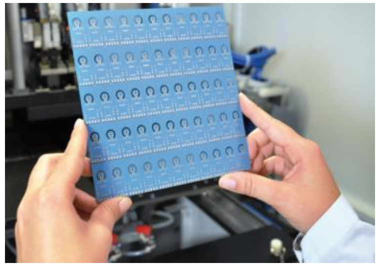
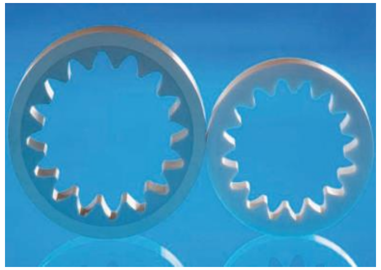
Packaging and Assembly with Ceramic Circuit Boards

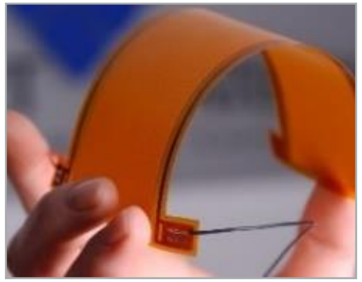
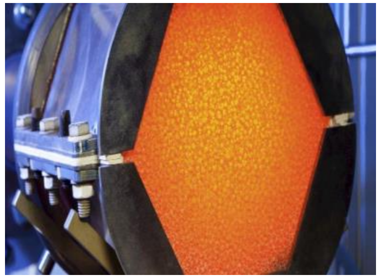
Dr.-Ing. Steffen Ziesche, Dr.-Ing.Uwe Partsch, Dipl.-Ing. Uwe Scheithauer

26.11.2019 Vortrag FED-Regionalgruppe, Turck Beierfeld GmbH

Competency in Ceramics



TÜVRheinland ZERTIFIZIERT
Management System
ISO 13485:2003
www.tuv.com
ID 0000029868

TÜVRheinland ZERTIFIZIERT
Management System
ISO 9001:2008
ISO 14001:2004
www.tuv.com
ID 1100005194

www.ikts.fraunhofer.de

Fraunhofer IKTS

Sites of the Fraunhofer IKTS

Headquarters

- Dresden, Winterbergstraße

Other sites

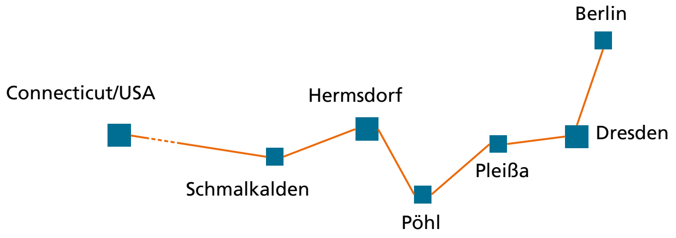
- Hermsdorf, Thuringia
- Dresden-Klotzsche

Fraunhofer Center

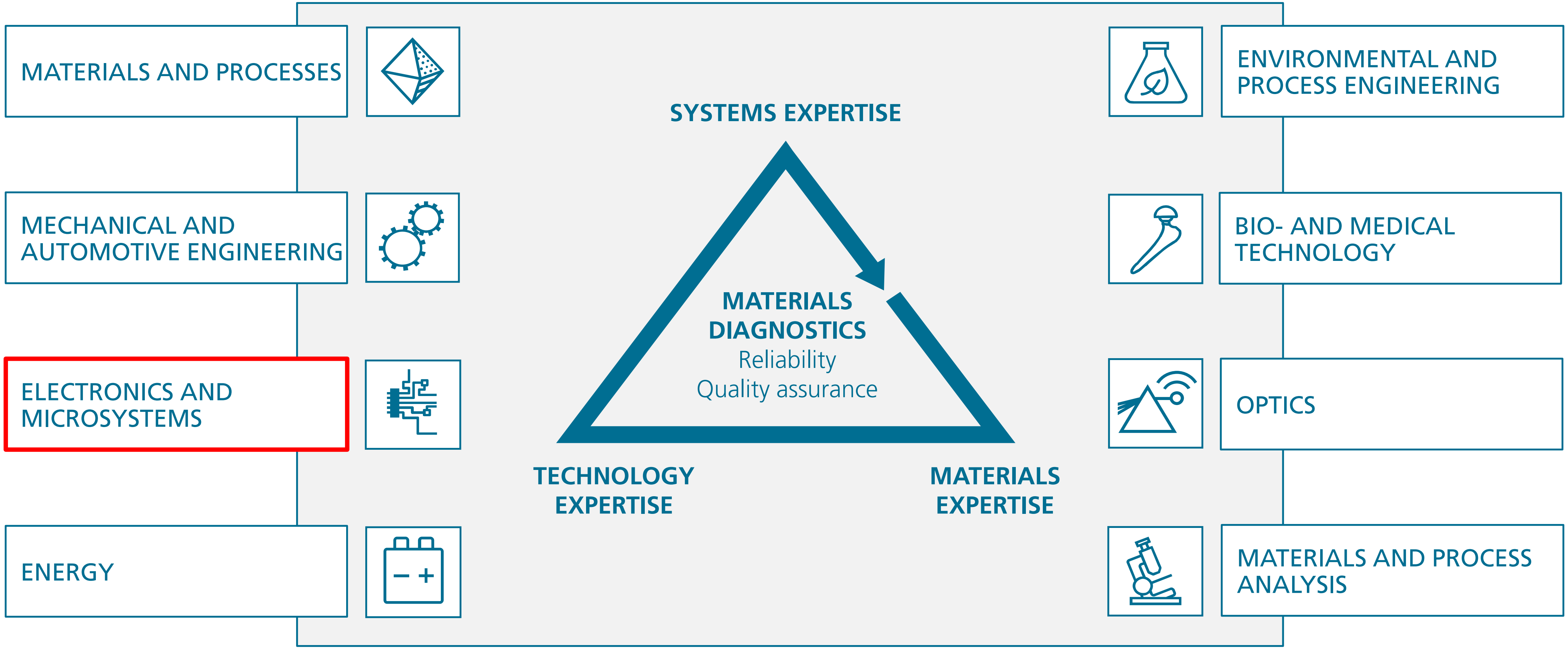
- for Energy Innovation CEI, USA

Application Centers

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



Our Business Divisions



Buisness Division Electronics & Microsystems

Department Hybrid Microsystems

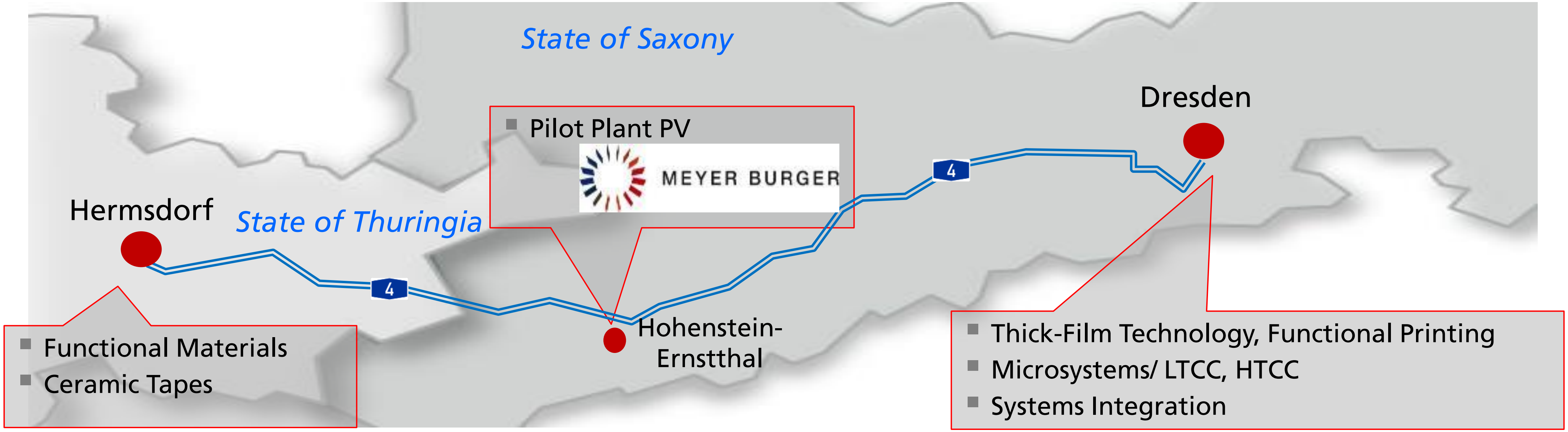
Functional Powder Synthesis and Processing → Functional Semi-finished Materials → Component and Systems Design → Technology Development and Scale Up → Functional Characterization and Reliability

