Materials and Applications of the Ceramic Thick-Film and Multilayer Technology

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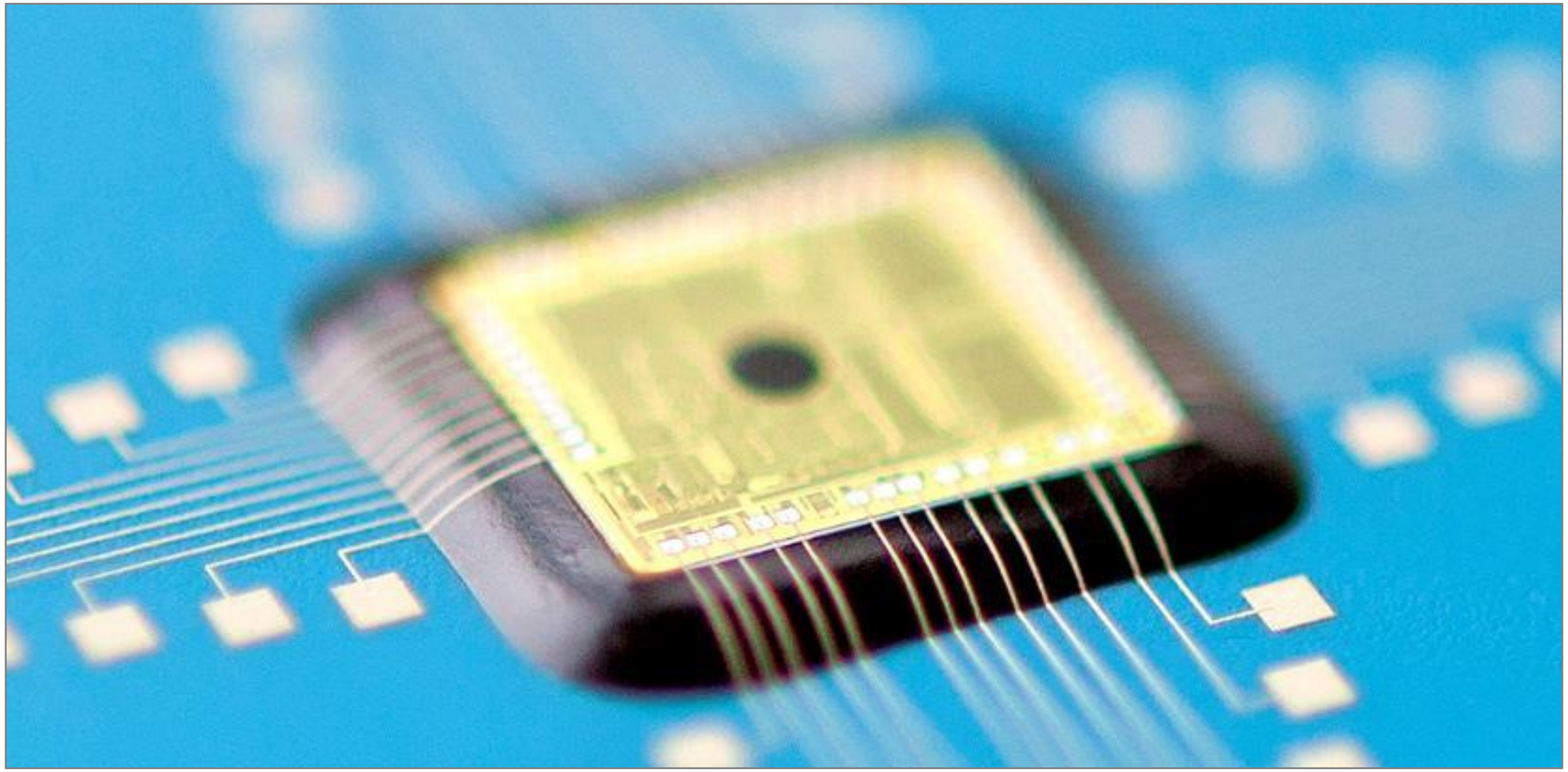

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Latest update: 25.05.2016

Fraunhofer IKTS

Outline

- Fraunhofer Gesellschaft, Fraunhofer IKTS
- Department Hybrid Microsystems @ IKTS
- Ceramic Thick-Film and Multilayer Technology
- Application Examples

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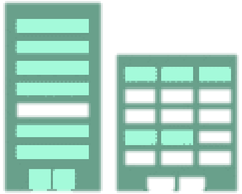
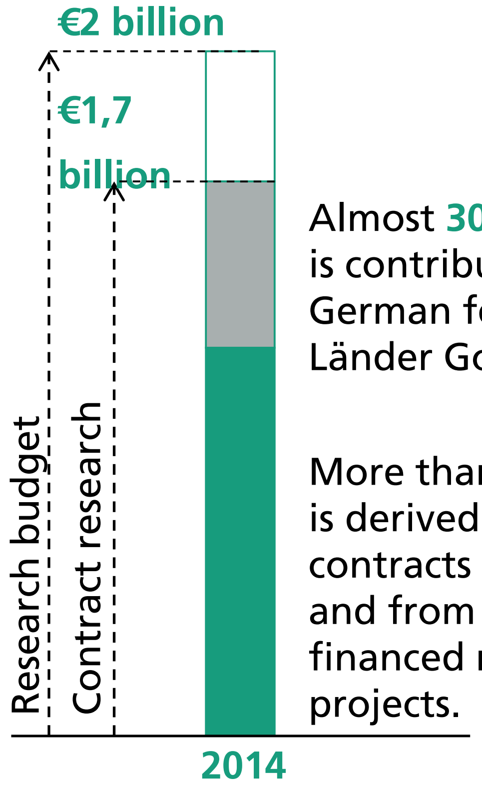
The Fraunhofer-Gesellschaft at a Glance

Applied research for the immediate benefit of the economy and society

Nearly 24,000 employees



66 institutes and research units



Almost 30% is contributed by the German federal and Länder Governments.

More than 70% is derived from contracts with industry and from publicly financed research projects.

Fraunhofer IKTS

Research Landscape Dresden

- **10 Universities**
- **4 Max Planck Institutes**
- **5 Leibniz Institutes**
- **10 Fraunhofer Institutes and Units**

- Numerous competence centers, institutions for technology transfer and networks, e.g.:
  - BioMeT Dresden
  - DRESDEN-concept e. V.
  - Dresden Fraunhofer Cluster Nanoanalysis
  - Energy Saxony e. V.
  - Material Research Network Dresden e. V.
  - Silicon Saxony e. V.

Fraunhofer in Dresden

10 institutes und units, biggest site of the Fraunhofer-Gesellschaft

- **FEP** Institute for Organic Electronics, Electron Beam and Plasma Technology
- **IFAM** Institute for Manufacturing Technology and Advanced Materials
- **IIS-EAS** Institute for Integrated Circuits, Design Automation Division
- **IKTS** Institute for Ceramic Technologies and Systems
- **IPMS** Institute for Photonic Microsystems
- **IVI** Institute for Transportation and Infrastructure Systems
- **IWS** Institute for Material and Beam Technology
- **IWU** Institute for Machine Tools and Forming Technology
- **IVV** Institute for Process Engineering and Packaging, Branch Lab for Processing Machinery and Packaging Technology
- **IZM-ASSID** Institute for Reliability and Microintegration, All Silicon System Integration

Fraunhofer
IKTS

Intellectual Property Rights at Fraunhofer

Active inventions 2014: 6618
Patent applications 2014: 563

2013: Fraunhofer in
➔ **14^{th} place** of the most active **patent applicants** and
➔ **6^{th} place** of the most active **trademark applicants** at the German Patent and Trademark Office

2014: Fraunhofer is counted among the 100 largest applicants at the European Patent Office (place 56).

2014: According to a study by the international media concern Thomson Reuters, Fraunhofer is counted among the **»Top 100 Global Innovators«.**
(the other 3 German companies in the TOP 100 are BASF, BOSCH, Siemens)

Fraunhofer IKTS in Figures

Branches and Sites of Fraunhofer IKTS

Headquarter

- Dresden, Winterbergstraße

Branches

- Hermsdorf, Thuringia

- Dresden-Klotzsche

Fraunhofer Center

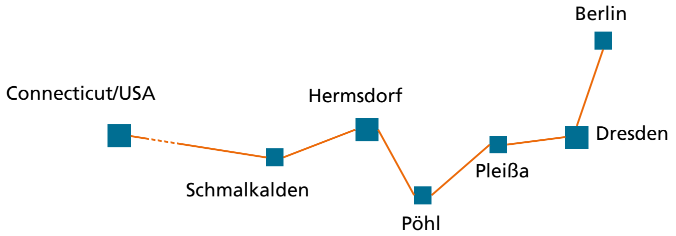
- for Energy Innovation CEI, Connecticut/USA

Sites

- Application Center Battery Technology Pleißa, Saxony

- Application Center Bioenergy Pöhl, Saxony

- Application Center Membrane Technology Schmalkalden, Thuringia



Fraunhofer IKTS in Figures

Branches and Sites of Fraunhofer IKTS










Branches and sites	Head-quarter	Hermsdorf branch	Dresden-Klotzsche branch	Total
Personnel (full-time equivalents)	**310**	**145**	**125**	**580**
Operating budget in million €	**26.3**	**10.8**	**13**	**50.1**
Industrial revenues in million €	**9.2**	**5.1**	**4.3**	**18.6**

Latest update: April 2015

Institute Director:

