and high frequency range), imaging, NDT
- Single fiber transducers for ultrasonic computer tomography (USCT)
- Patch sensors, actuators

05

Protective ceramics and structural ceramics

Defense and security research application

Protective ceramics & structural ceramics

Transparent ceramics

Transparent ceramics and PERLUCOR® – for optical systems, medical technology and ballistic protection

Application

- Domes and lenses for military systems
- Detection and sensor windows
- Windows for laser communication
- Infrared temperature scanners
- Infrared night vision devices
- Thermographic devices
- Transparent armor for military and civil use
- Vehicle windshields
- Ground windows for helicopters
- Explosion shields for aircraft
- Windshields for aircraft and spaceship windows
- Security windows in armored vehicles with reduced weight
- Unmanned vehicles, drones

Protective ceramics & structural ceramics

Transparent ceramics

Transparent ceramics and PERLUCOR® – for optical systems, medical technology and ballistic protection

Advatage

- Extreme robustness, hardness and scratch resistance for longer visibility and functionality
- Efficient use under extreme conditions in industry for safe monitoring of processes, e.g. in production, high-temperature areas, furnace, vision and rotary windows
- Durable protection of optical and sensor systems in harsh environments

Protective ceramics & structural ceramics

Transparent ceramics for optical systems, medical technology and ballistic protection

Raw density	**ρ**	**≥ 3.57 g/cm³**
Hardness (according to Vickers)	HV_1	≥ 13.8 Gpa
Refractive index	n	1.72
Transparency IT (thickness 1 - 10 mm)		≥ 80%
Thermal conductivity	l	≥ 12 W/mK
Modulus of elasticity	E	≥ 280 Gpa
Poisson ratio	υ	~ 0.22
Speed of sound	V_L	≥ 10,000 m/s
Dielectric constant		8–9
Flexural strength	$б_B$	250–350 MPa
Compressive strength	б	≥ 2000 MPa
Coefficient of thermal expansion (30 - 200 °C)	α	~ $6.9*10^{-6}$/K

Transparent ceramics and Perlucor®

Protective ceramics & structural ceramics

3D ceramic reinforcements for novel protection concepts

DuktAr – realization of 3D protection concepts

Challenge

Protection concepts for highly dynamically loaded components in mechanical, plant and vehicle engineering can currently only be realized with high weight (metallic) or with very limited formability (ceramic).

Solution

Use of 3D "topologically interlocked structures" (3D-TIS) made of ceramics (SiC, B4C, Al_2O_3) + flexible carrier material.

Protective Ceramics & Structural Ceramics

3D ceramic reinforcements for novel protection concepts

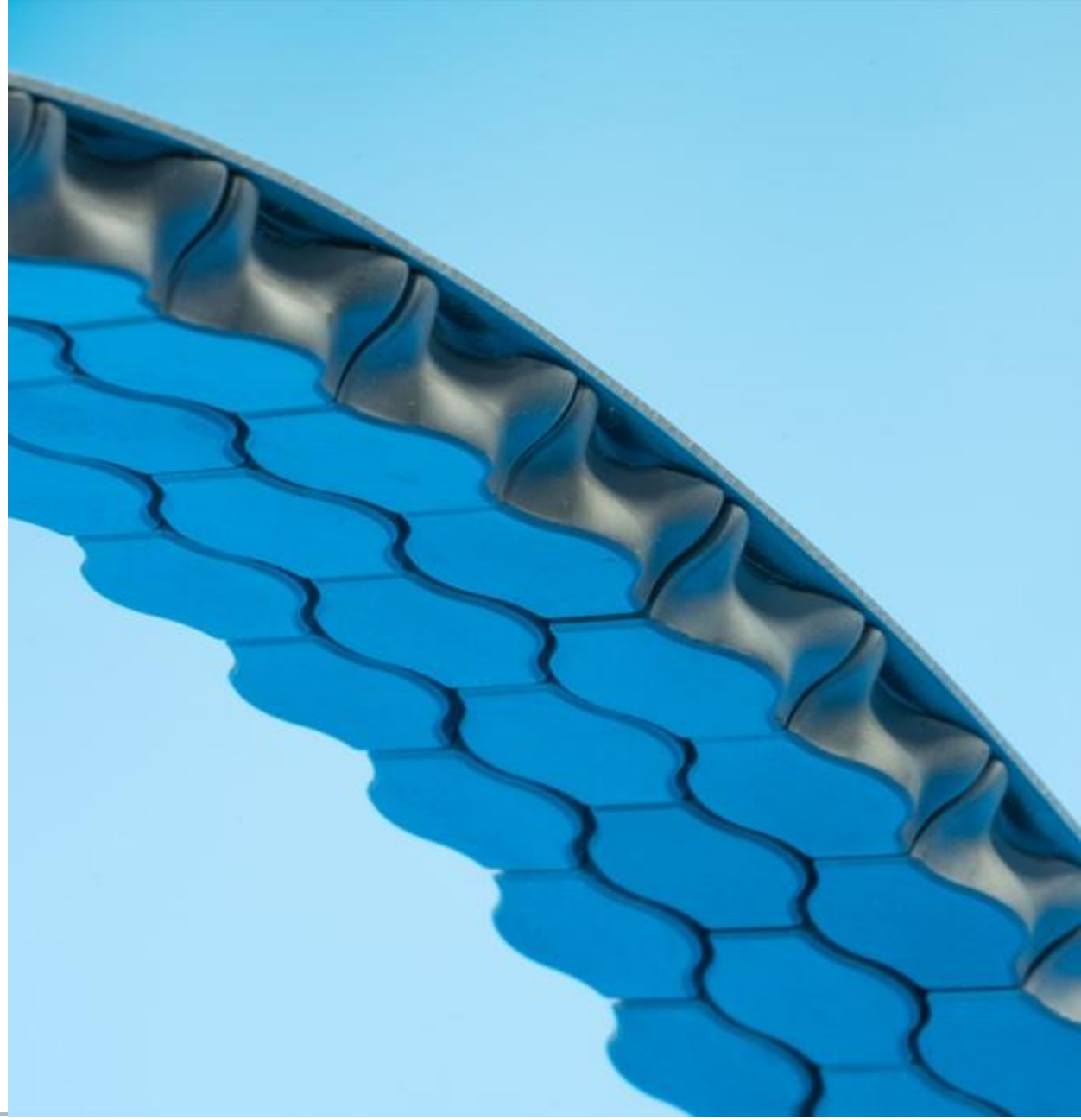
DuktAr – realization of 3D protection concepts