- 323 – Functional Materials
- 321 – Thick-Film Pastes
- 326 – Ceramic Tapes
- 322 – Thick-Film and Multilayer Ceramic Technology
- 324 – Systems Integration and Packaging

Department Hybrid Microsystems

Facts & Figures

- 3 sites, 5 working groups
- 44 employees
- Budget 2018 approx. 5.7 Mio. €
- Focused topics: ceramic thick-film and multilayer technology



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

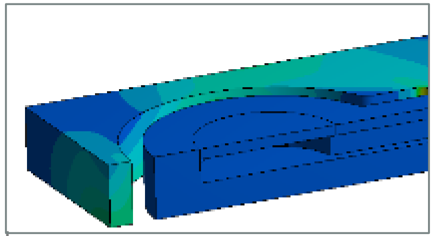
Pastes/ Inks

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

Tapes

- Development/ Manufacturing
- Characterisation

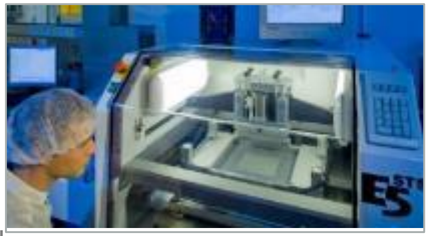
Component and Systems Design



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

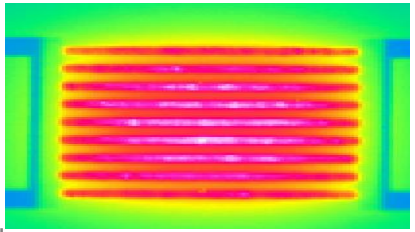
Firing

- 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 IKTS

Ceramic Thick-Film and Multilayer Technology

- **Why Ceramics?**
  - Robust and reliable
  - Thermally (> 1000 °C) and chemically stable
  - Stable under UHV
  - Thermomechanical adaption to Si, SiC, GaN, GaAs..
  - High temperature depending isolation resistance
  - Excellent heat conductors
  - Low permittivity and dielectric loss
  - Excellent heat conductors

Ceramic Thick-Film and Multilayer Technology

	Ceramics/ Glass-Ceramic Substrates				Isolated Metal Substrates		Polymer Substrates	
	Al_2O_3	SN	AlN	LTCC	Steel	Al	PI	FR4
Post (DiS)/ Co-firing (ML)	+/+	+/-	+/-	-/+	+/-	+/-	-/-	-/-
$T_{sinter\ max}$ [°C]	1600	1500	1400	900	900	600	260	120
CTE [10^{-7}/K]	75	31	34	30 - 70	125	231	270	300
Thermal Cond. [W/mK]	20	110	200	4 - 6	25	235	1,2	0,2
ε_{rel}	9,5	5	10,0	3 - 7	-	-	3,5	5,0
tan δ ($\cdot 10^{-3}$) @10MHz	0,3	4,5	2,0	0,1	-	-	3,0	5,0
Cost factor approx.	1	< 40	< 40	10	4	1	0,5	0,25

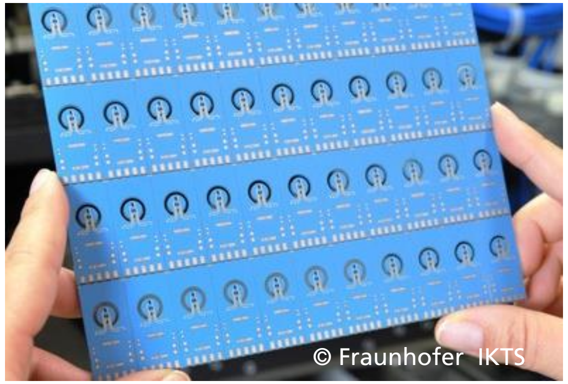
Functional printing moves towards 3rd Dimension

Technologies for hybrid ceramic 2D and 3D components

Thick film technology

- 2D (Option: tubular)
- Max. structural resolution 30 µm
- Screen- and stencil printing, Aerosol-Jet printing

Multilayer ceramic



- 2.5D
- Max. structural resolution 30 µm
- Screen- and stencil printing, Aerosol-Jet printing

Ceramic Injection Molding (CIM)

- 3D
- Max. structural resolution 100 µm
- Aerosol jet printing, Dispensing, Dispens-jetting

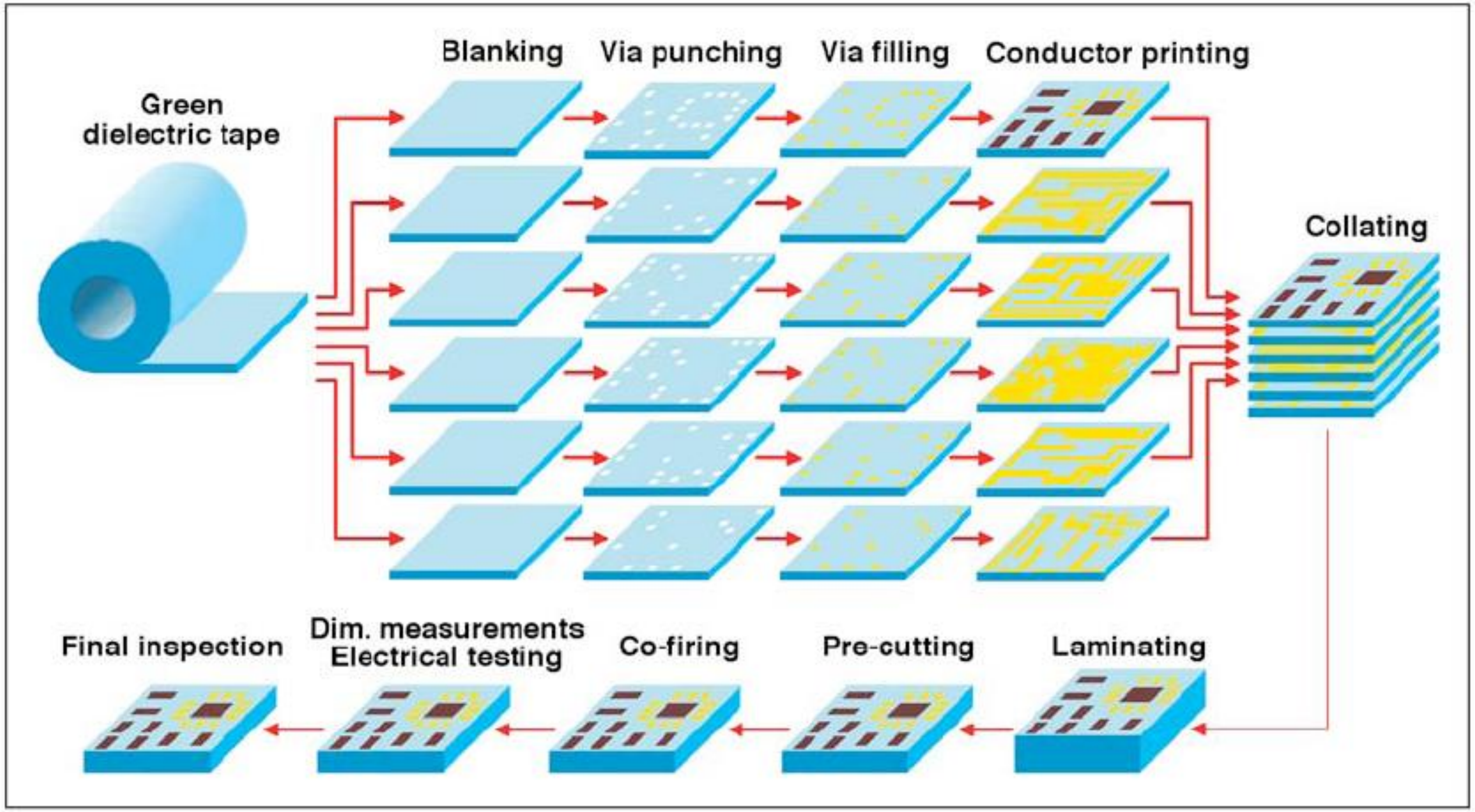
Lithography-based Ceramic Manufacturing (LCM)