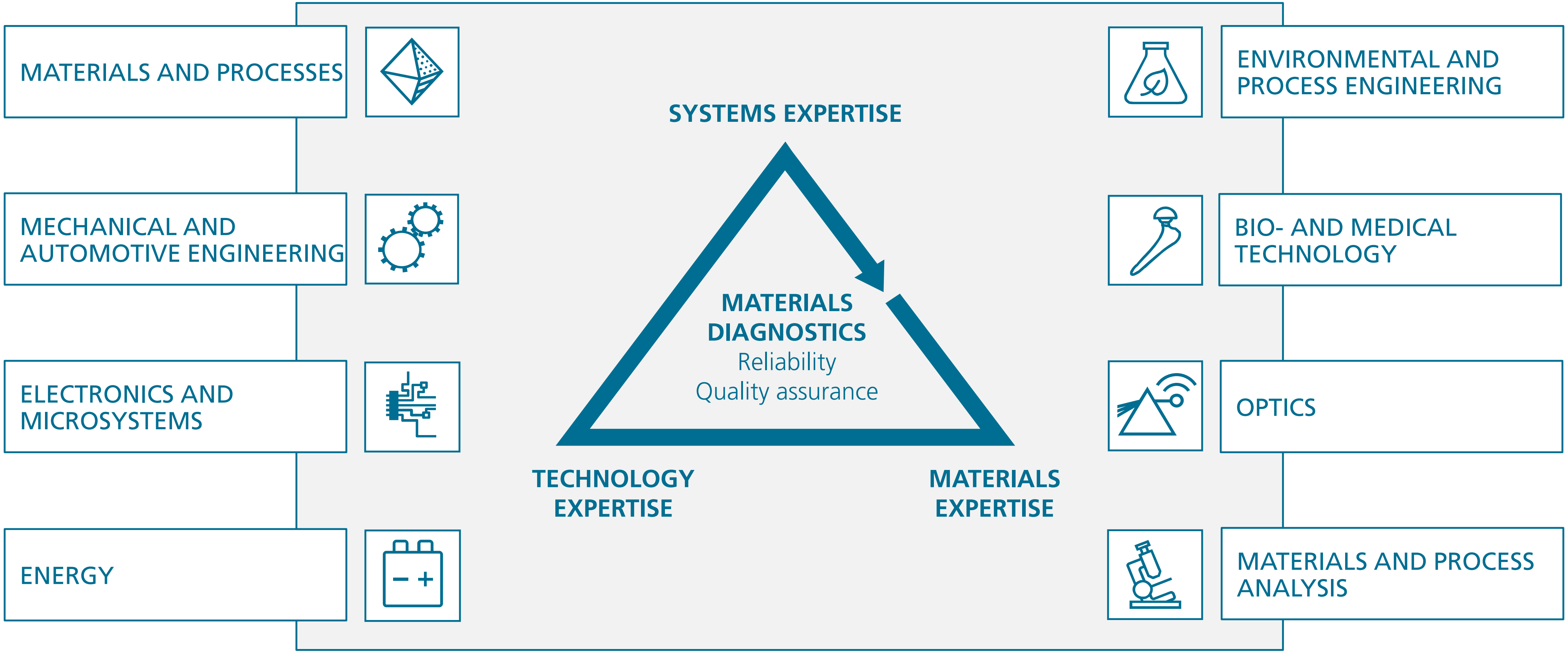
Prof. Dr. Alexander Michaelis

TÜVRheinland CERTIFIED
Management System
ISO 13485:2003

TÜVRheinland ZERTIFIZIERT
Management System
ISO 9001:2008
ISO 14001:2004

Fraunhofer IKTS

IKTS Business Divisions

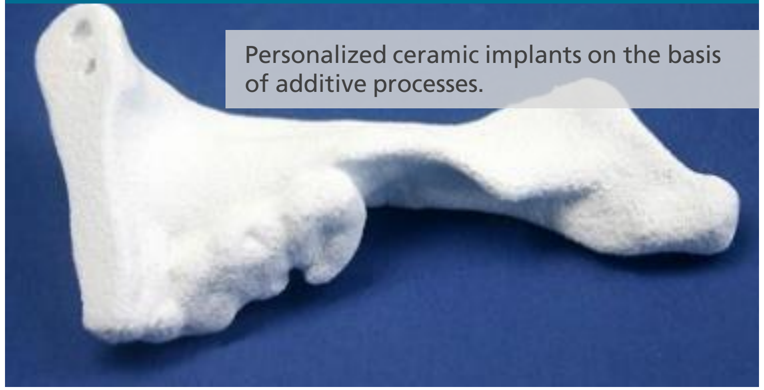


Current Research Projects

eneramic® fuel cell system

Power and heat from one source – compact, decentralized and efficient.

Additive manufacturing

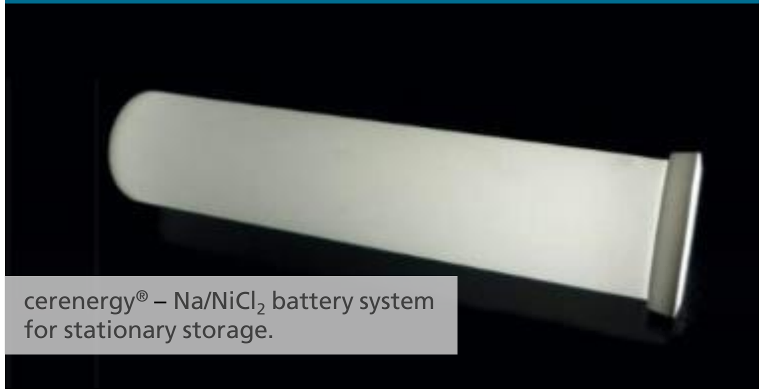


Personalized ceramic implants on the basis of additive processes.

Superhard wear-resistant materials

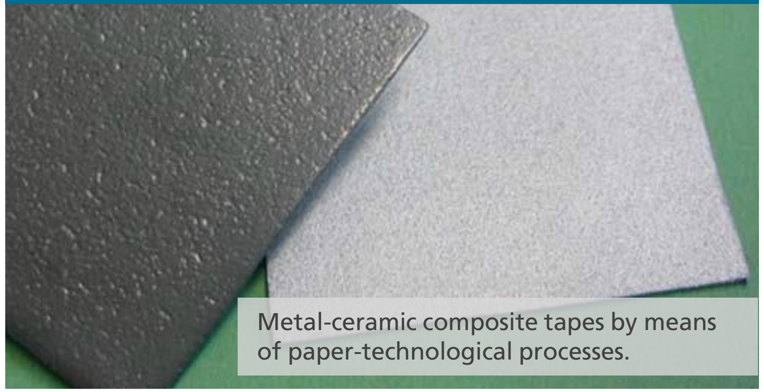
SiC/diamond materials for components subject to high loads in the mining industry.

High-temperature energy storage



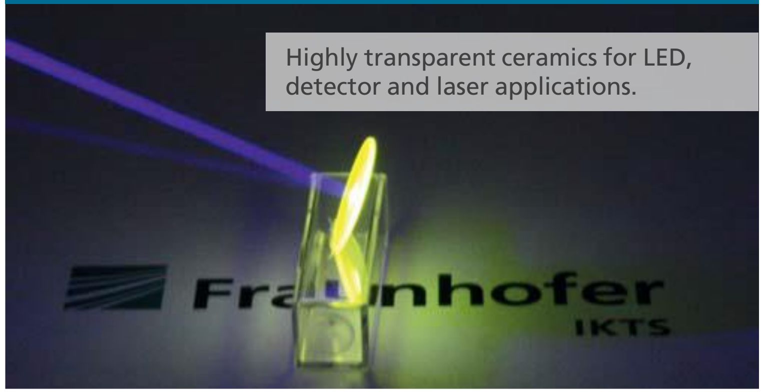
cerenergy® – $Na/NiCl_2$ battery system for stationary storage.

Composites



Metal-ceramic composite tapes by means of paper-technological processes.

Active optoceramics



Highly transparent ceramics for LED, detector and laser applications.

Current Research Projects

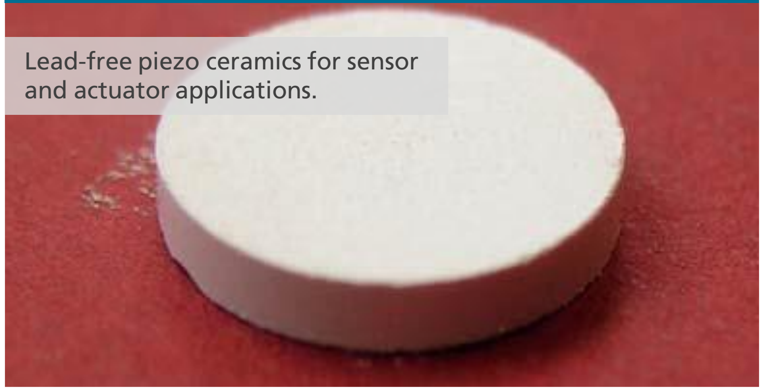
Ceramic tapes (specifically UV-curable)

Sustainable UV-curable binder systems for ceramic tapes.

Ceramic foams as bone replacements

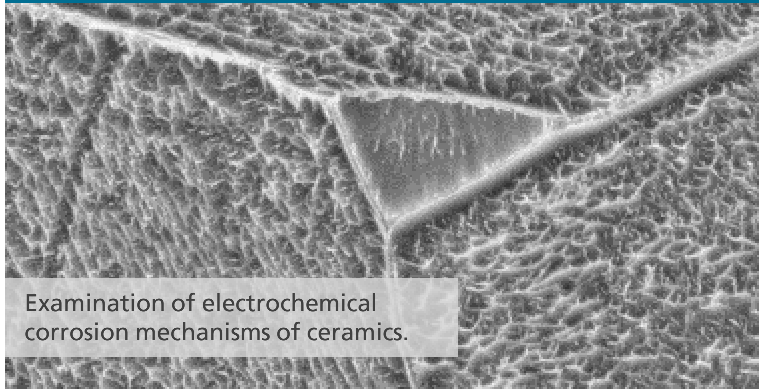
Freeze foamed thumb bone replica.

Smart materials



Lead-free piezo ceramics for sensor and actuator applications.

Corrosion of ceramic materials

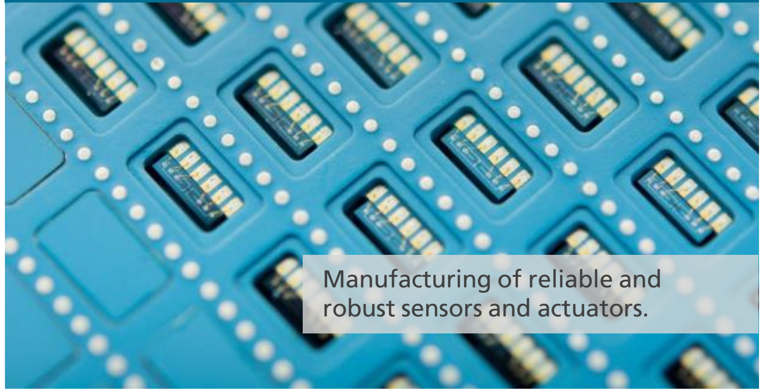


Examination of electrochemical corrosion mechanisms of ceramics.

Plasma-gel coatings

Ceramic coatings for e.g. surgical tools.

LTCC-MEMS packaging



Manufacturing of reliable and robust sensors and actuators.

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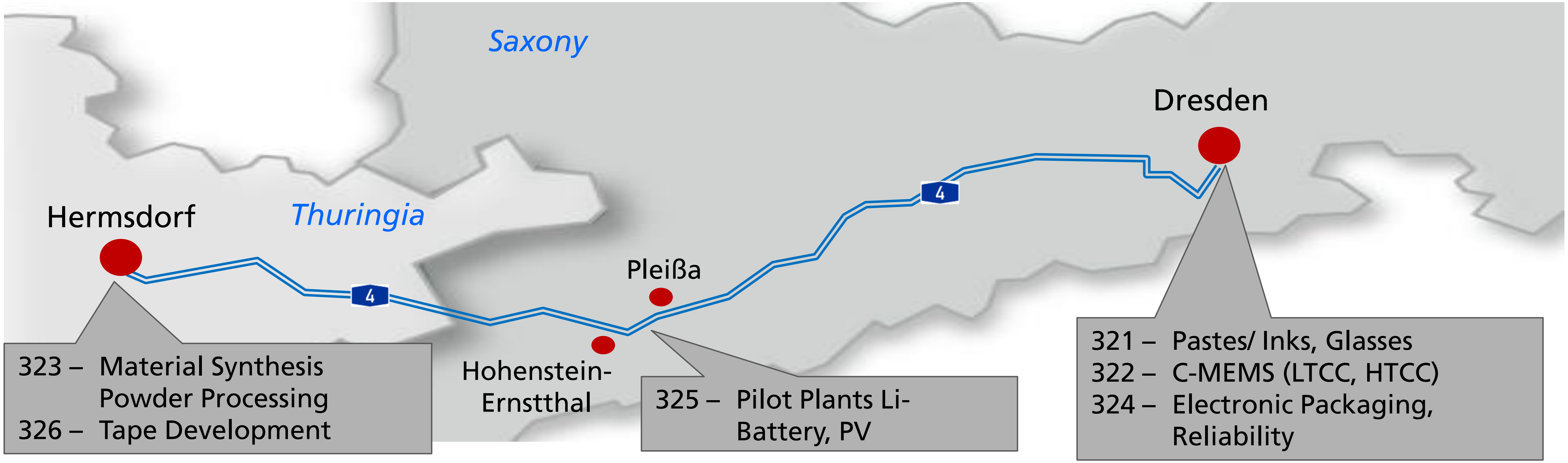
Department Hybrid Microsystems
Figures