Application

Protective devices for centrifuges, rotors, recycling plants or for high-speed machining.

Advatages

- Shape optimization and variable size for maximum protection (max. radii of curvature)
- Cost-effective mass production and processing of 3D TIS ceramic bricks (without subsequent mechanical post-processing)
- TIS attachment techniques on flexible carrier material



Protective ceramics & structural ceramics

Diamond-materials for wear applications

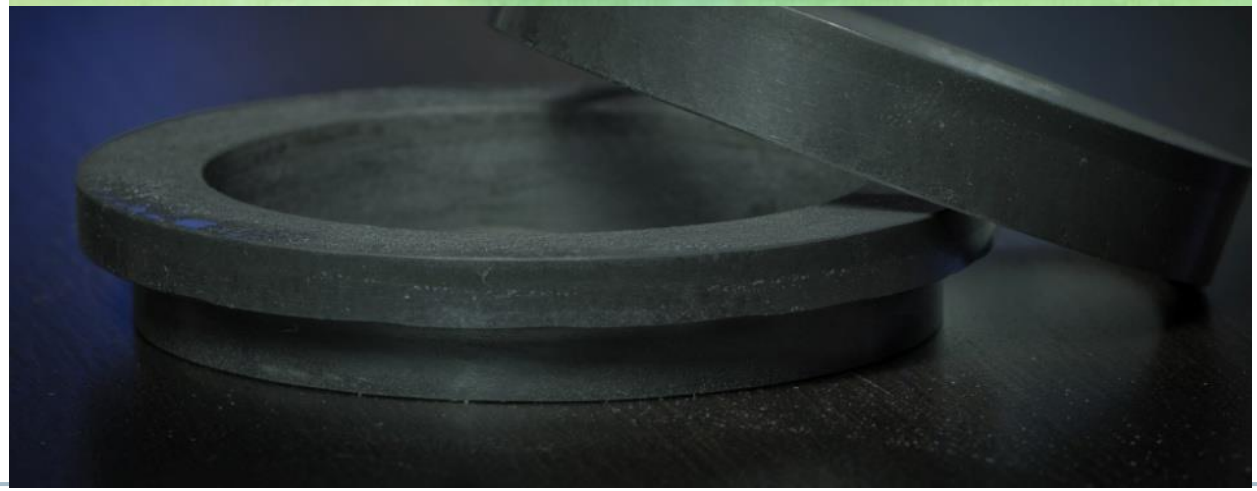
Superhard large scale SiC-bonded diamond-materials produced without high pressure

Advantage

- Hardness > 35 GPa, KIC = 4-5 MPam1/2;
- Strength 300-500MPa
- Abrasive wear > 10 times better as B4C- ceramic
- Friction coefficient like CVD-diamond coatings
- Thermal conductivity up to 650 W/mK
- Dense graded SiC-Diamond-materials possible (SiC-Diamant layer thickness 0.3 – 10 mm)