- 3D
- Max. structural resolution 100 µm
- Aerosol jet printing, Dispensing, Dispens-jetting

MULTILAYER CERAMIC TECHNOLOGY

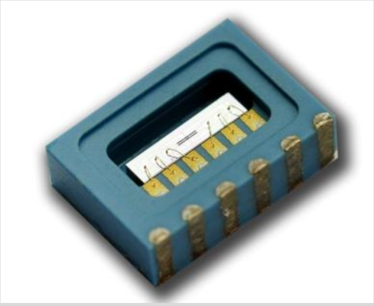
Multilayer Ceramic Technology

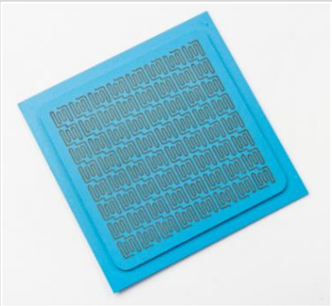
Technological process

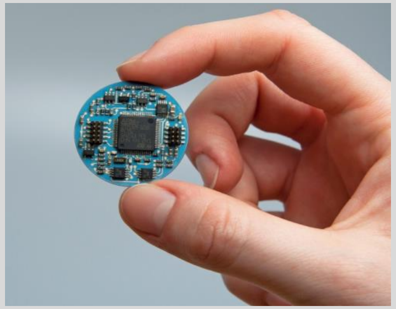


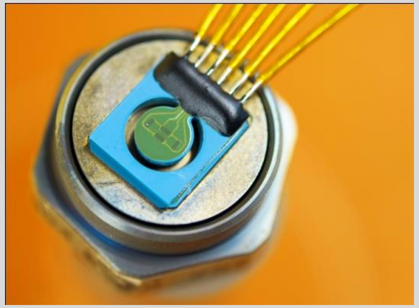
Multilayer Ceramic Technology
Process characteristics

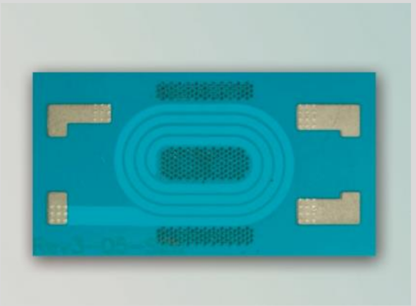
- Thermomechanical adaption to silicon (TEC: 3,2 – 5,8 ppm/K)
- Hermetic encapsulation and integration of passive components (R, L, C)
- Stability at increased temperatures (>1000°C), aggressive atmospheres and vibrations
- Miniaturized Electrical rewiring within and on top layer of ceramics (Fine Line, Aerosol Jet)
- Providance of electrical interfaces (BGA, FGA)
- High frequency capable base materials (HF-Integration)


MEMS-Ceramic housing


LTCC-Matrix heaters


Electronic substrates


High temperature pressure sensor

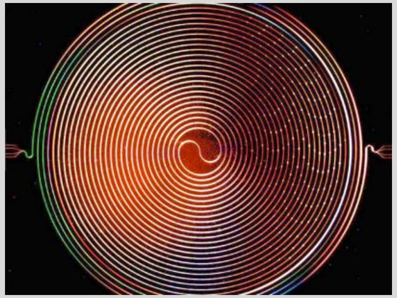

100 W-Transformer

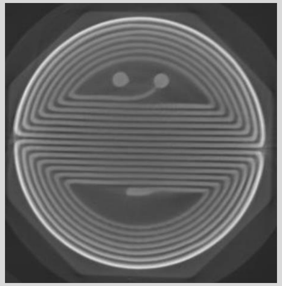
MLC – Manufacturing example

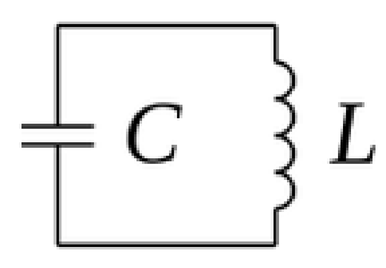
Sensors: Eddy current based rotation speed measurement

Rotation speed measurement for turbochargers

- SOTA Wounded wire coils > simple geometries, limited stability under vibration and temperature
- LTCC: Complex geometries, Multilayers, T = -40 bis 230 °C



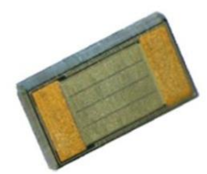


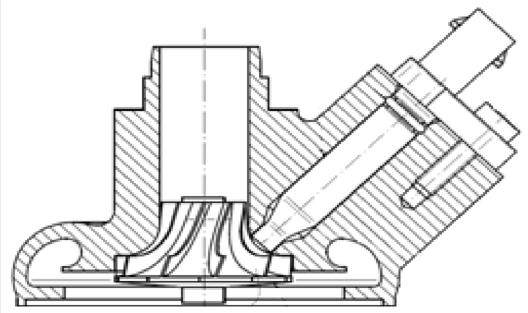


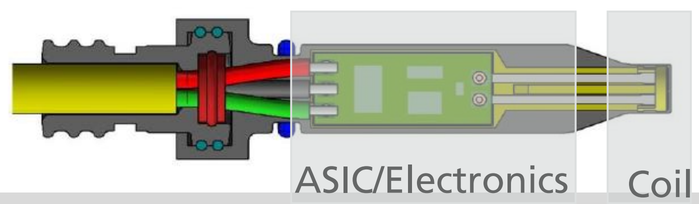
$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R_L^{\,2}}{L^2}}$$