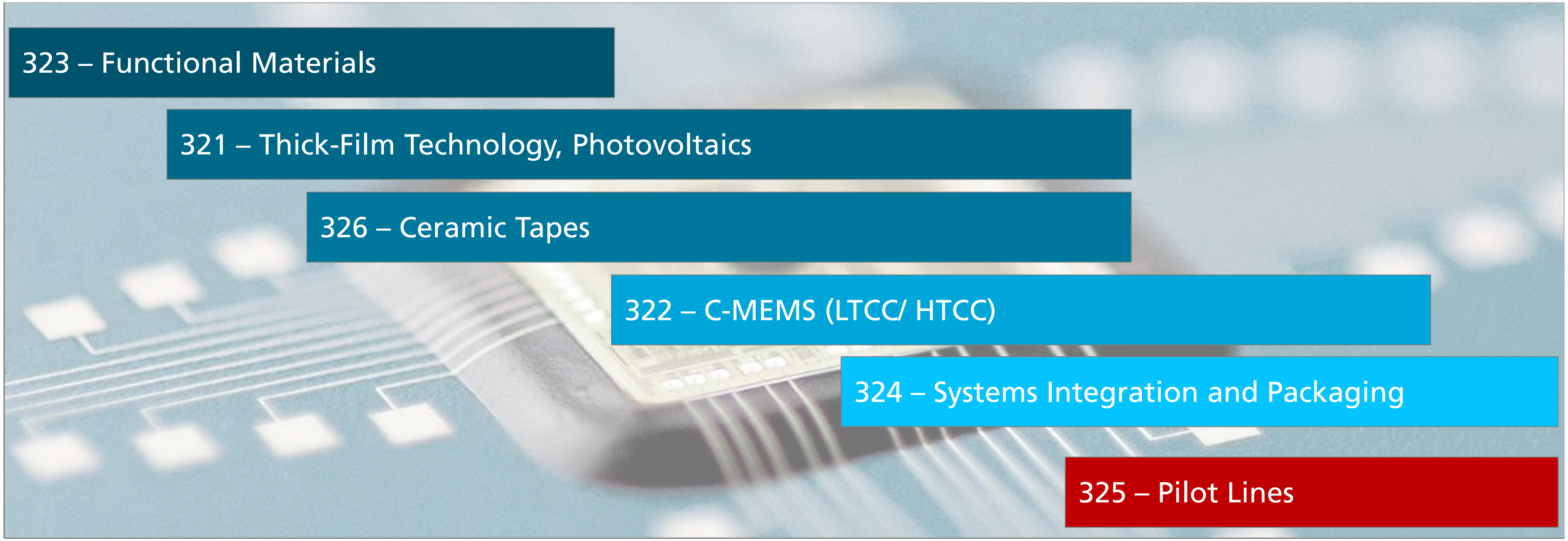
- 3 sites, 6 working groups
- 48 employees
- Budget 2015 approx. 5.9 Mio. €
- Focused topics: **Ceramic thick-film and multilayer technology**



Department Hybrid Microsystems

Value Chain

Functional Powder Synthesis and Processing → Functional Semi-finished Materials → Component and Systems Design → Technology Development and Scale Up → Functional Characterization and Reliability



Fraunhofer IKTS

Department Hybrid Microsystems
Value Chain

Functional Powder Synthesis and Processing

Functional Materials
- Magneto-ceramics
- Ferroelectrics
- Non-linear resistors (PTC, NTC)
- Luminescent materials

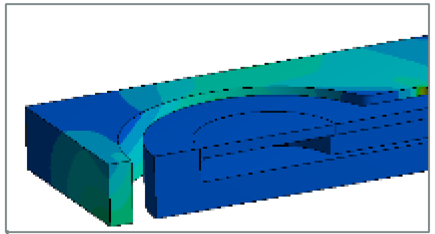
Powder Preparation
- High energy milling
- Spray tower
- Freeze drying

Functional Semi-finished Materials

Pastes/ Inks
- Development/ Manufacturing (Conductors, R, L, C, glasses, sensors …)
- Characterisation (Rheology, PSD, Sinter behaviour)

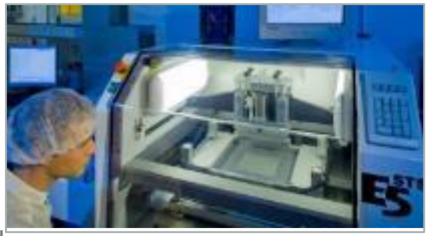
Tapes
- Development/ Manufacturing
- Characterisation

Component and Systems Design



Component Design
- FE-Simulation (Multi-Physics)
- Circuit Design (3-D-Routing)

Technology Development and Scale Up



µPrinting
- Mask Based/ Digital

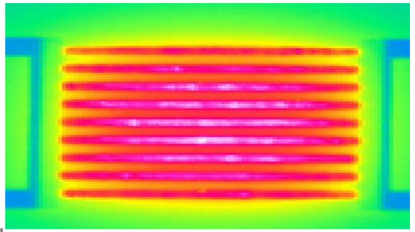
µStructuring
- Laser, µPunching, µEmbossing

Lamination
- uniaxial, isostatic

Firing
- Air, N2, red., 0-Shrink

Electronic Packaging
- Soldering, Gluing, Bonding

Functional Characterization and Reliability



Pastes/ Inks
- Characterisation (Rheology, PSD, Sinter behaviour)

Components
- Electrical characterization (R, TCR, tan δ, eps, µ, U_D, STOL, |Z|…)
- Thermal and power cycling
- Humidity aging
- IR-imaging

Fraunhofer
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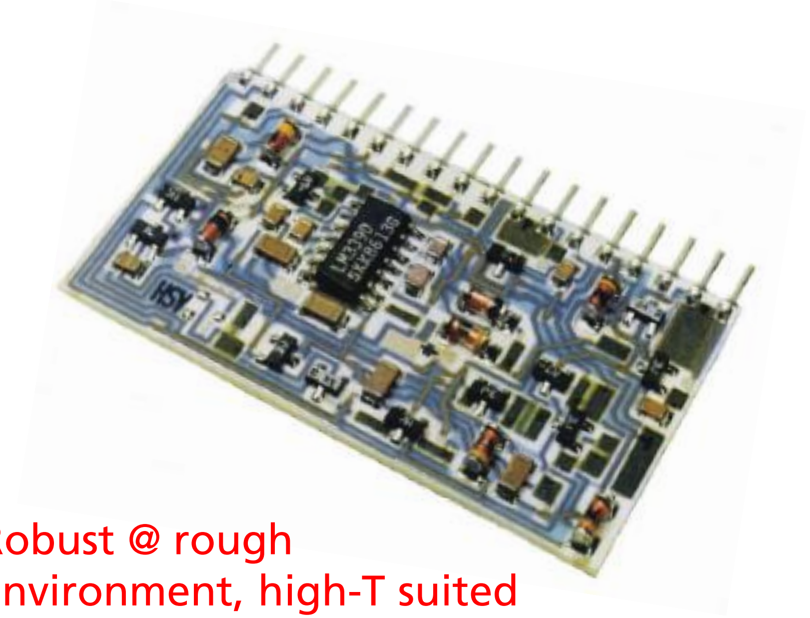
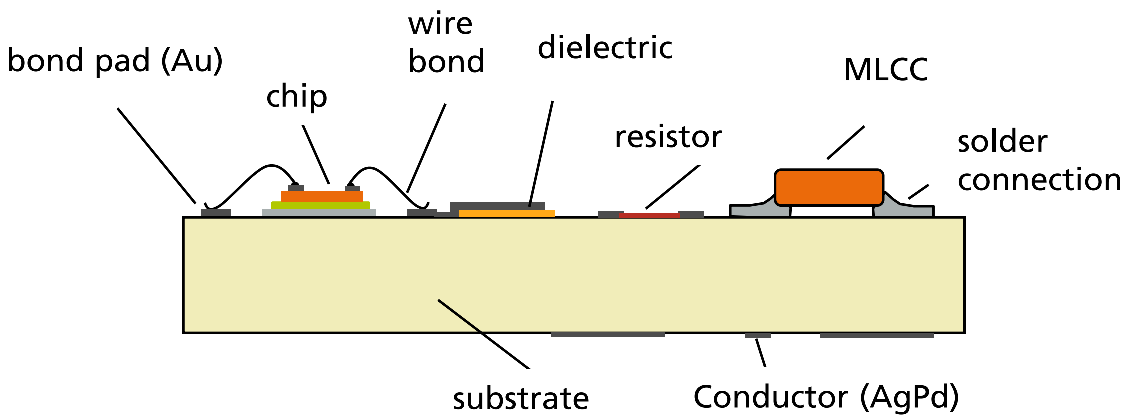
Ceramic Thick-Film and Multilayer Technology

- Thick-film based hybrid circuits
  Electronic modules consisting of different components, materials and manufacturing technologies, integrated on a sintered ceramic substrate

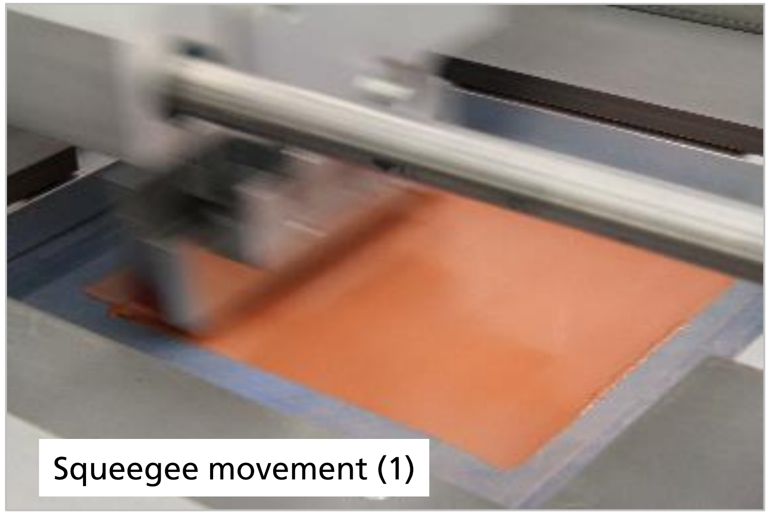


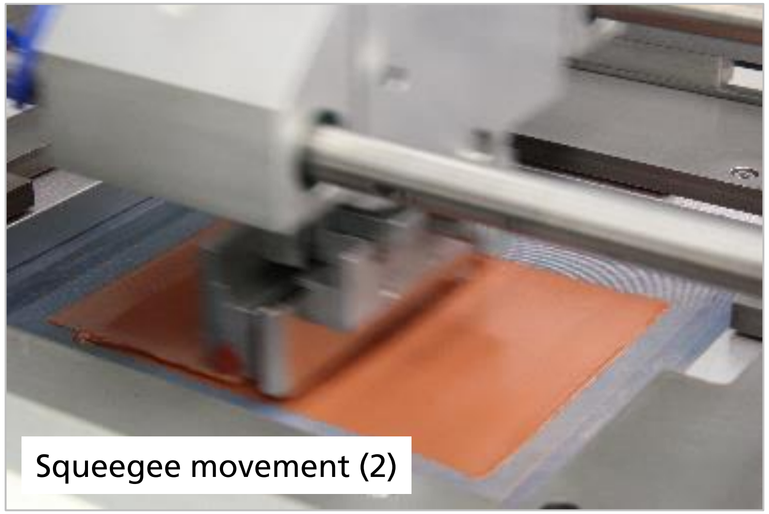


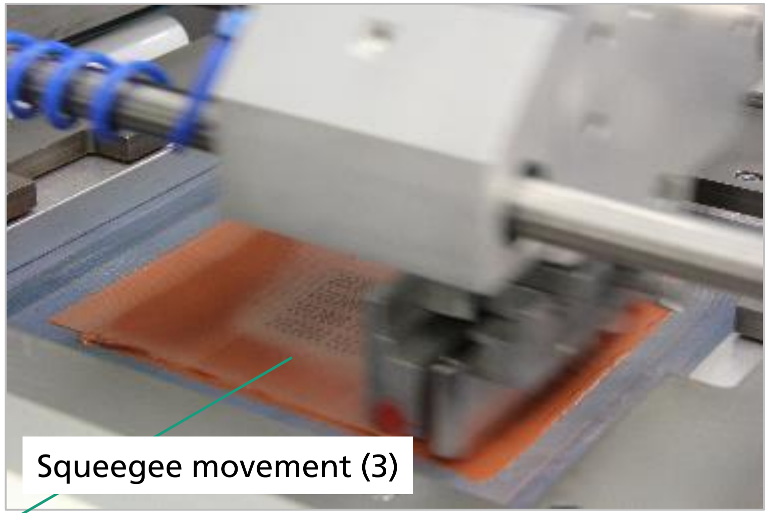
- Robust @ rough environment, high-T suited
- High thermal losses
- Perfect electrical isolation, RF-suited
- Reliable (thermo-mechanical matching to Si)