Application

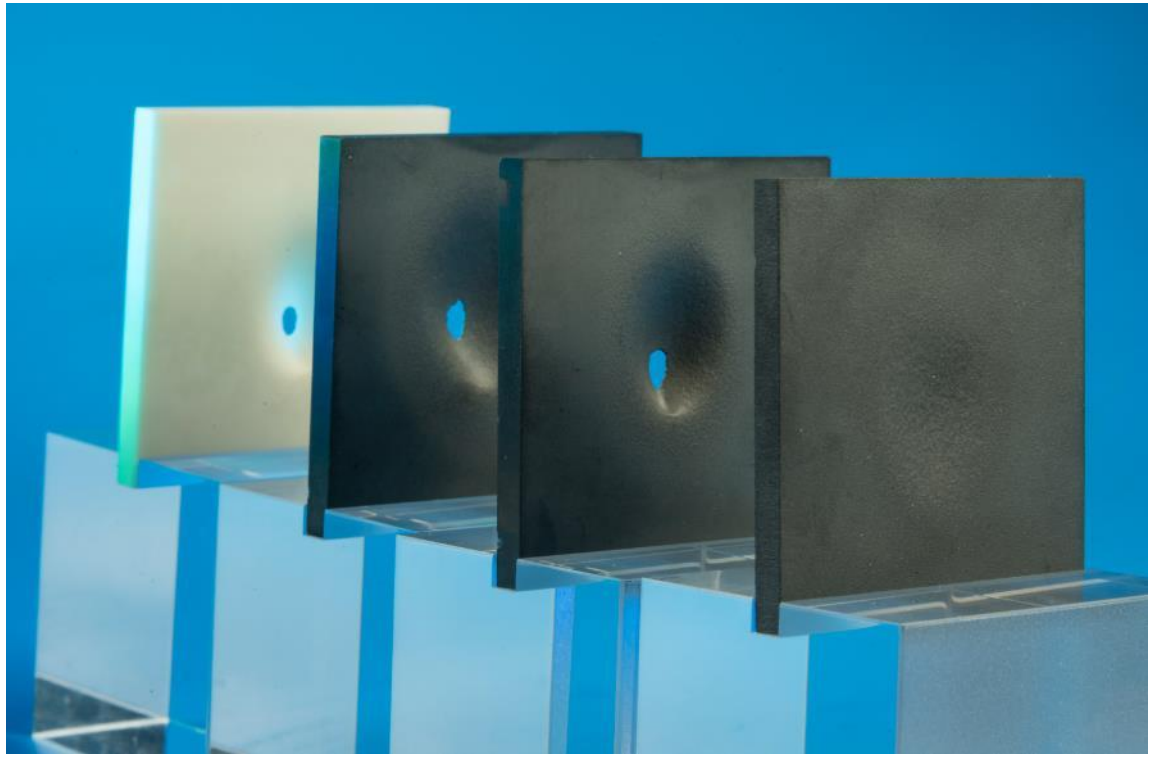
- Wear parts , protective ceramics
- Components with high thermal conductivity