f = 3,2 MHz

L_{Soll} = 1,5 µH, Q = X_L/R ↑





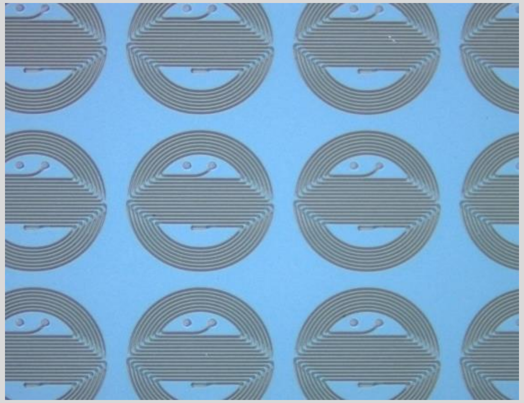


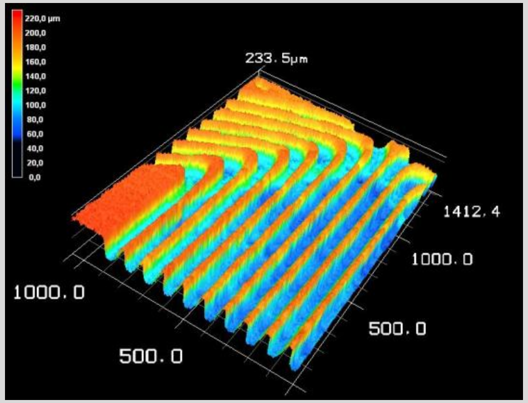
Fraunhofer IKTS

MLC – Manufacturing example

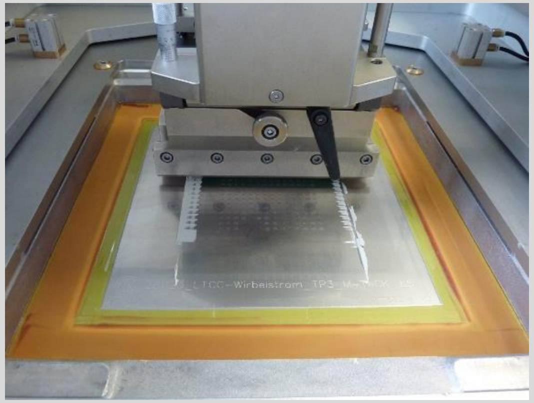
Sensors: Eddy current based rotation speed measurement

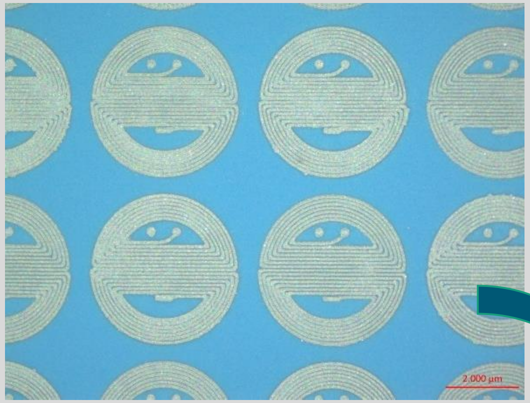
Laser processing: channel depth up to 120 µm + vias



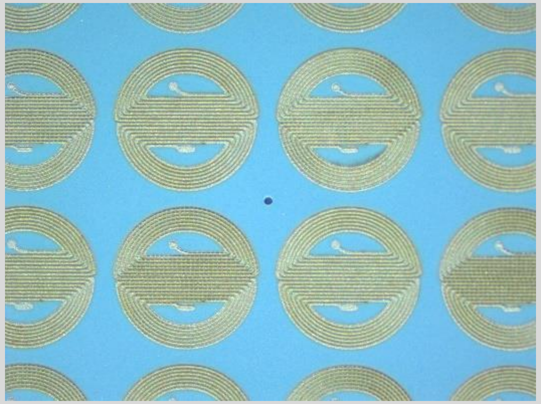


Printing/filling process: line width 70, Space 30 µm

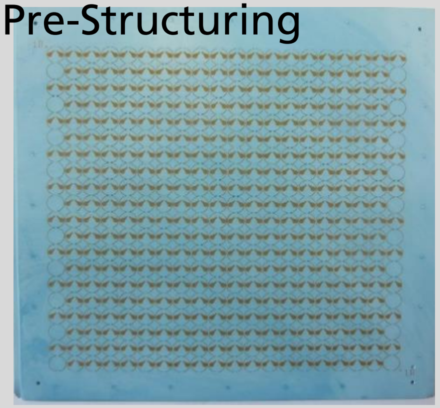




„Laser cleaning“ process

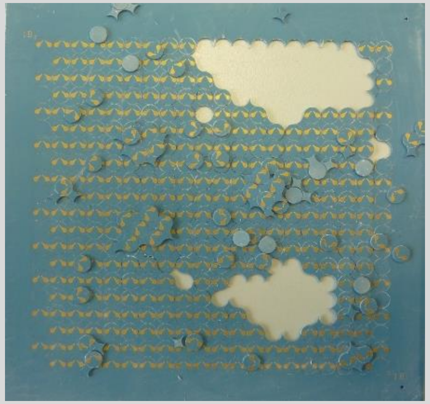


Laminating and Pre-Structuring



Pressure sintering

Sintered panel

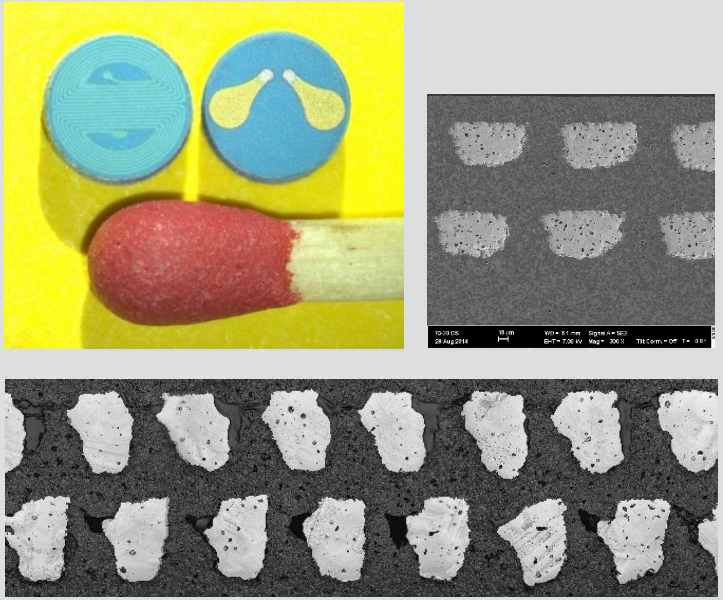


MLC – Manufacturing example

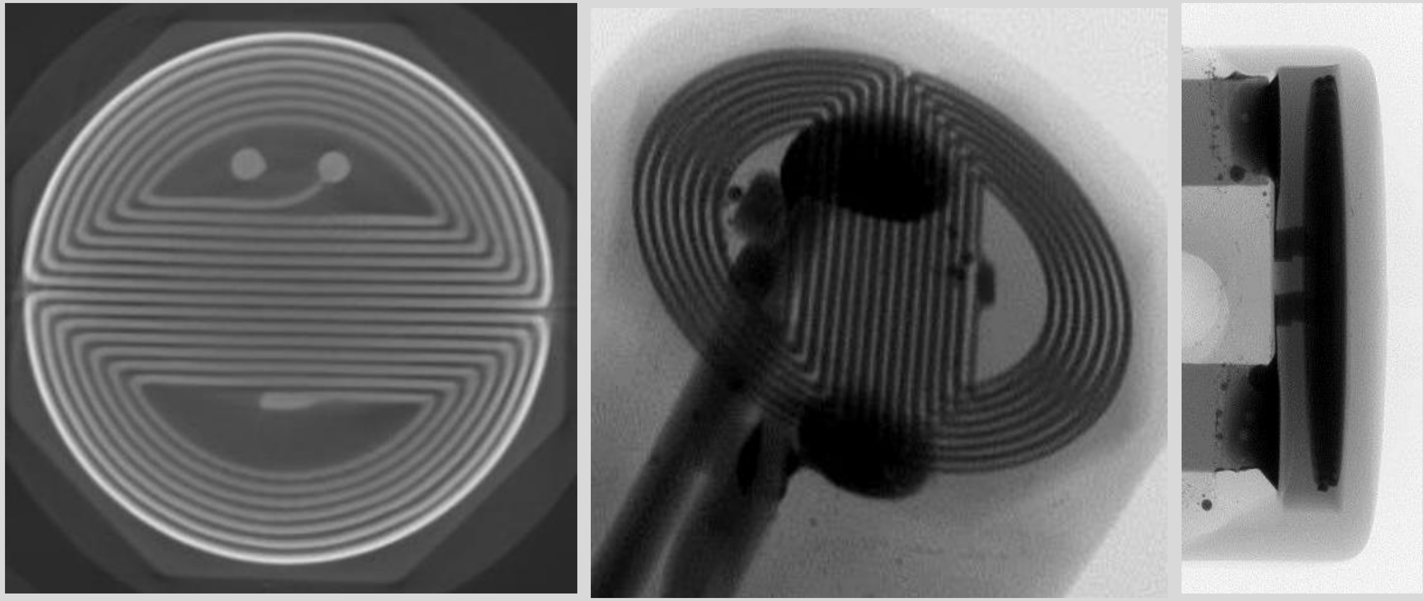
Sensors: Eddy current based rotation speed measurement