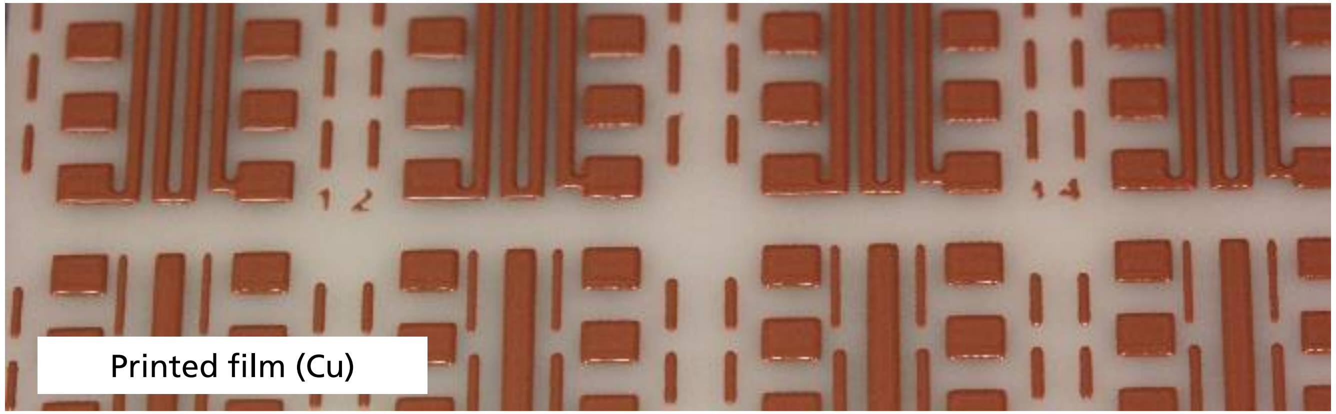
Ceramic Thick-Film and Multilayer Technology

Film Deposition - Screen /Stencil Printing

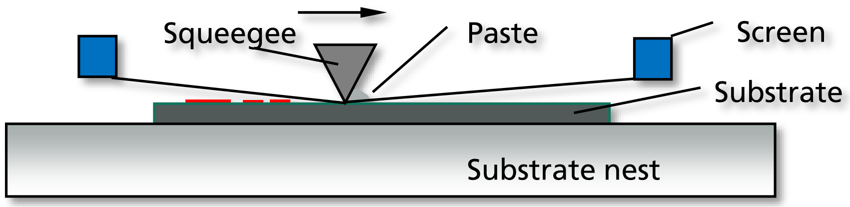








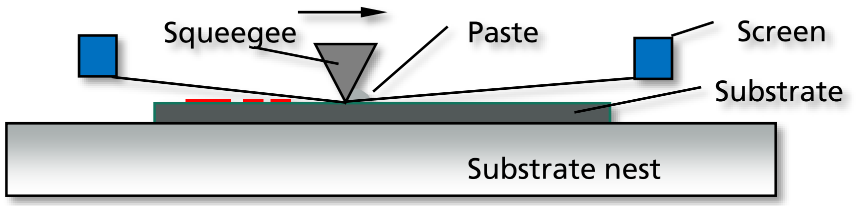
Paste Transfer through a structured mesh

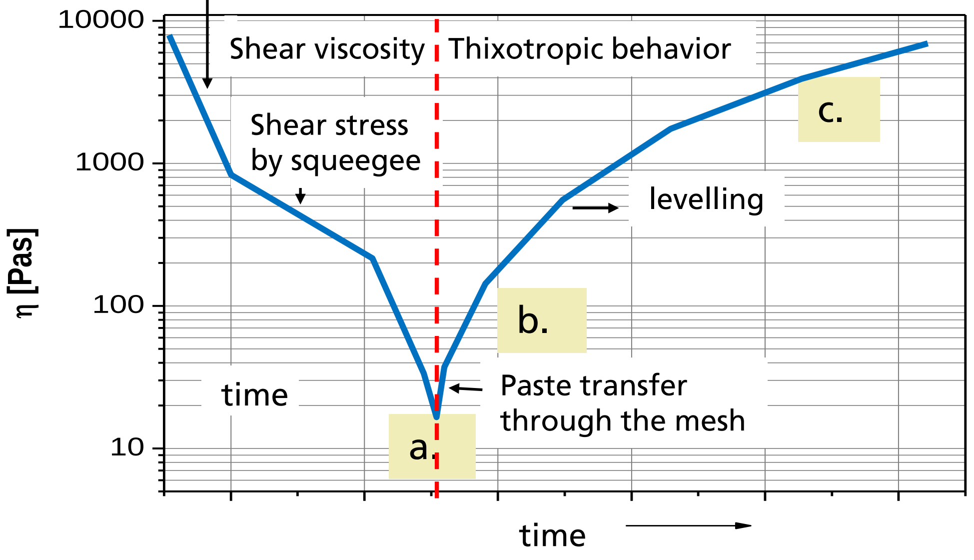


Ceramic Thick-Film and Multilayer Technology

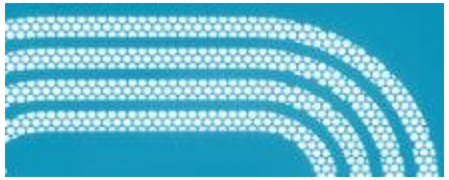
Film Deposition - Screen /Stencil Printing

- Functional pastes/ films
  - Conductor lines (Ag, AgPd, Cu, Ni, Au, Pt, W)
  - Passives (R, L, C)
  - Glasses
  - Sensors, actuators, ion conductors …
- Structural sizes
  - thickness = 2.. 100 µm/ width = 0.1 .. 5 mm
- process
  - printing, drying, firing
  - …

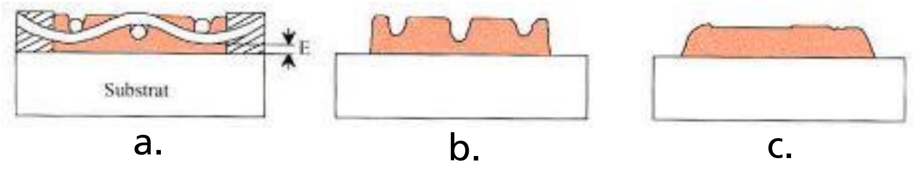




Screen-emulsion, -mesh © Koenen



Stencil mask © Fraunhofer IKTS



Ceramic Thick-Film and Multilayer Technology
Film Deposition - Screen /Stencil Printing

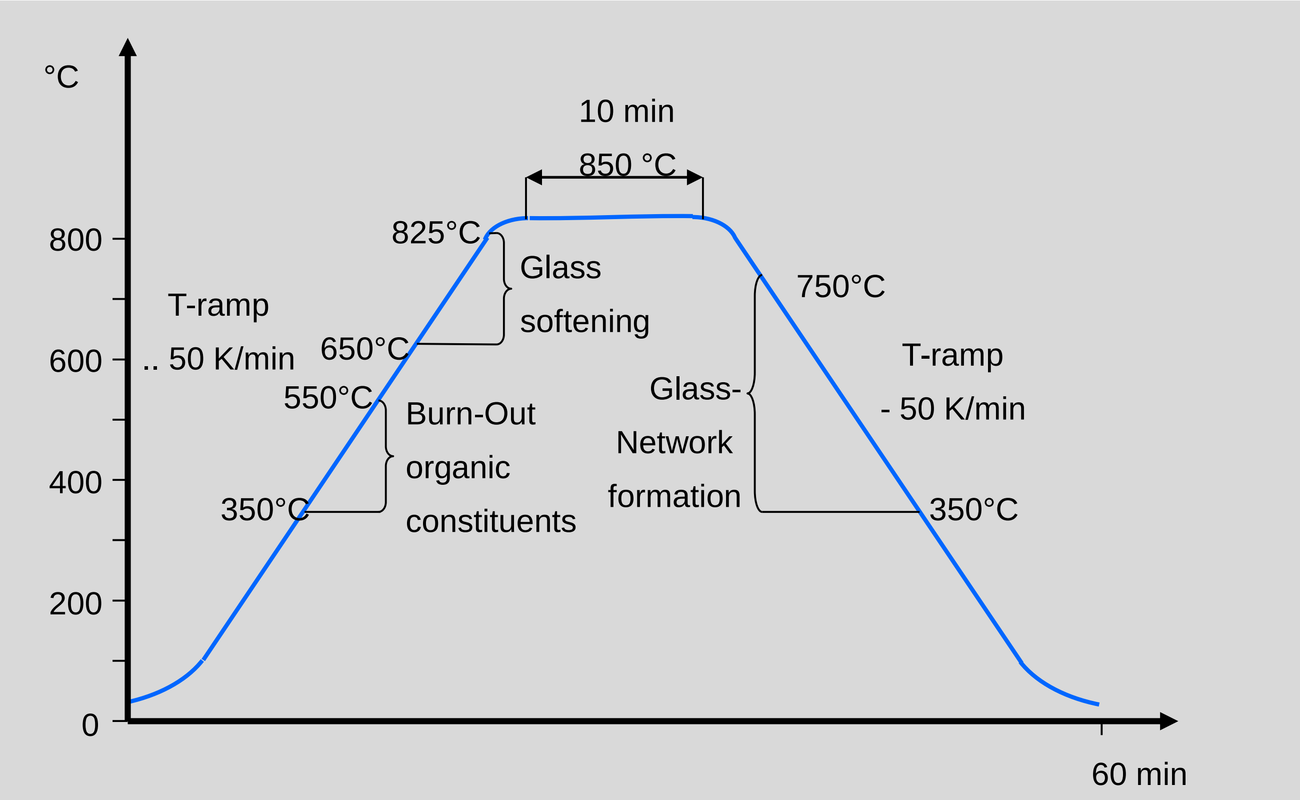
- Metallization pastes

Paste material	Resistance [mΩ/□]	Adhesion [kg/mm²]	Soldering	Bonding	Costs	Remarks
Ag	1 – 10	0,7 – 0,9	✓	--	+	Ag-migration
AgPd	10 – 30	0,9 – 1,1	✓	±	±	Standard paste
AgPt	3 – 20	0,9 – 1,1	✓	+	-	Migration stable
Au	1 – 6	0,9 – 1,1		++	-	Bond pads, MIL
AuPd	20 – 100	0,6 – 0,8	✓	++	-	MIL
AuPt	20 – 100	0,7 – 0,9	✓	+	--	Solder able
Cu	1 – 4	0,5 – 0,7	✓	±	++	Cost effective

Ceramic Thick-Film and Multilayer Technology

Film Sintering – Belt Oven

- Typical thick-film thermal processing



Belt-oven Centrotherm DO 4800
for thick-film applications

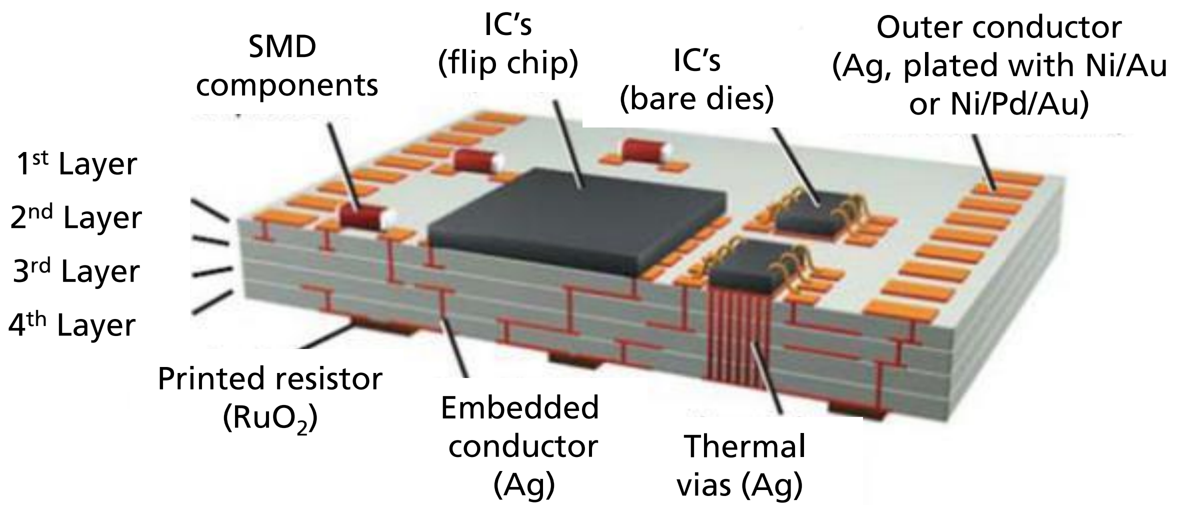
Source: Fraunhofer IKTS

Fraunhofer IKTS

Ceramic Thick-Film and Multilayer Technology

- Ceramic multilayer
  Succession of (different) ceramic layers which are differently structured, printed with functional layers and subsequently pressed (laminated) and are sintered.