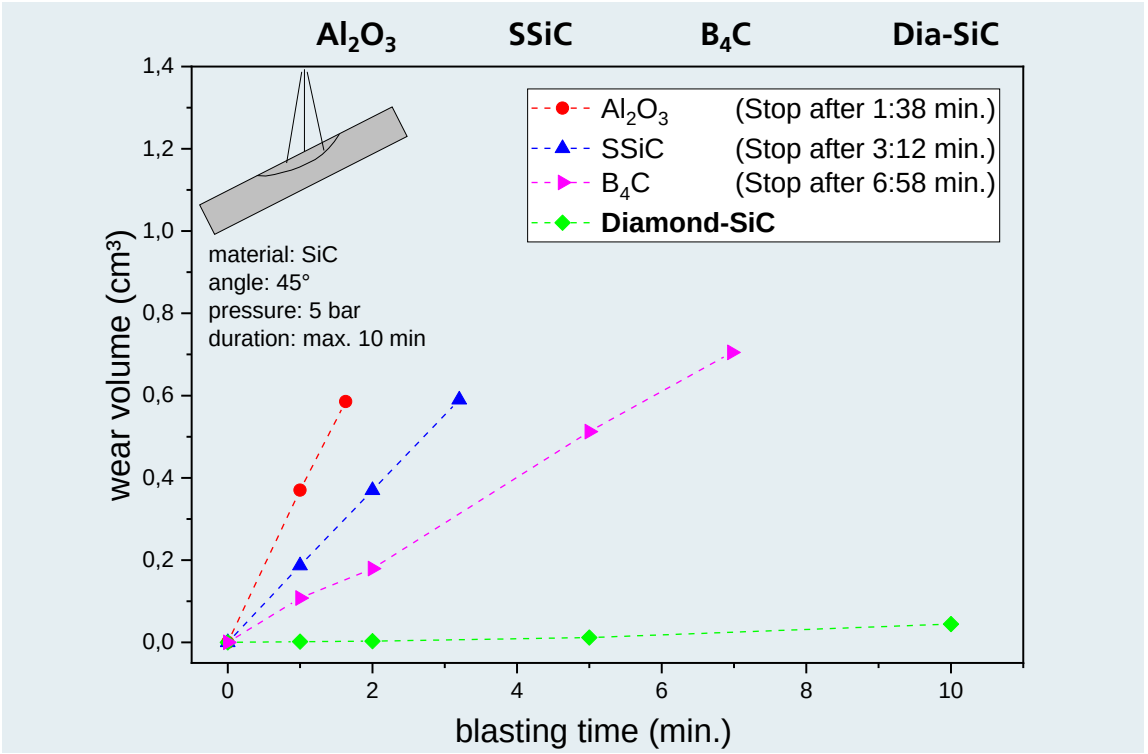


Protective ceramics & structural ceramics

Diamond-materials for wear applications

Impact wear sand blasting test with 45°



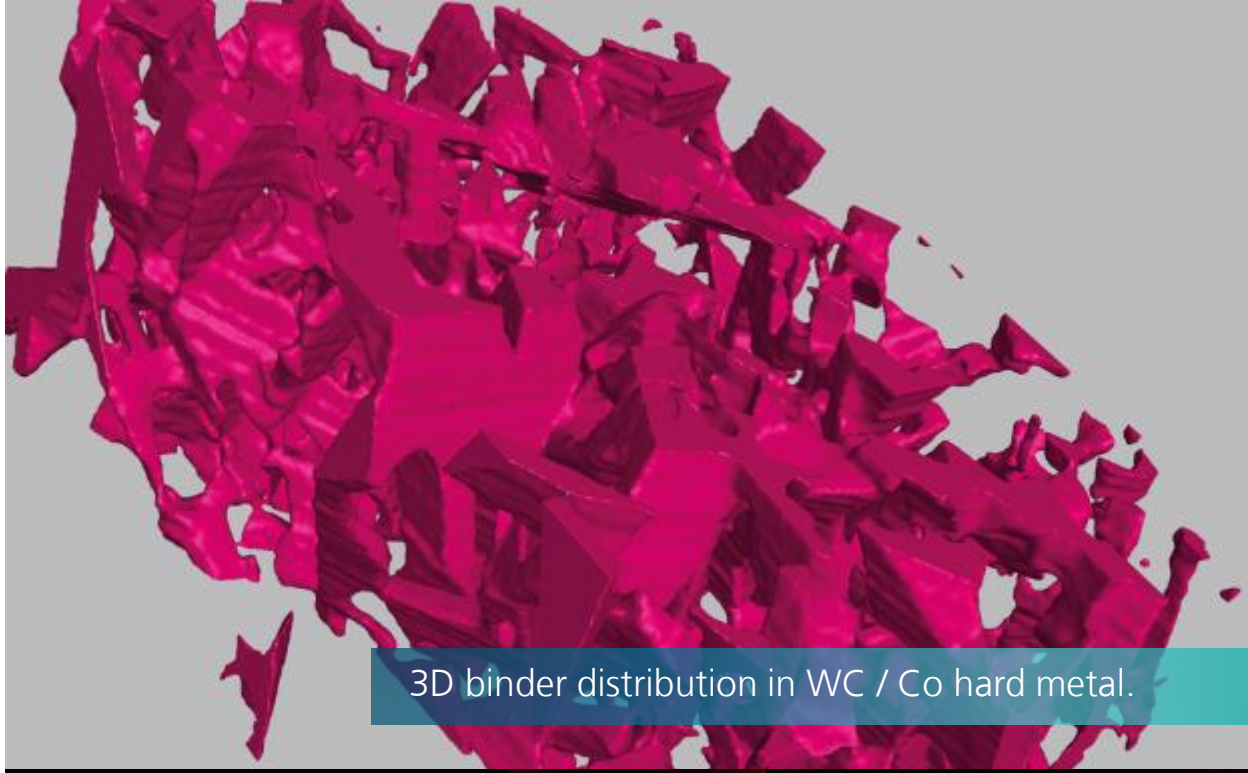


Protective ceramics & structural ceramics

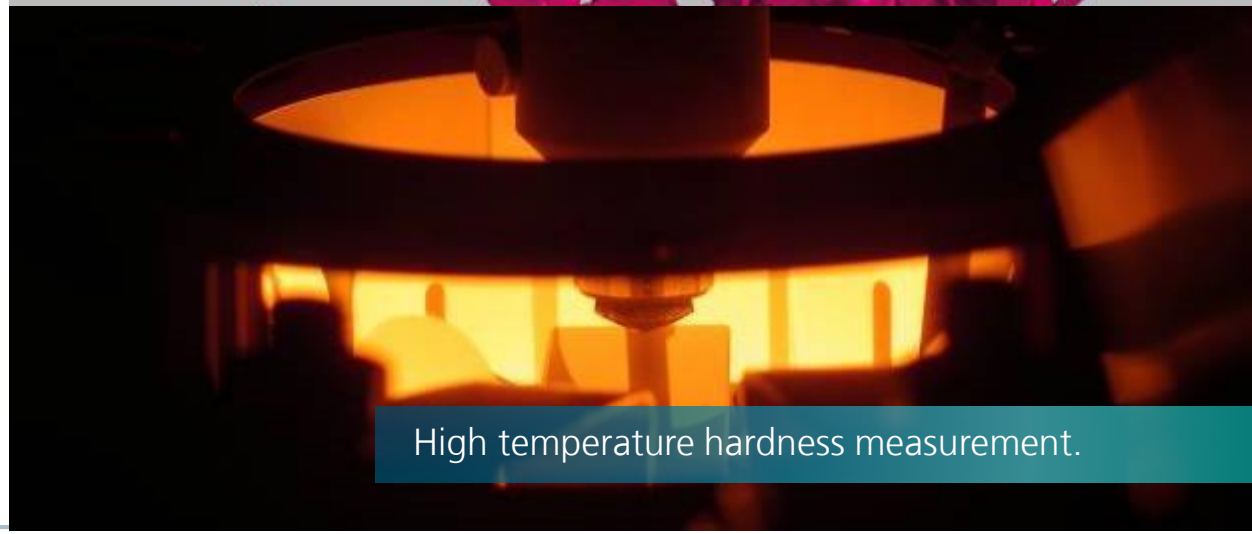
Characterization of ceramic materials, hard metals and components

Equipment and Know how for characterization of…

- Ceramic microstructures as a basis for correlation with properties
- Characterization of mechanical , elastic, electrical, optical properties of materials and components
- Wear mechanisms of ceramic components
- Failure analysis as a basis of improvement of systems



3D binder distribution in WC / Co hard metal.



High temperature hardness measurement.