- Metallization: Line/Space 70/30 µm, Thickness 55-100 µm → Aspect ratio > 1
- Upscaling: Reduction of single element spacing on multiple panel → 380 coils on 4”x4” panel
- Technology transfer to LTCC mass manufacturer

Manufactured 4 mm coils



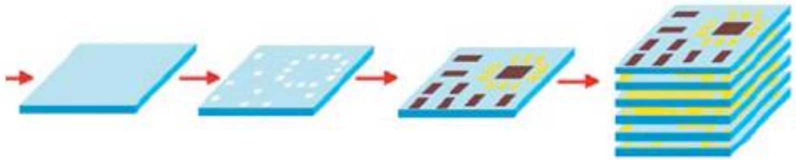
CT pictured of coil integrated in sensor setup



HYBRID CERAMIC INJECTION MOULDING

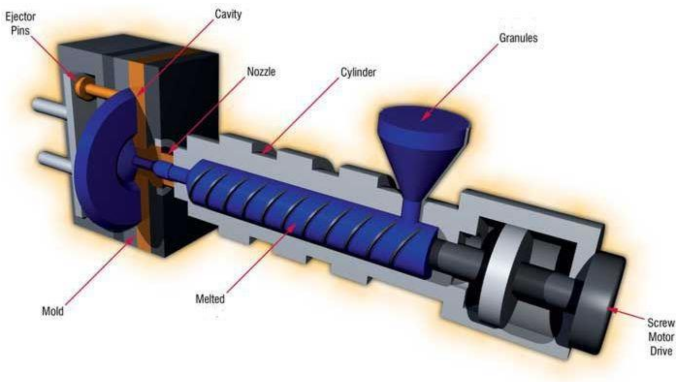
Hybrid Ceramic Injection Moulding

Multilayer Ceramic Technology (MLC)



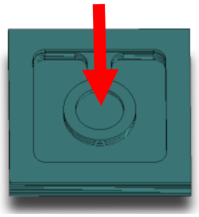
Mass production ☺
Geometrical freedom 😐
Functionalization ☺

Ceramic Injection Moulding (CIM)