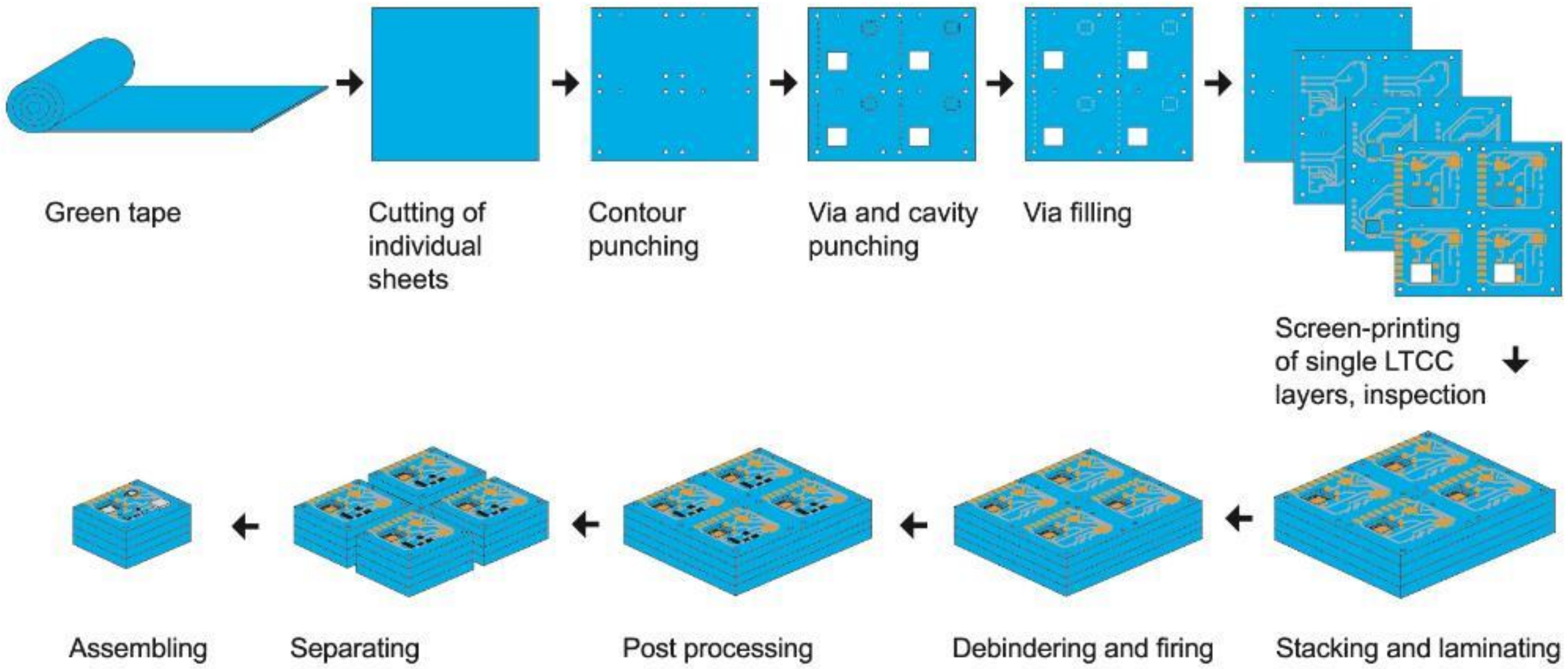
- Technology features
  - Co-firing!
  - 20 and more layers (> 1000 @ MLCC)
  - Layer thickness 5.. 300 µm
  - Lateral dimensions up to 8" x 8"
    (multiple printed boards)
- Applications (high density interconnects)
  - Rough environment
  - RF
  - High reliability



Source: Murata

Ceramic Thick-Film and Multilayer Technology

Process flow



Ceramic Thick-Film and Multilayer Technology

Materials for Ceramic 3D-Substrates

Property	Al_2O_3	HP Si_3N_4	AlN	LTCC	CCM	PI	FR4
	Ceramics/ Glass-ceramics				Steel	Polymers	
Sintering temperature [°C]	> 1500	> 1500	> 1400	< 900	1000	260	120
CTE [10^{-7}/K]	75	31	34	50 - 70	125	270	300
Thermal Conductivity [W/mK]	20	50	150	4 - 6	25	1,2	0,2
Dielectric constant	9,5	5	10,0	3 - 5	5-6	3,5	5,0
Loss tangent (x 10^{-3}) @10 MHz	0,3	4,5	2,0	0,1	2,0	3,0	5,0
Cost factor approx.	1	< 40	< 40	10	4	0,5	0,25

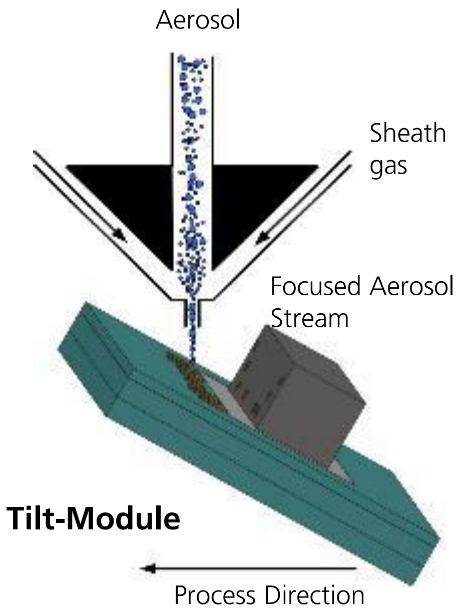
Ceramic Thick-Film and Multilayer Technology

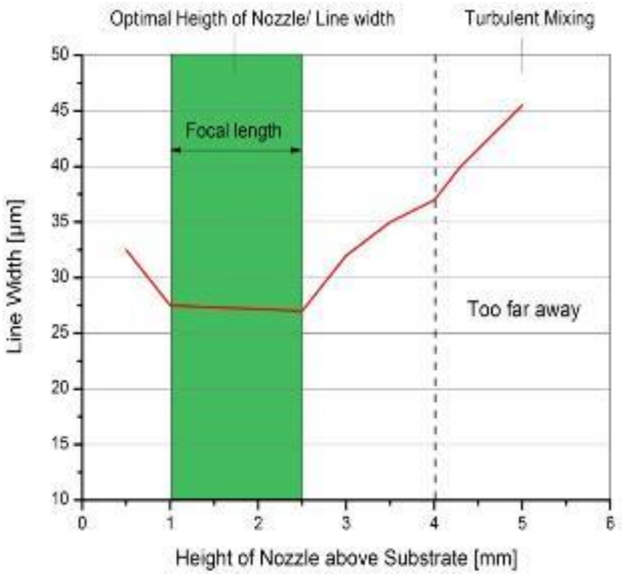
Film Deposition Technologies

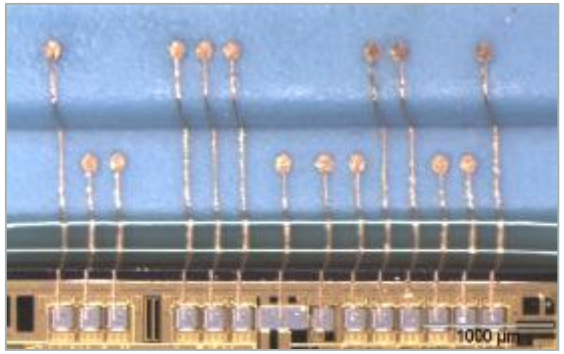
	Screen-/ stencil printing	Tampon printing	Micro-extrusion/ dispensing	Ink-jet-printing	Aerosol-jet-printing
Type	Mask-based		digital		
Viscosity [mPa*s]	10.000	10.000	10.000	10	10..1000
Particle size [µm]	0,1 - 5	0,1 - 5	0,1 - 5	0,01 - 0,1	0,01 - 1
Clock rate [s]	1,5	3	Structure depended	Structure depended	Structure depended
Printing resolution [µm]	30 - 50	80	50	40	10
3D-Option	tubular	restricted	restricted	no	yes

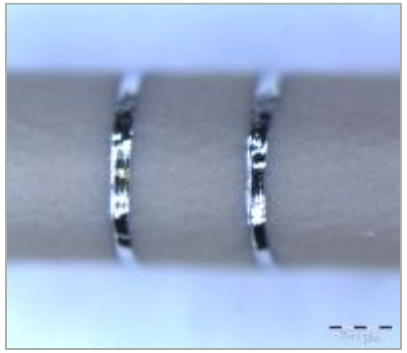
Ceramic Thick-Film and Multilayer Technology
Aerosol-Jet Printing

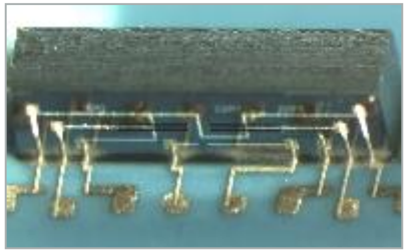
- Fully digital, no masks
- Extremely high printing resolution (10 µm)
- 3D-capability
- Nano-Inks (e.g. silver) with low sintering temperatures (polymer substrates)

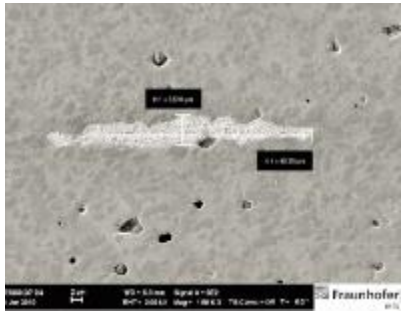










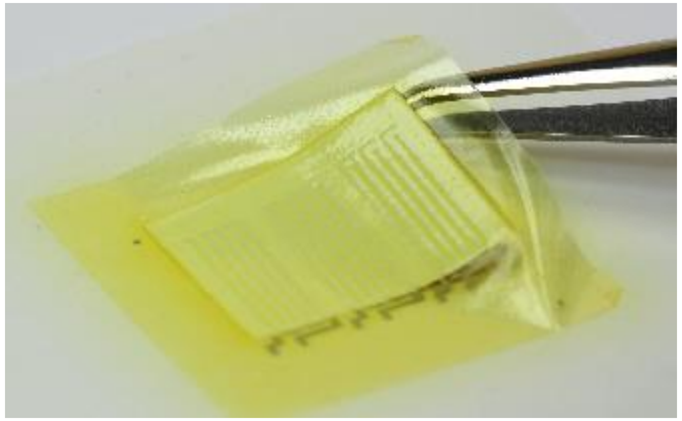


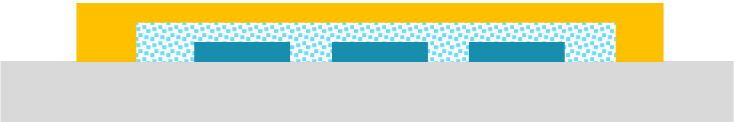
Fraunhofer IKTS

Ceramic Thick-Film and Multilayer Technology

Decal-Transfer Technology

- Process
  - Pre-print of the functional layers on siliconized paper
    - Silver
    - Encapsulation
    - Transfer layer
  - Transfer to the substrate (2D, 3D)
  - Co-firing
- Bulk resistance, good adhesion, high isolation resistance