Ceramic metal composites

For wear, penetration and shielding applications

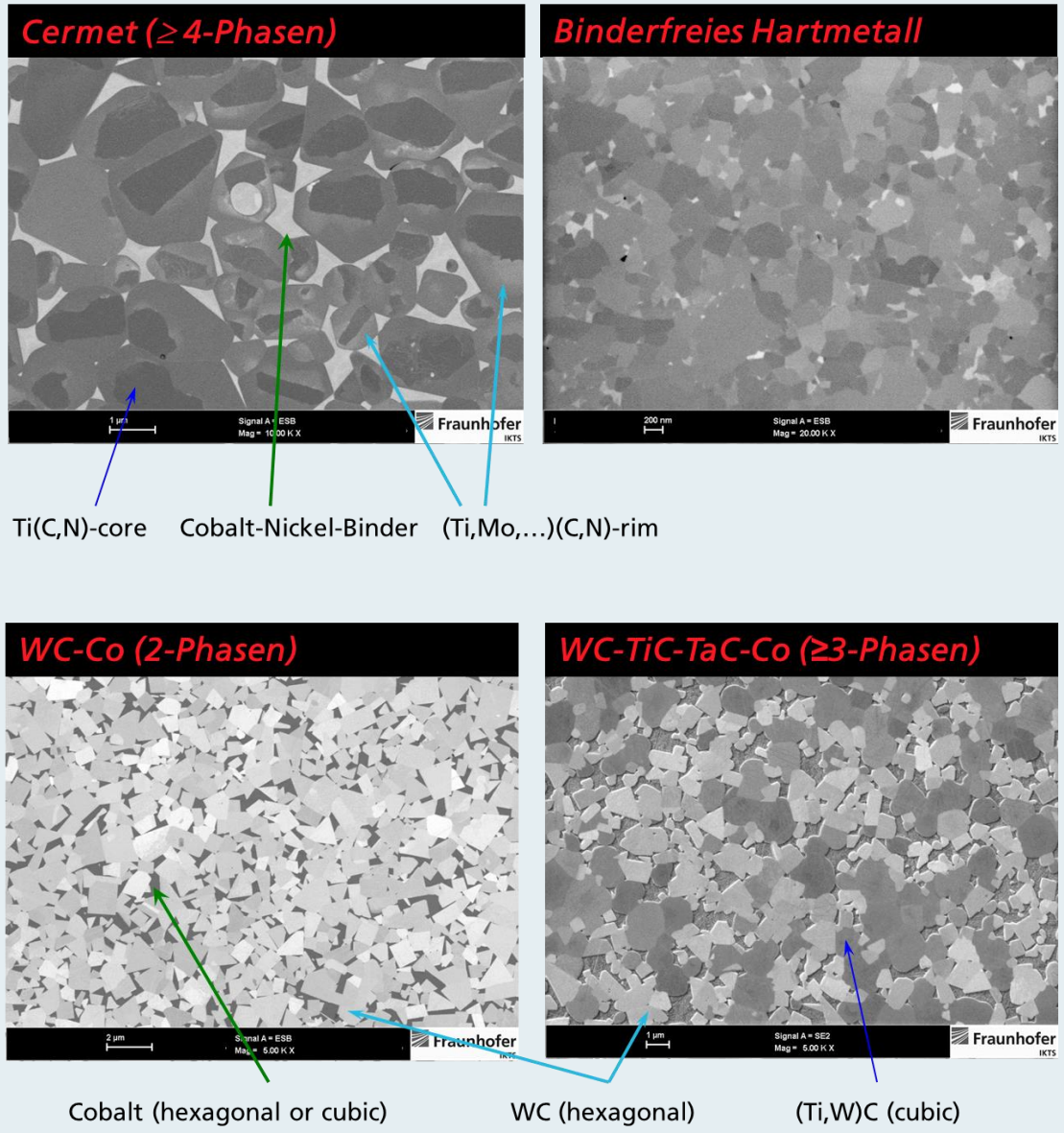
Combination of high hardness and toughness with high wear resistance)

Solution with heavy elements:

- WC and/or Mo2C and metal binders (Co, Fe, Ni and more) → densities up to 15 g/cm³
- Binderless WC or W-based mixed carbides → densities up to 17 g/cm³