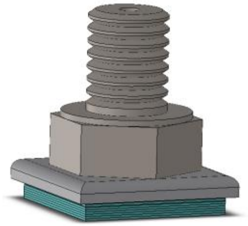


Mass production ☺
Geometrical freedom ☺
Functionalization 😐

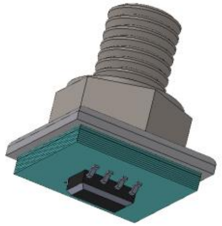
Pressure sensing membrane



Laminate

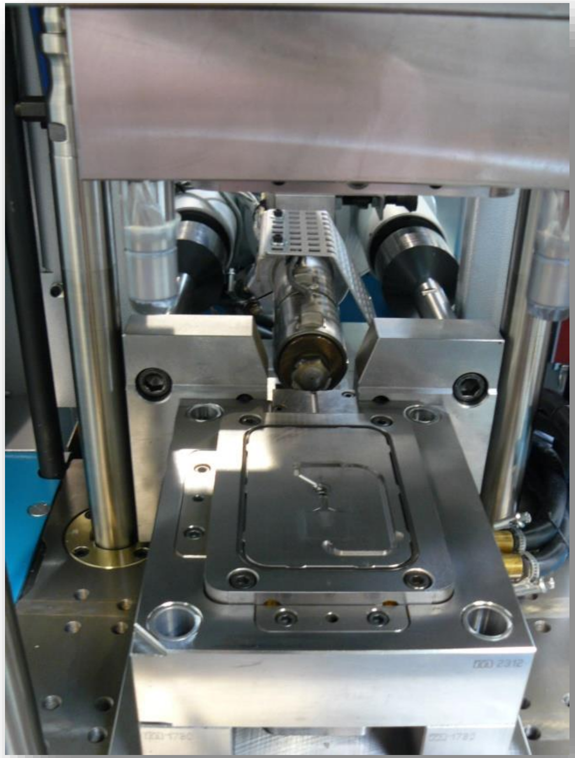


CIM based media port



Cofired sensor

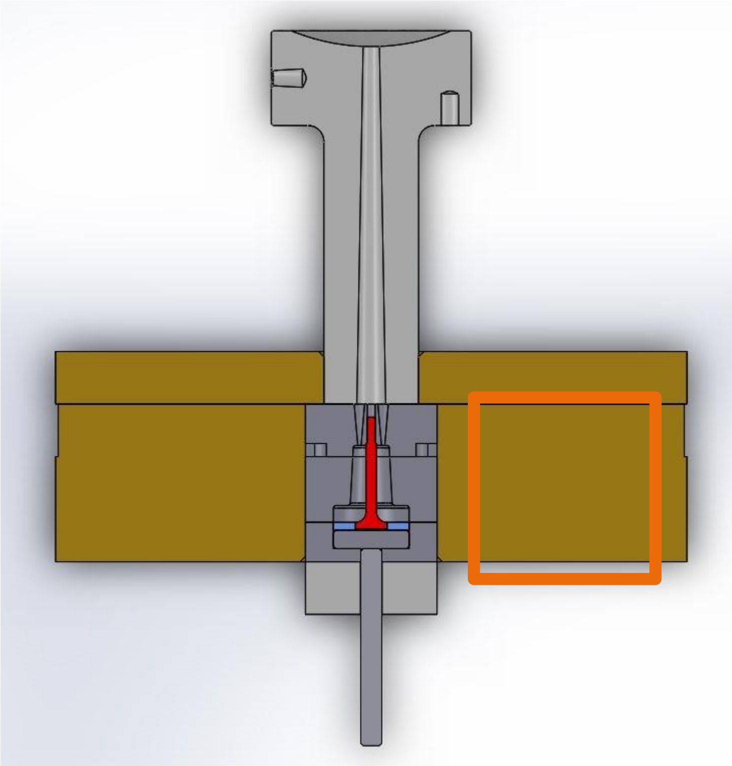
Hybrid Ceramic Injection Moulding

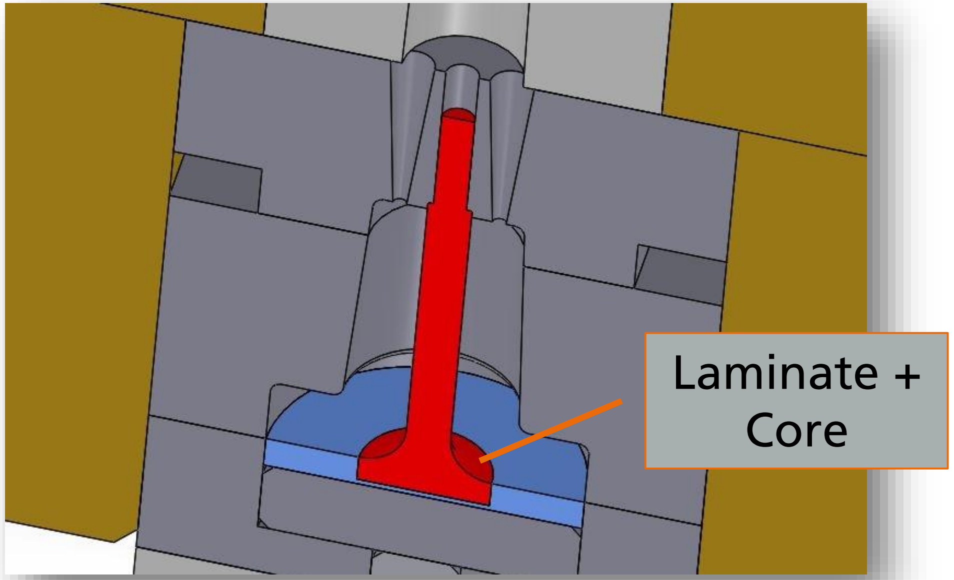


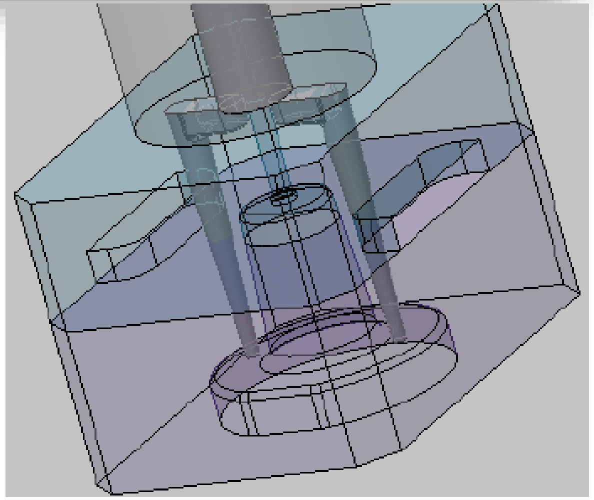
Injection Molding experiments on a 2K-Molding machine BOY 35 E VV

- Vertical opening of the mold
- 14 mm screw in vertical and horizontal position

Hybrid Ceramic Injection Moulding



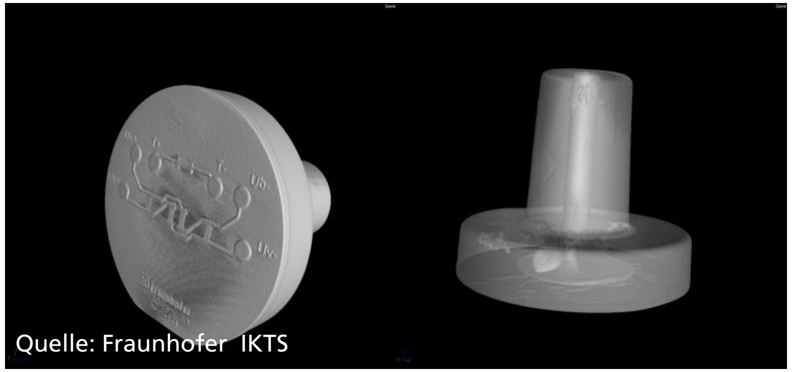


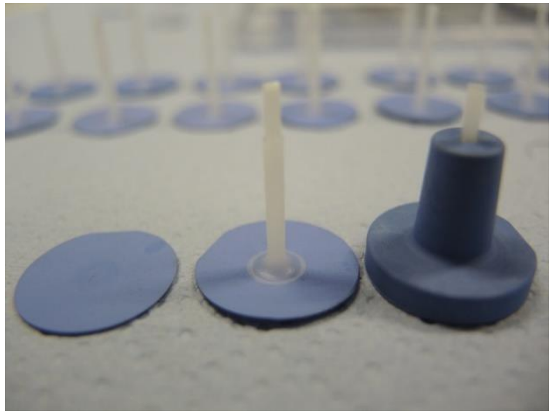


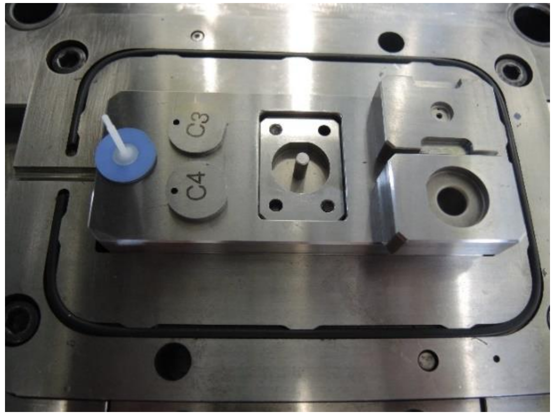
- Manual insert of unfired Multilayer Ceramic part
- Injection of sacrificial core (POM)
- Injection of LTCC-feedstock and removal

Hybrid Ceramic Injection Moulding

- Combination of CIM & Ceramic Multilayer Technology
  - Generation of 3D-surfaces on ceramic substrates (MID)
  - Avoidance of substractive processes (structure integration functionalities (cavities, cooling structures)
  - Combination with 3D printing and 3D pick & place processes





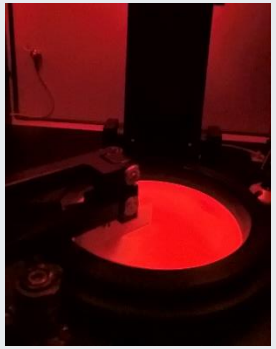
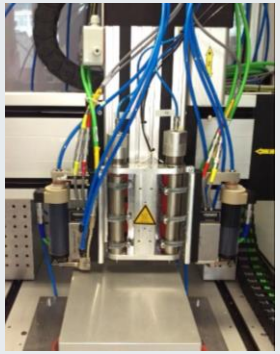
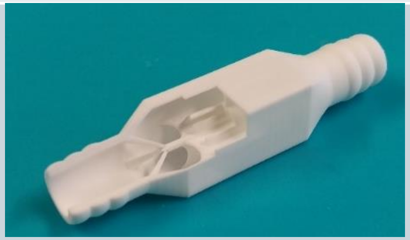


Fraunhofer IKTS

ADDITIVE MANUFACTURING

Additive Manufacturing - Current Development

Technologies for 2D and 3D ceramic circuit Technologies

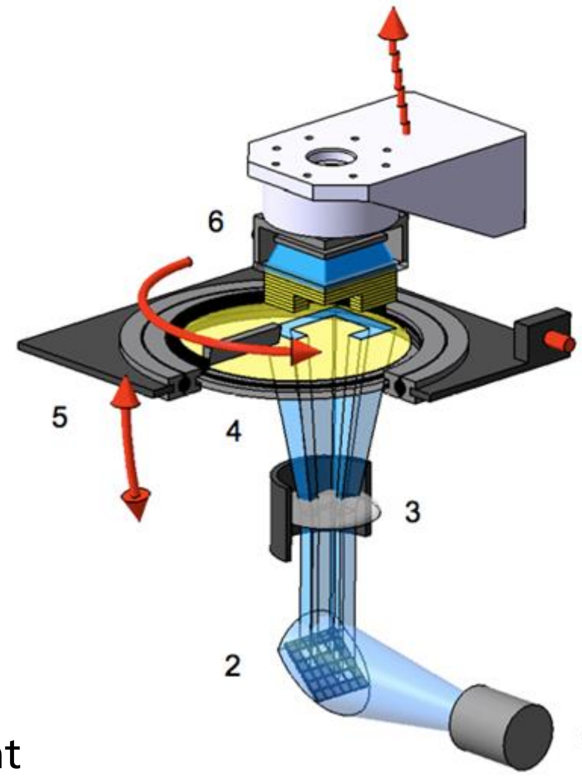
Binder Jetting CerAM BJ	Lithography-based Ceramic Manufacturing (LCM) CerAM VPP	Thermoplastic 3D-Printing CerAM T3DP	Fused Filament Fabrication CerAM FFF	Laser Sintering CerAM LS
				