Siliconized paper

Glass window

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Application Examples

Ceramic Thick-Film and Multilayer Technology

Integrated Substrates for Electronic Packaging

- **DCB, AMB-Substrates**
- **Thick-Film Substrates** (Al_2O_3, AlN, Si_3N_4)
- **Multilayer Substrates**
  - LTCC[i], HTCC[ii]

Electronic Components

- MLCC[iii]
- Chip Resistors
- MLIP[iv] (MLRC[v], MLV[vi], MLI[vii]..)
- MEMS-Packages

EM-Absorber

Energy Applications

- Fuel Cells (SOFC)
- Li-Ion-Batteries

Sensors

- Mechanical (p, a, F)
- Chemical (λ-probe)

Actuators

- Piezo-Multilayer actuators
- Piezo bending actuators

μ Fluidic Applications

- Micro-mixer, -reactors
- Heat exchanger

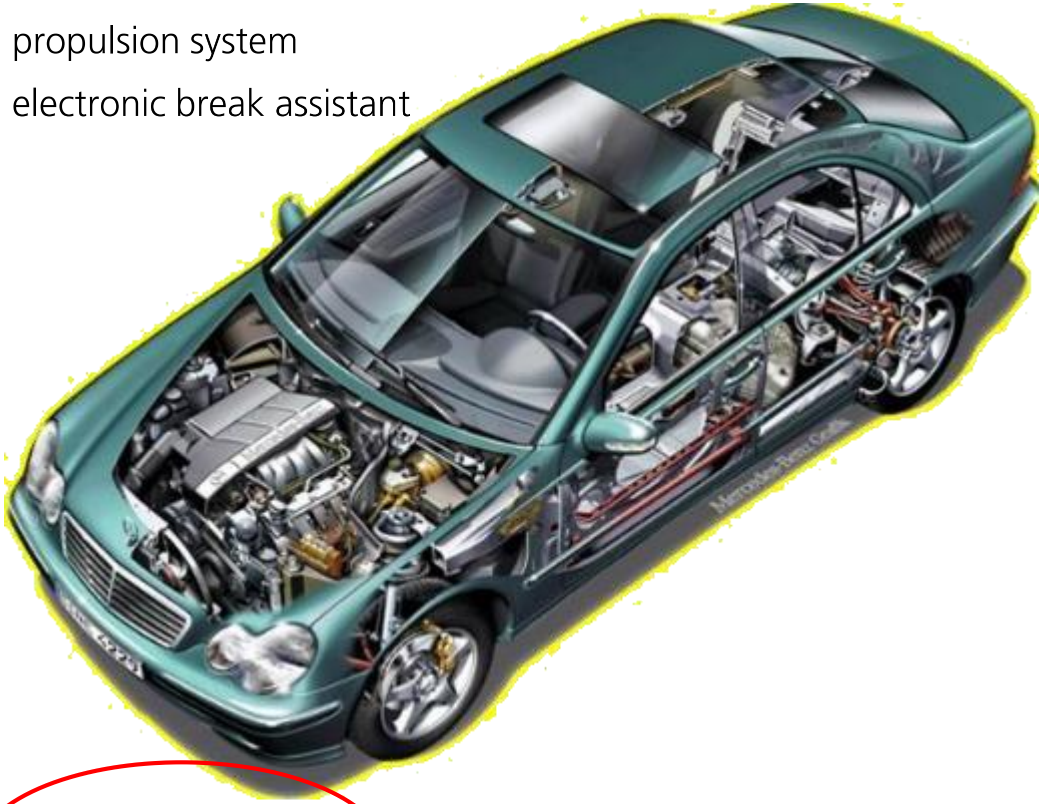
Quantity

i	LTCC	Low Temperature Cofired Ceramics
ii	HTCC	High Temperature Cofired Ceramics
iii	MLCC	Multilayer Ceramic Capacitor
iv	MLIP	Multilayer Integrated Passives
v	MLRC	Multilayer RC-Netzwerke
vi	MLV	Multilayer Varistoren
vii	MLI	Multilayer Inductor

Application Examples
Automotive Applications

Around engine: <150°C (170)

- propulsion system
- electronic break assistant



Engine, gear control: <300°C

Passenger cell: 85°C (up to 105°C)

- navigation system
- comfort functions
- cruise control
- safety systems

Components near wheel: <300°C

- brake by wire
- steer by wire

Source: DaimlerChrysler AG, Project: HotEl
www.mikrotechnische-produktion.de

- Ceramic Substrates/ Components
  - High/ low temperature
    - Engine → 300°C
    - Near wheel → 300°C
    - Exhaust → 600°C
  - Thermal shock, cycles
  - Mechanical shock, vibration
  - Voltage spikes
  - Electrostatic discharge
  - Salt spray, humidity, break fluid, transmission fluid, engine coolant,oil

Application Examples

Automotive Applications - LTCC-based Gear Control

Application Examples

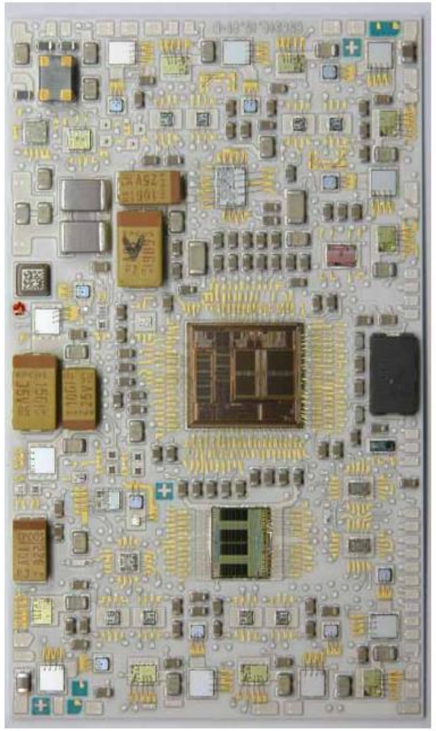
Automotive Applications - LTCC-based Gear Control

Applikationsbeispiel Automobilelektronik

ECU in LTCC Technologie für Mercedes Benz 7G- Tronic

ECU für die Getriebesteuerung enthält

- 32-BIT uC-Core Motorola MPC555, 448 kByte internes Flash, 26 Kbyte internes RAM
- 1 Mbyte externes Flash
- 4 kByte EEPROM
- 3,3V- und 5V-Spannungsversorgung
- Endstufen zur Ansteuerung von Proportionalventilen
- Integrierter Temperatursensor
- CAN Interface
- Frequenzeingänge/Analogeingänge
- EMV optimiertes Design

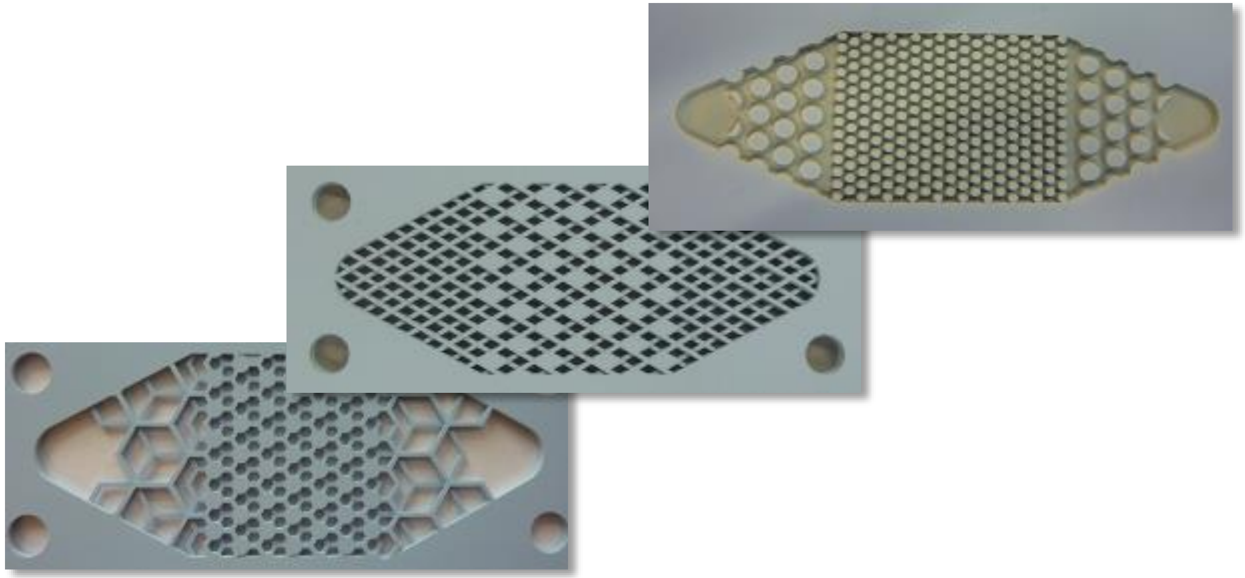


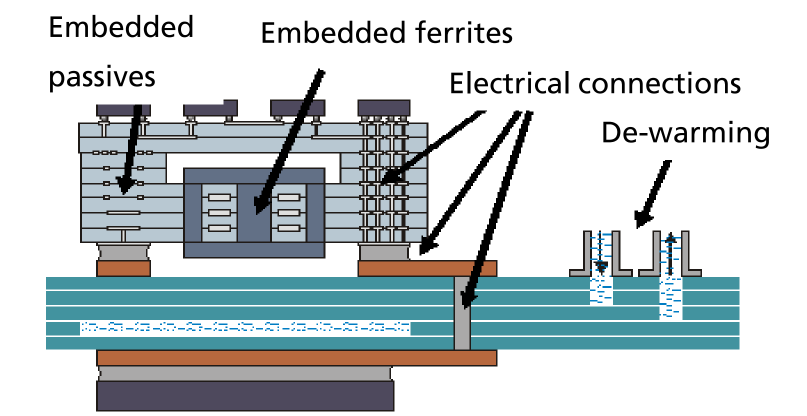
Quelle: SIEMENS VDO AG

Application Examples

Power Electronics - Ceramic Multilayer DCB-Substrates

- „Ceramic packages for robust signal- and power electronics“ - KAIROS
  - Funded by: BMBF (VDI/VDE-IT), 07/2011 – 07/2014
  - Project partner: Continental, Siemens AG, Curamik, Via Electronic, Friedrich-Alexander-University Erlangen-Nürnberg (LEB)