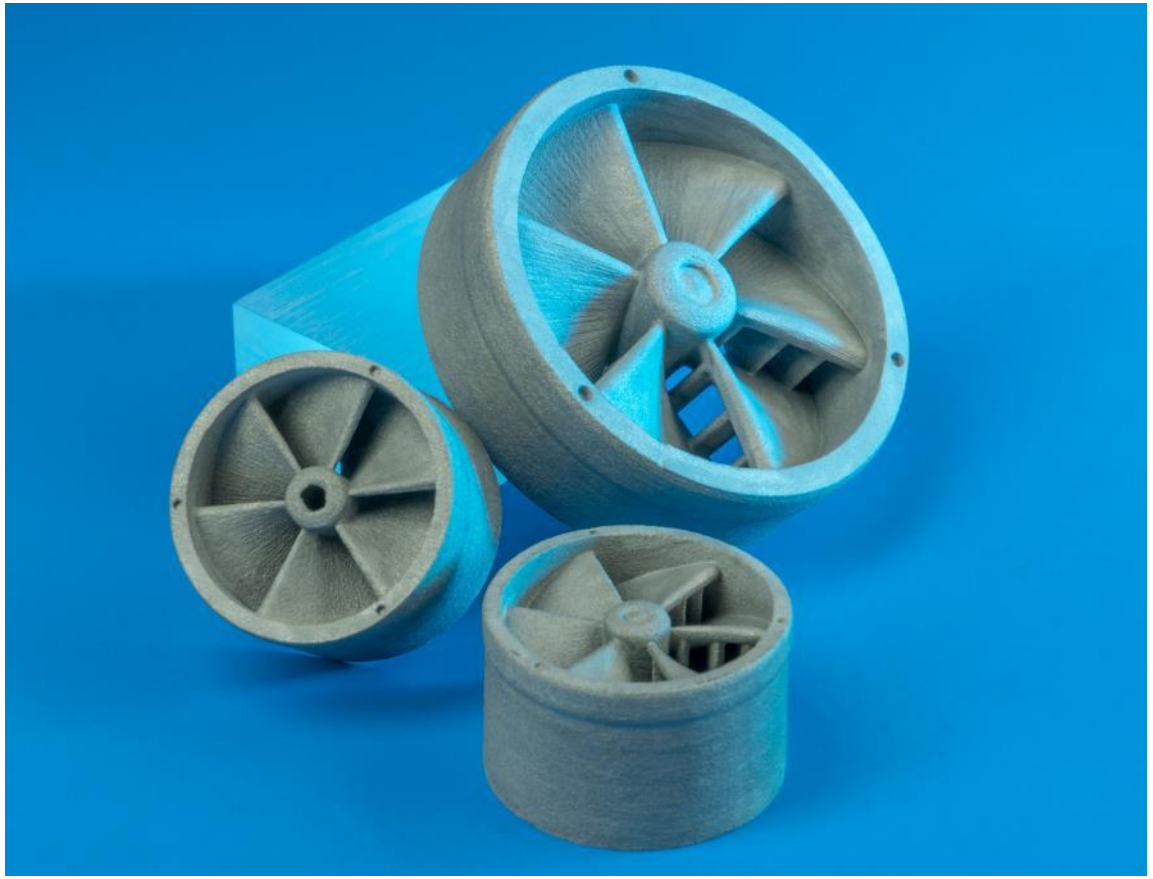
Solutions with light elements:

- TiC, NbC etc. with Co, Fe, Ni binders → densities of around 7 g/cm³
- High entropy based carbides, metal binders and composites (patent pending)
- Higher design freedom and complex integration



Additive manufacturing of cermets and hardmetals by Binder Jetting

For wear, penetration and shielding applications



Protective ceramics & structural ceramics

Ceramic reactor for space application

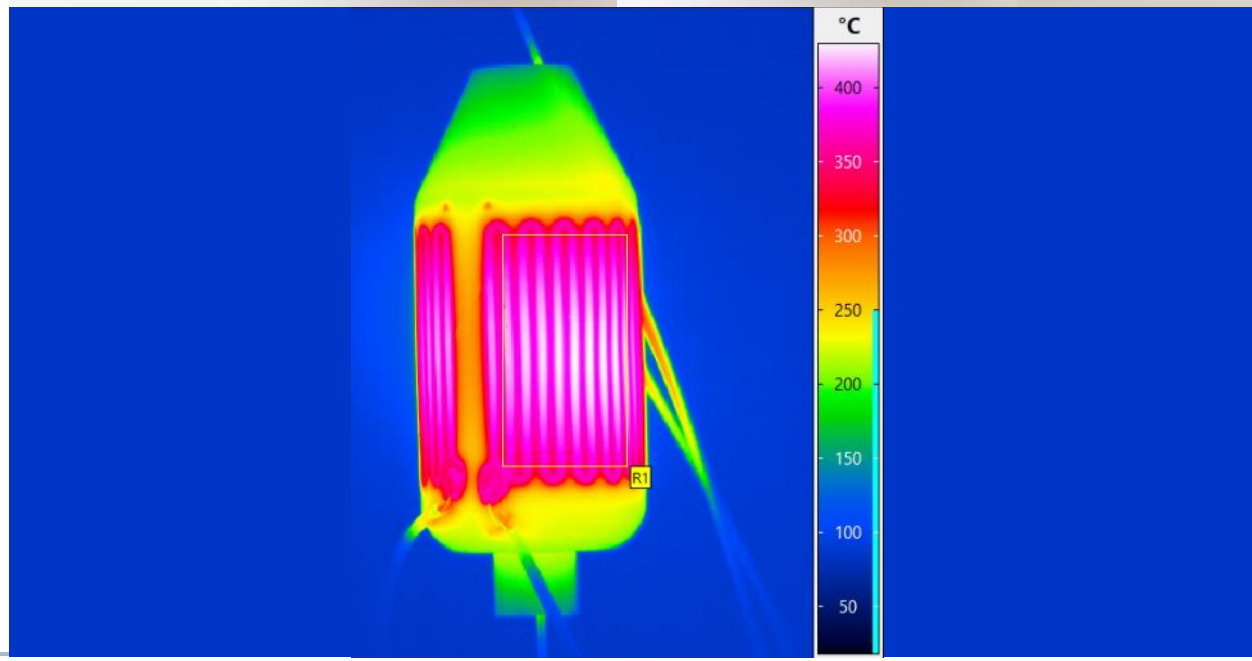
Application for the turbines / CerAMfacturing + Thick-film technologies

Callenge

Development of new reactor concepts for fuel-efficient turbines in space applications.