Powder based	Suspension based	Thermoplastic feedstock	Thermoplastic filament	Powder based
Ceramic components, porous structures, dense hard metal components	Ceramic with dense microstructure, high geometrical resolution, attractive material properties	IKTS Technology Development, Multi-material-parts, e.g. Metal - Ceramic	High deposition rate, low geometrical resolution	Special materials z. B. SiSiC
				

Fraunhofer
IKTS

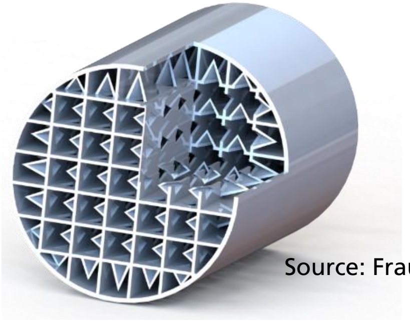
Lithography based Ceramic Manufacturing (LCM)

Technologies for 2D and 3D ceramic circuit Technologies

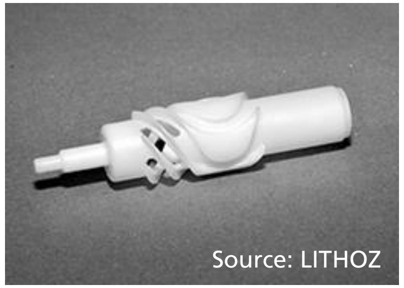
- LCM (Lithography-based Ceramic Manufacturing)
  - Additives Manufacturing Process
  - Layer based exposure of ceramic slurry with DLP
  - Spezifications (CeraFab 7500, Fa. LITHOZ)
    - Lateral printing resolution: 40 µm (635 dpi)
    - Layer Thickness: 25-100 µm
    - Max. Space: 76 x 43 x 150 mm³
    - Deposition rate: 2,5-10 mm/h
  - Materials
    - Al_2O_3, PSZ, Si_3N_4 .. further materials under development



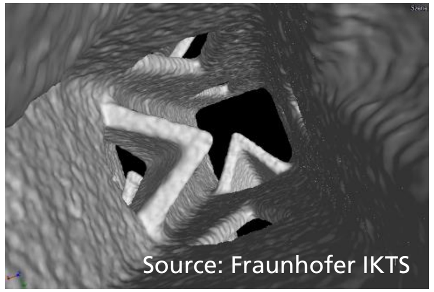
CeraFab 7500@ IKTS



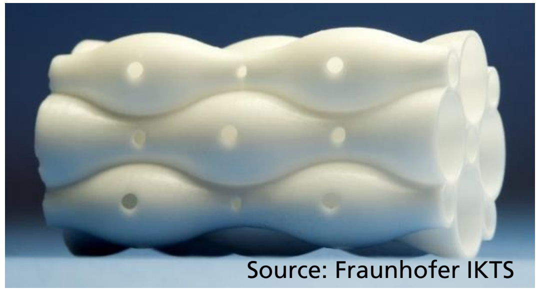
Source: Fraunhofer IKTS



Source: LITHOZ



Source: Fraunhofer IKTS

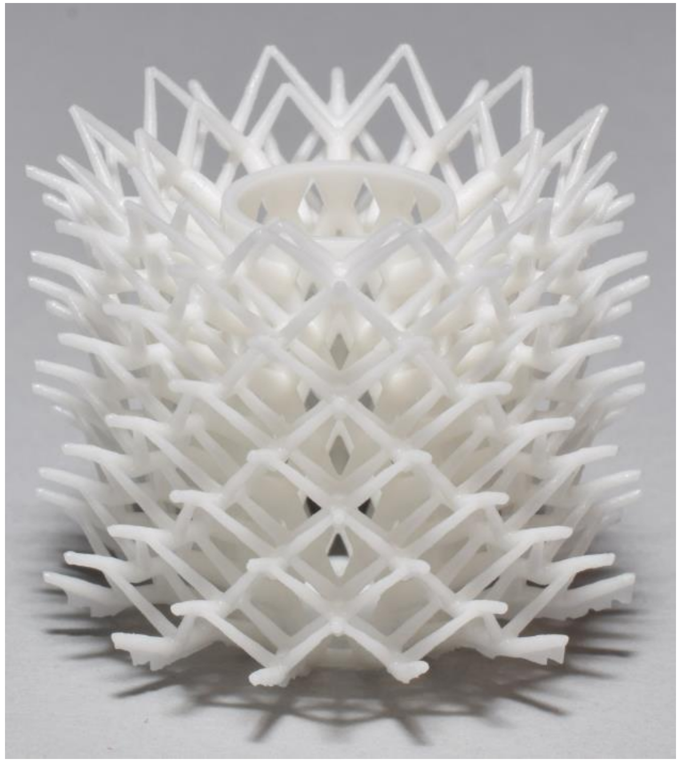


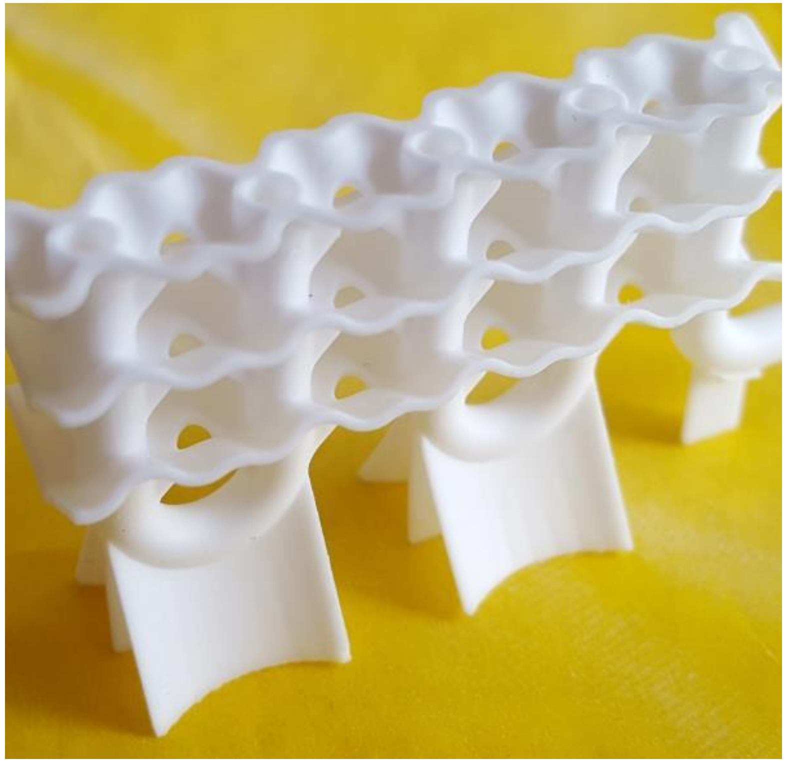
Source: Fraunhofer IKTS

Source: Fraunhofer IKTS

Lithography based Ceramic Manufacturing (LCM)

- challenge: maximizing of surface for heat transfer





- d = 30 mm, h = 25 mm
- d_p = 10 mm, d_w = 1 mm
- surface: > 7750 mm²

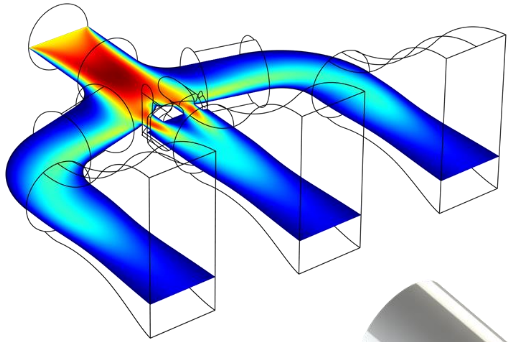
- 45 x 45 x 10 mm³
- d_p = 2.2 mm
- surface: > 6500 mm²