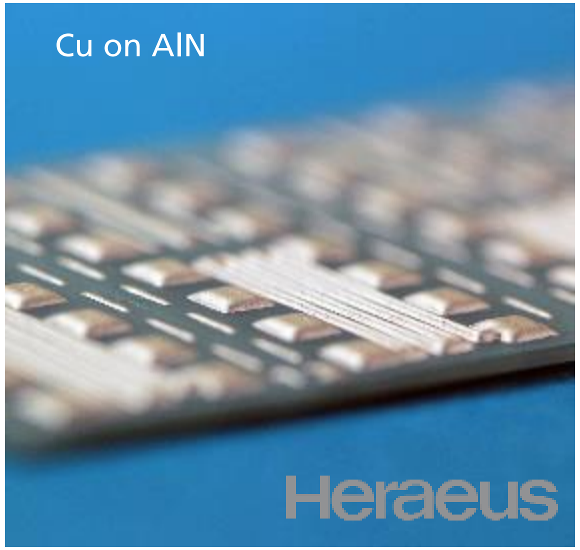


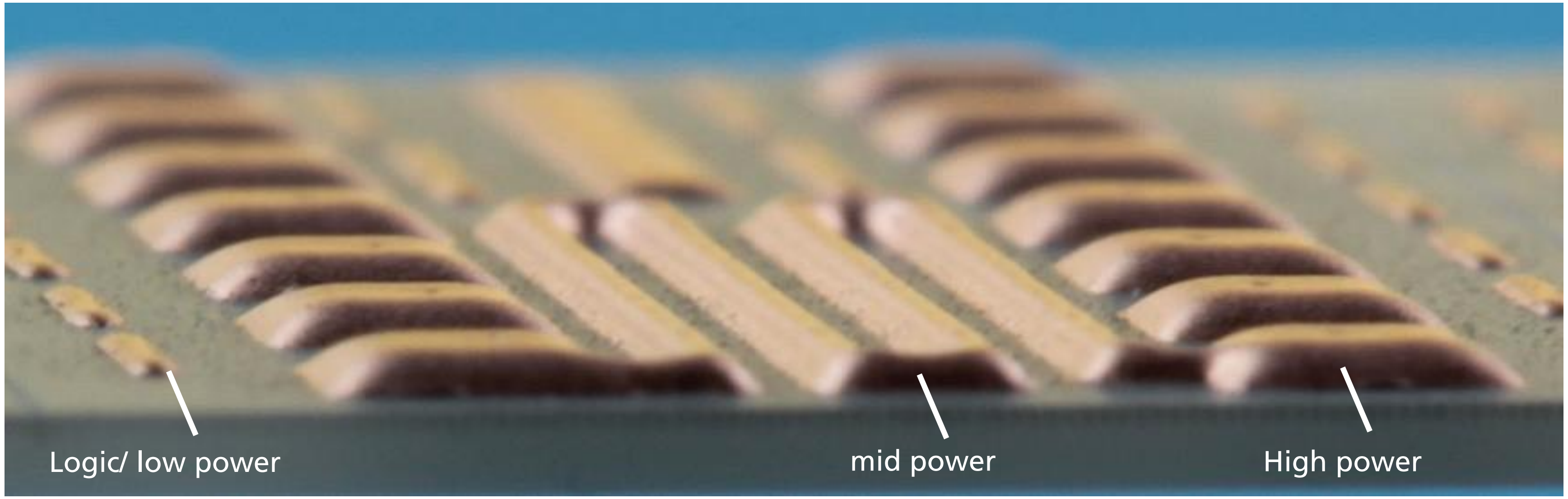


- Frequency converter 10 kW
- Integration of logic and power functionality on one DCB substrate
- DCB integrated cooling using HTCC-technology

Application Examples
Power Electronics - Thick-Cu Metallization

- Thick-film Ag, AgPd, Cu on Al_2O_3, AlN, Si_3N_4
- Alternative to DCB/ AMB
  - High printing resolution (< 100 µm)
  - Thickness from 15 up to 300 µm (combination of logic and power on one substrate)
  - "Smooth" topography, gradient layers prevent mechanical strain peaks





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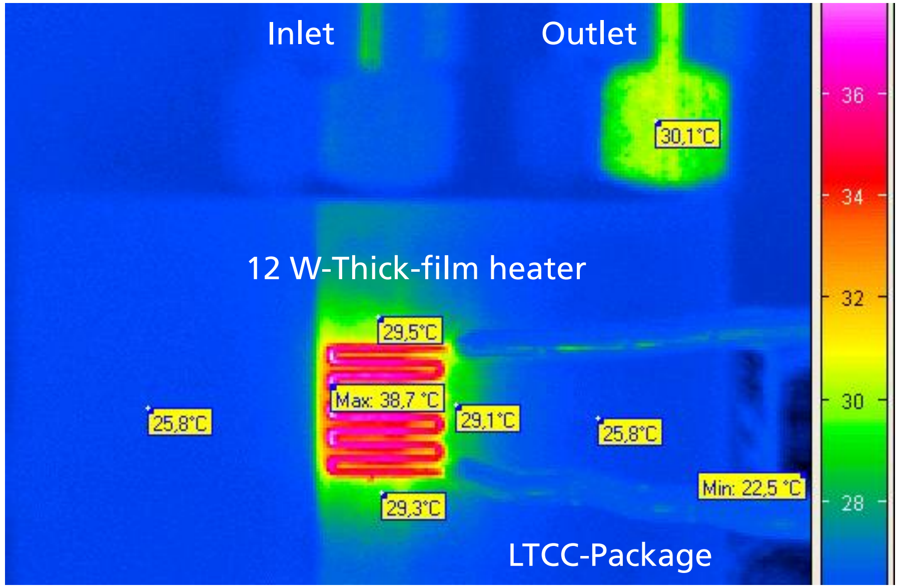
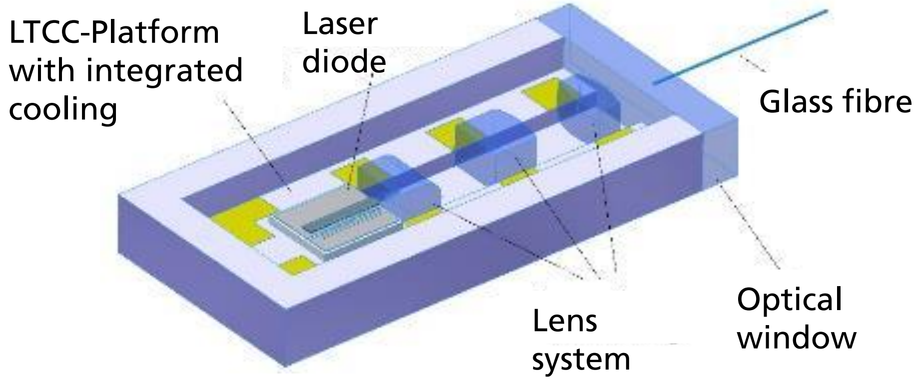
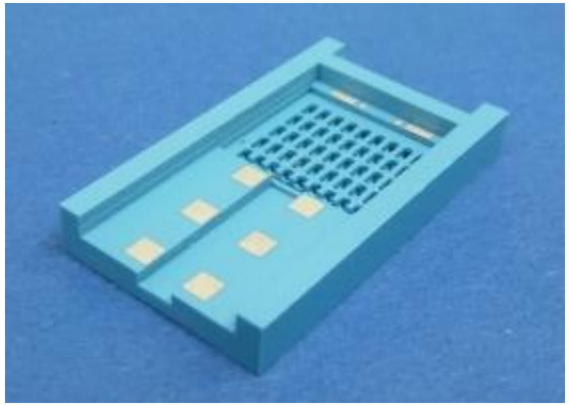
Application Examples

Microsystems – Laser-optical LTCC-Package

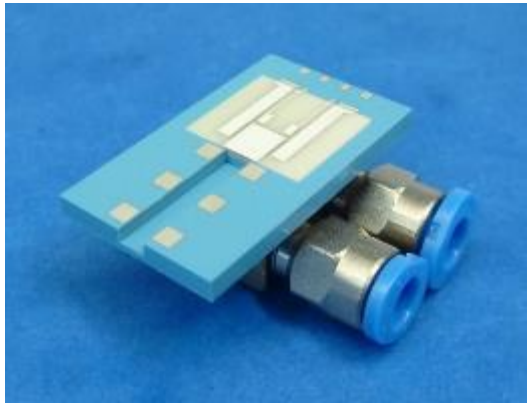
- 20 W Laser Emitter (8 W optical) → Simulation with thick-film heater (12 W) on AlN with active cooling (water)
- T max (heater spreader 29,5 °C), without active cooling 270 °C → R_{th}=0,31 K/W (@ 0,3 bar cooling pressure)







LTCC package with open cooling channels



LTCC-package with mounted AlN-substrate and liquid connectors

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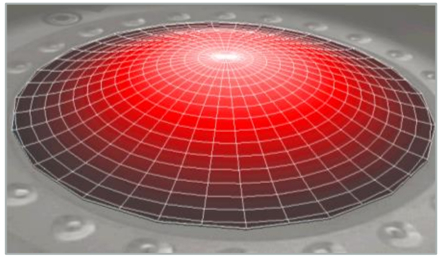
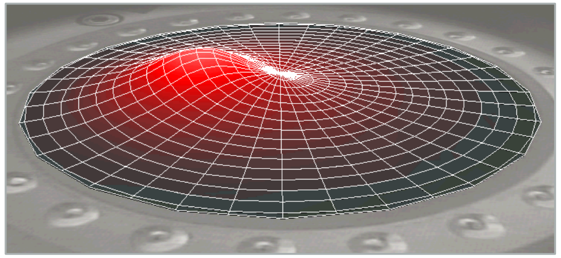
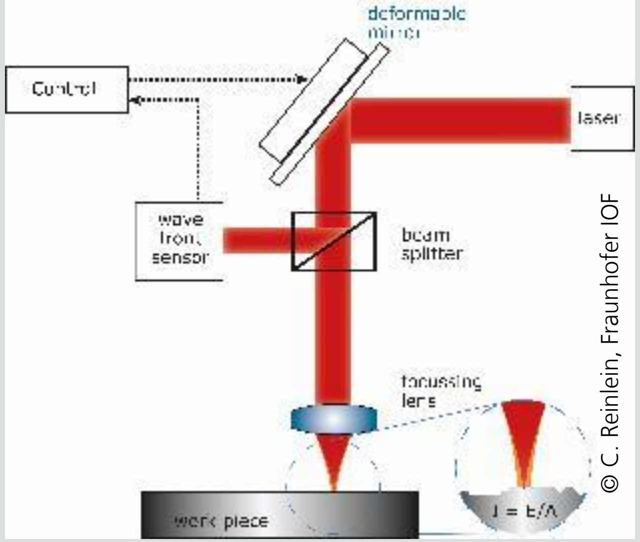
Application Examples

Microsystems - LTCC-based deformable Mirror

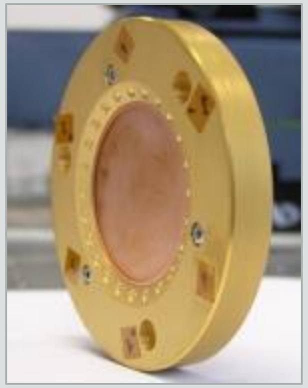
- Deform-able mirror for beam shaping in Laser technology
- 6 PZT-Oktagones for the compensation of thermal effects (Correction of wave front)

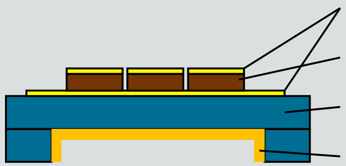





© C. Reinlein, Fraunhofer IOF







LTCC Membran:	220 µm
Durchmesser:	34.7 mm
PZT Dicke:	100 µm
Cu-Schicht:	150 µm

Backside: PZT Thick-Film on LTCC, Frontside: Cu (plated)