Solution

- Highly integrated ceramic reactor
- Combination of additive manufacturing and screen printing allows new reactor concept using H_2O_2 instead of hydrazine
- Integrated heating system for quick chemical reaction



Protective ceramics & structural ceramics

Ceramic reactor for space application

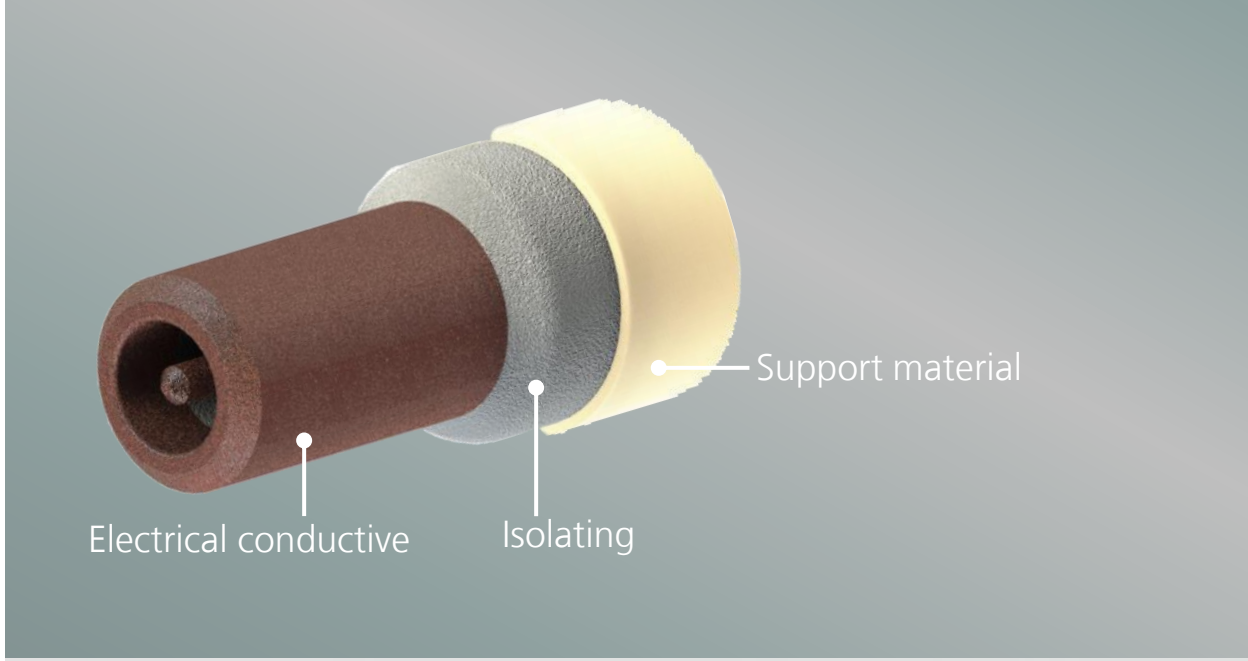
Application for the turbines / CerAMfacturing + material expertise (thermal co-processing)

Callenge

Complex and highly integrated ignition system.

Solution

- Combinated co-processing of Si_3N_4 + $MoSi_2$ for integrated igniter in ceramic turbine
- Higher design freedom and complex integration



06

Environmental and process engineering

Defense and security research application

Environmental and process engineering

Power-to-X for alternative fuels

Environment and civil protection

Challenge

Due to their high energy density and ease of storage, liquid fuels will retain their importance for mobility in the short and medium term.

Solution

- Valuable base and special chemicals from various (renewable) energy sources
- Synthesis gas production from methane, LPG, biogas, ethanol, diesel
- Synthesis of olefins by dehydration of methanol (MTO)
- Fuels by dehydration of methanol (GTO)
- Synthesis of dimethyl ether (DME) from methanol
- Fischer-Tropsch synthesis
- Coupling of water electrolysis and synthesis gas production
- Methanol by oxidation of methane to methanol (GTL)

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Environmental and process engineering

Compact & self-sufficient water treatment solutions

Environment and civil protection

Application

Water supply for the civilian population and in the event of a disaster.

Solution

- Self-sufficient, flexibly deployable decentralized supply and storage systems for electricity, heat and water - autartec®
- Highly integrated combination of Advanced Oxidation Process, nanofiltration and disinfection
- Free of biological and chemical consumables
- Real-life piloting in offgrid sea-region
- Compact system design

autartec®: self-sufficient supply in the "FreiLichtHaus".

Click for further information.

Environmental and process engineering

Self-sufficient water treatment in rural areas

Environment and civil protection

Advantage

- Water treatment system for 4-person household
- Degradation of organic components and safe disinfection
- No consumables needed, no chemicals or biology
- Simple water treatment for developing countries
- Combination of catalysis and membrane filtration
- Use of ceramic NFE
- Energy supply for water 2 m^3 drinking water / day

Example

Water treatment for developing countries with catalytic ceramic membranes.

Environmental and process engineering

Treatment of radioactive contaminated wastewater

Environment and civil protection

Challenge

Purification of the water from pollutants.

Solution

With our radionuclide laboratory, we have an infrastructure that allows us to perform special radiochemical analyses, e.g. by gamma spectrometry or liquid scintillation. Dissolving contaminated media, such as the destruction / elimination of radioactive substances in waste water and residues or the development of processes for separating arsenic, uranium or CHCs from groundwater.