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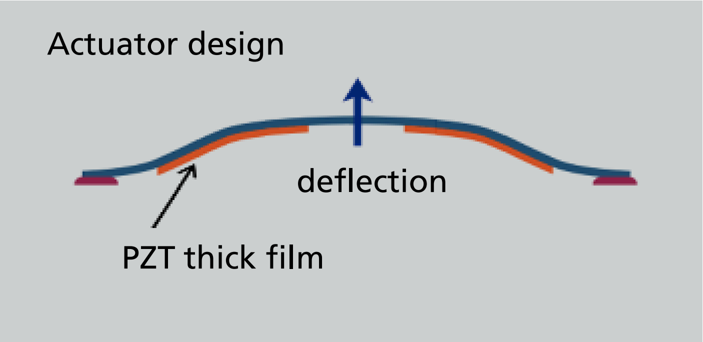
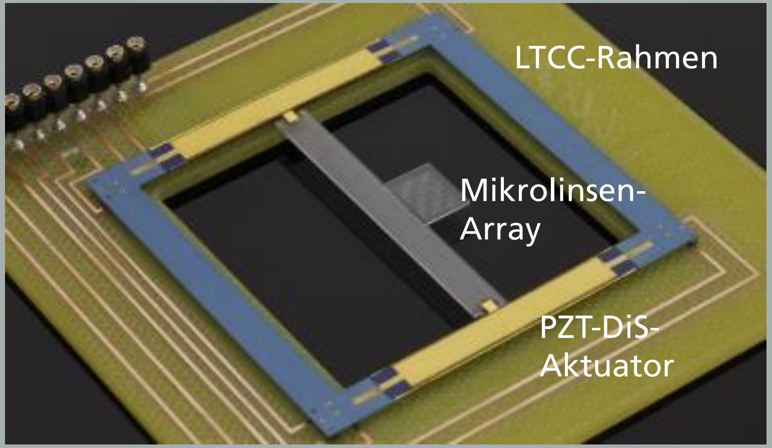
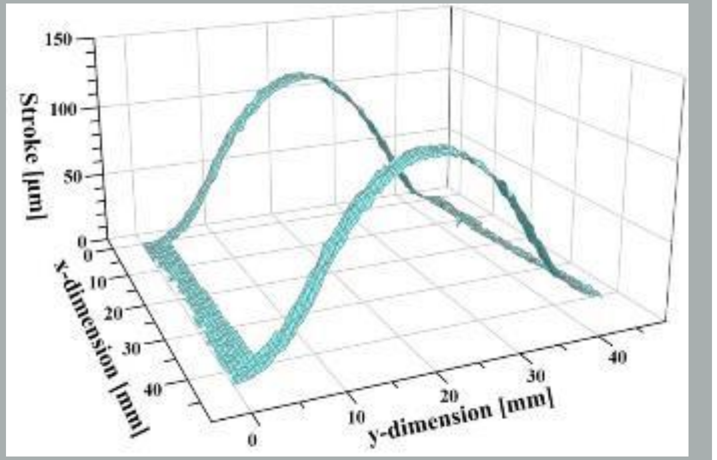
Application Examples

Microsystems - LTCC-based Micro-Positioning Stage

- Experimental Set-up
  - LTCC 45 x 45 x 0.17 mm^3 with internal wiring
  - Piezo-electric (PZT) Actuator 25 x 4.2 x 0.1 mm^3
  - Micro lens-Array 5.7 x 4.3 mm^2
- Experimental results
  - Deflection Δz = 115 µm @ E = 2 kV/mm, linear behavior
  - Blocking force F_B = 110 mN @ E = 2 kV/mm

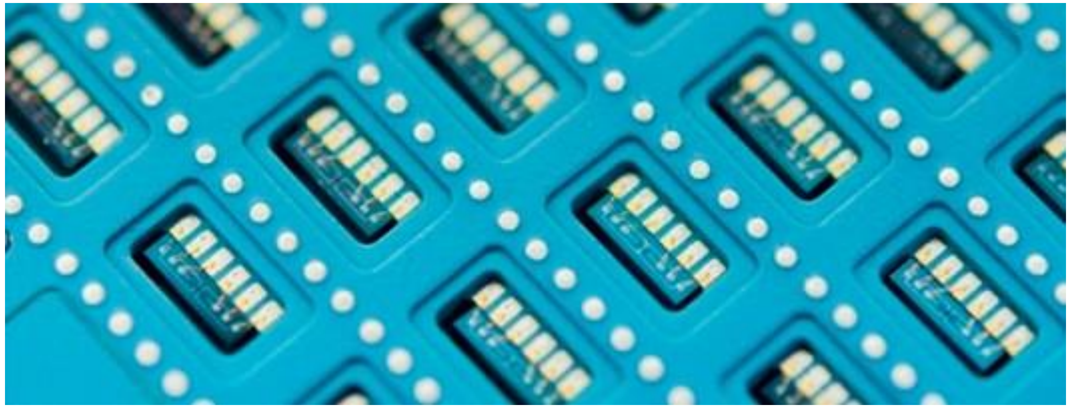




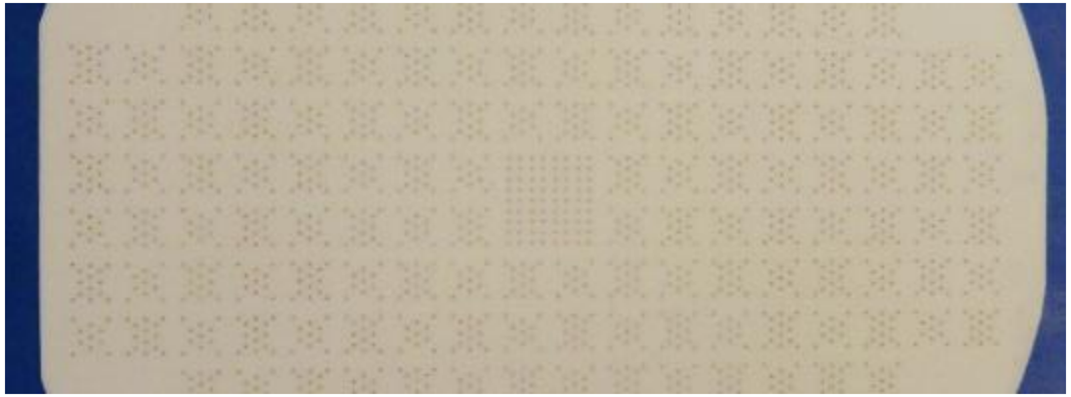


Application Examples
Microsystems - LTCC-based MEMS Packages

- LTCC = 3D-Package for
  - MEMS
  - MOEMS
  - LED
  - Electronic components
- requirements (HT-stable)
  - Mechanical positioning
  - Electrical contacts
  - De-warming
- Packaging Technologies
  - Soldering, bonding, gluing
  - Anodic bonding



LTCC-MEMS-Package (© Fraunhofer IKTS)

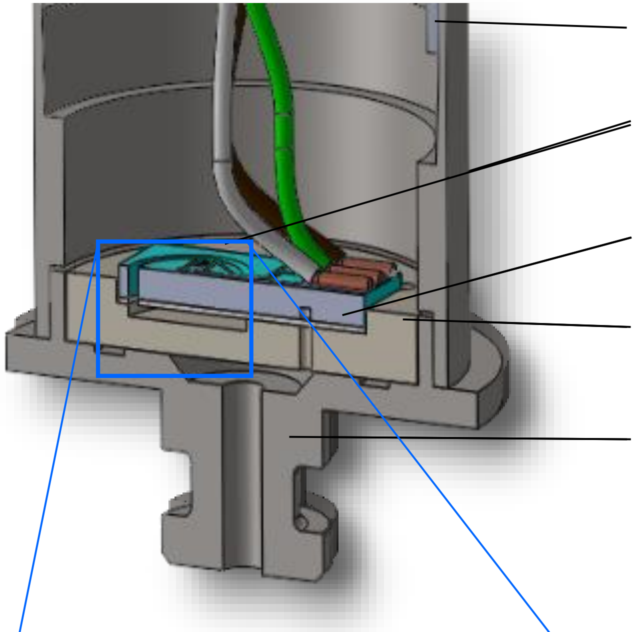


LTCC-Substrate for MEMS-Package (Wafer Level) (© Fraunhofer IKTS)

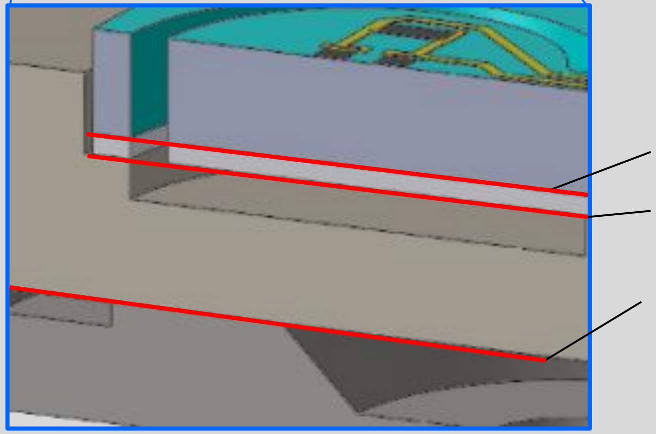
Application Examples

Sensors - LTCC-Pressure Sensor for T=300°C

- Structural materials
  - LTCC DP 951 (Sensor)
  - Alumina (96 % Rubalit® 708 S - Interposer 1)
  - Kovar® (1.3981, Fe-29Ni-17Co - Interposer 2)
  - Stainless steel (1.4542, X5CrNiCuNb16-4 – pressure connector, housing)



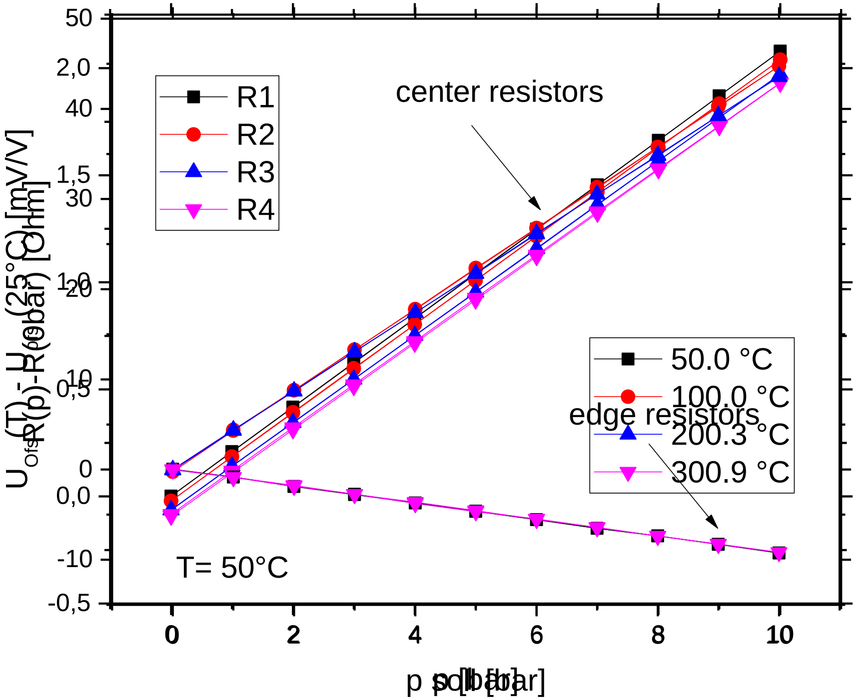
- Joining materials
  - Ni-hard braze (Joining step A; steel/Kovar)
  - AgCu-active metal braze (Joining step B; Kovar/alumina)
  - Glass joining (Joining step C; alumina/LTCC)



* *J. Schilm, A. Goldberg, U. Partsch, W. Dürfeld, D. Arndt, A. Pönicke and A. Michaelis, J. Sens. Sens. Syst., 5, 1–11, 2016*

Application Examples
Sensors - LTCC-Pressure Sensor for T=300°C

- Measurements (according DIN ISO 18086)
  - Characteristic curves (U_{ofs}, S, FS, L, H)
  - Temperature dependence (U_{ofs}, S, FS, L, H) = f(T)
  - Measurement of the single resistors
  - Thermal cycling Δ(U_{ofs}, S, FS, L, H) = f(T)
- Proper sensor functionality up to 300°C
- Small temperature dependencies of
  - U_{ofs}
  - S
- Full T-range: extremely low L (0.1%FS)
- H
  - Up to 200°C < 0.25%FS
  - Up to 300°C < 0.45%FS



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Thank you for your attention!

Further information:

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