Advantage

- Simple production of c-14 carbonates; capable of continuous filtration
- Treatment of ignitable and / or aggressive organic wastes
- Application for a wide range of substances
- Efficient separation of counter-nuclides by means of electrochemical processes

Environmental and process engineering

MOFs for filtration of hazardous substances

Metal Organic Frameworks (MOFs) for protective masks

Challenge

Metal Organic Frameworks for permeable protective clothings.

Solution

- Combination of MOFs with activated carbon closes absorption gap for higher protection
- Synthesis and tailored shaping of MOF materials

07

Monitoring of infrastructures

Defense and security research application

Inspection of composite aircrafts

Determination of heat damages / heat affected zones

Sensor Fusion for more successful CFRP testing

Challenge

The established methods for non-destructive testing of carbon fiber reinforced plastics (CFRP) separately provide only limited information about the material. Whether macroscopic properties, texture parameters or the state of the matrix material, none previously available test method alone can answer all questions.

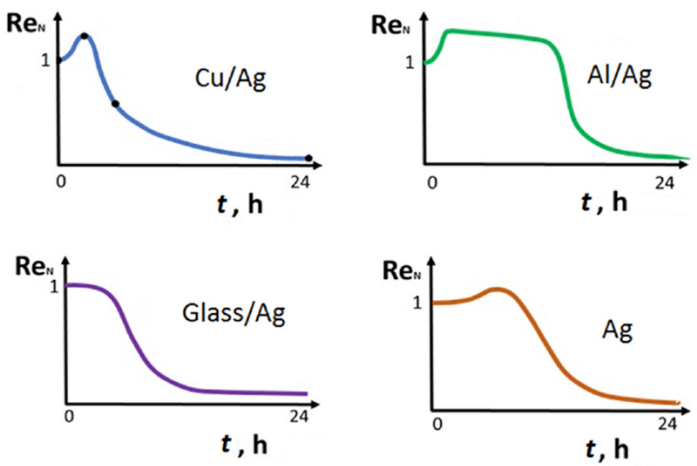
Solution

Together with the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) Fraunhofer IKTS is therefore working on the combination of different sensors and their measurement data to improve the informational value of non-destructive testing. Through this combination of ultrasonic, eddy current and infrared spectroscopy methods, a more meaningful test result is generated.

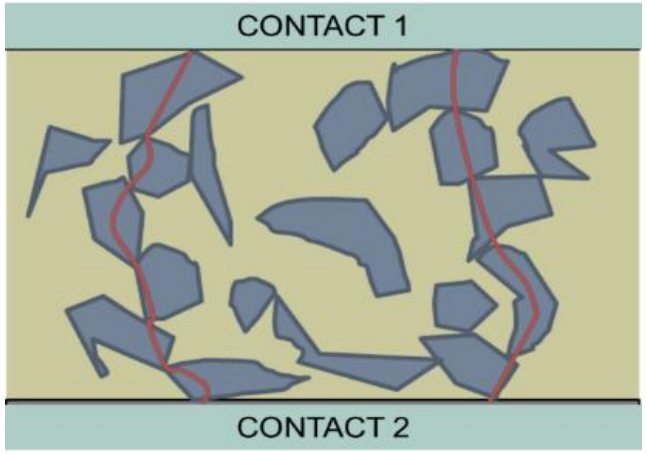
Inspection system for electrical conductive coatings on composite aircrafts

Solution

- High-frequency eddy current based impedance spectroscopy of characterization of the percolation process of wet conductive coatings.

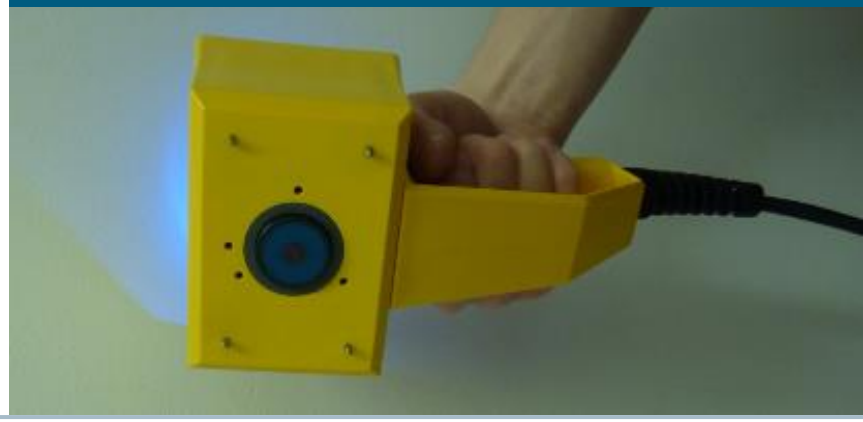


Inspection results: Drying curves for different coatings.



Film formation and percolation.

High Developed inspection system for Wright Patterson Air Base / Dayton Ohio.



Laser-Speckle-Photometrie

Inline troubleshooting in high-performance SLM systems

Challenge
Additive manufacturing of metal parts is an efficient strategy for handling of spare parts in distinct regions. Quality control is an essential part of the system to guarantee safety of the overall system.

Solution
The laser speckle photometry (LSP) method developed at Fraunhofer IKTS can ensure the reliability and optimal functioning of AM-process like Selective Lase Melting. The system allows a permanent inspection of every SLM-layer and identifies defects and cracks during operations.

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