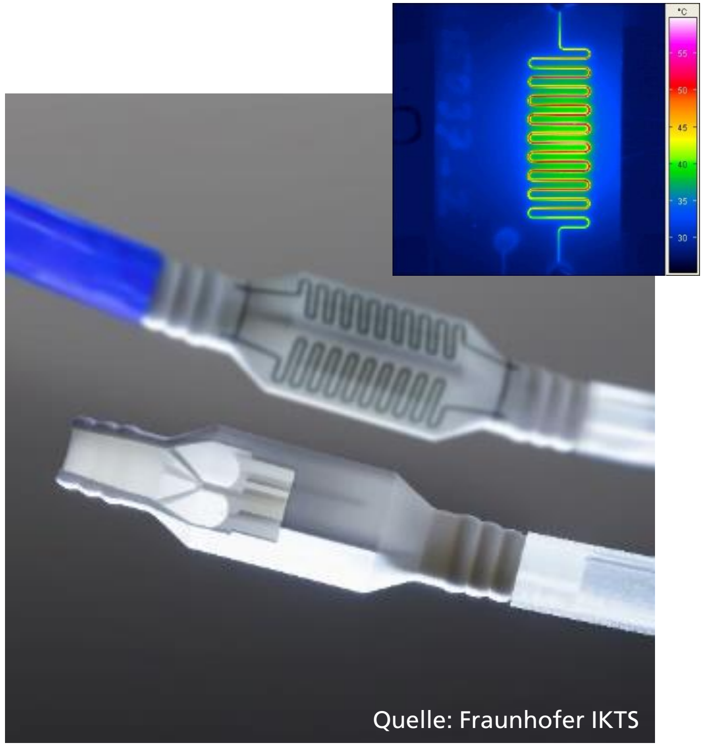
- d = 26 mm, h = 13 mm
- d_p = 2.2 mm
- surface: > 3500 mm²

Lithography based Ceramic Manufacturing (LCM)

Technologies for 2D and 3D ceramic circuit Technologies

- LCM (Lithography-based Ceramic Manufacturing)
  - Extreme geometrical complexities
  - Continuous enhancement of printing machines
    - Higher productivities
      - Deposition rates
      - Available space
    - Increased printing resolution
    - Optimized software
  - Increased material portfolio
- Combination of LCM + Functional printing
  - Surface integration of electrical wiring functions (conductors, heaters…)
  - Development of structural integrated components





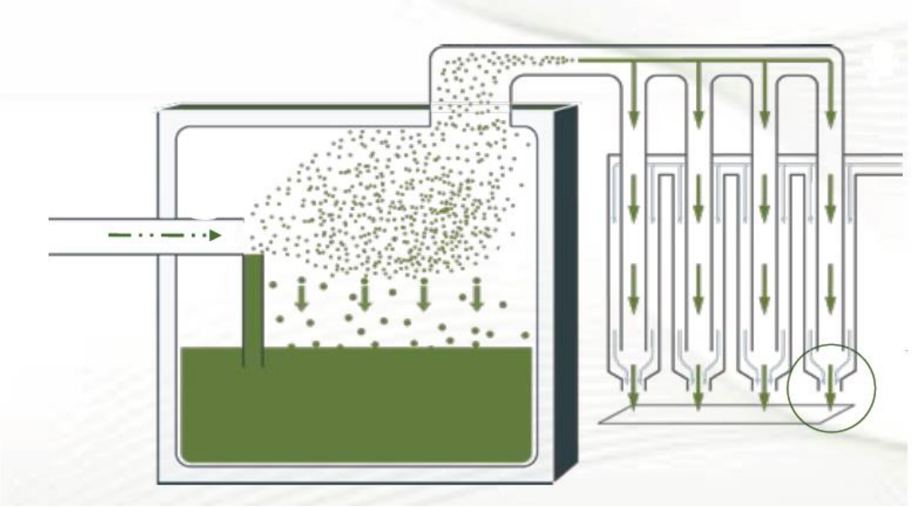
FUTURE PRINTING TECHNOLOGIES

Target Technology: Surface functionalization of 3D components

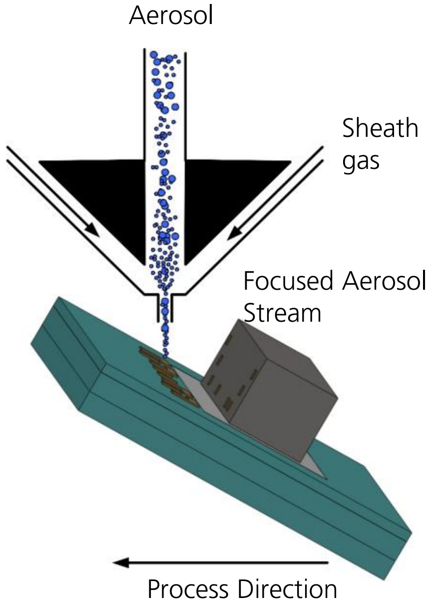
Aerosol-Jet Printing

Aerosol Jet Technology

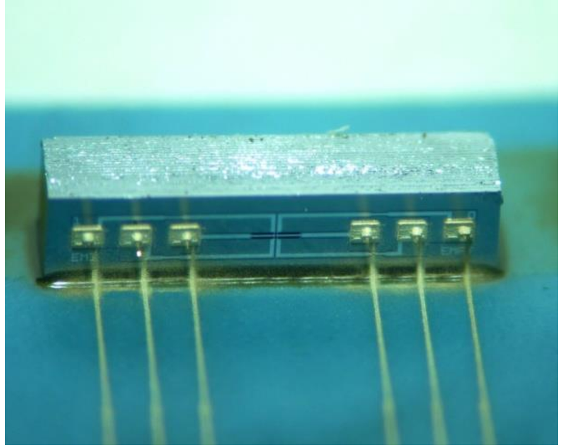
- **3D-capability**
- Fully digital, no masks
- High printing resolution (10-15 µm)
- Nanoparticle inks available (Ag, Au, Pt …)
- Low printing tolerance e.g. 30 ± 1-2 µm

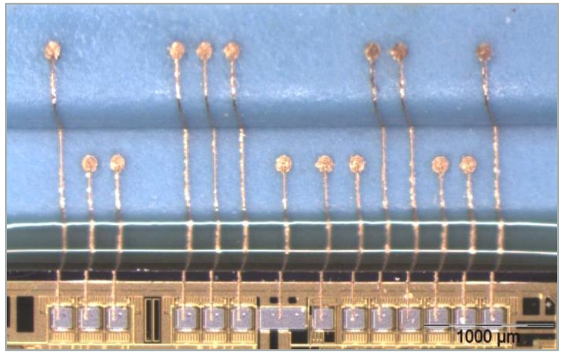


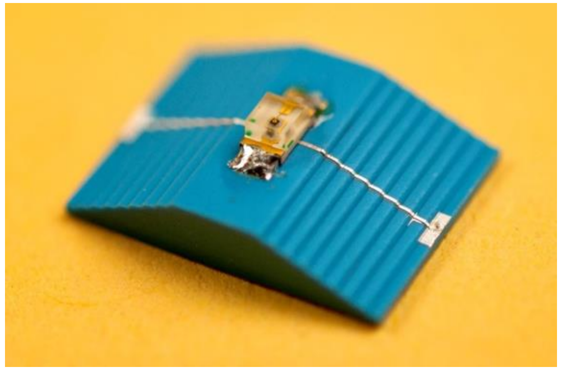
Source: Optomec



Tilt-Module



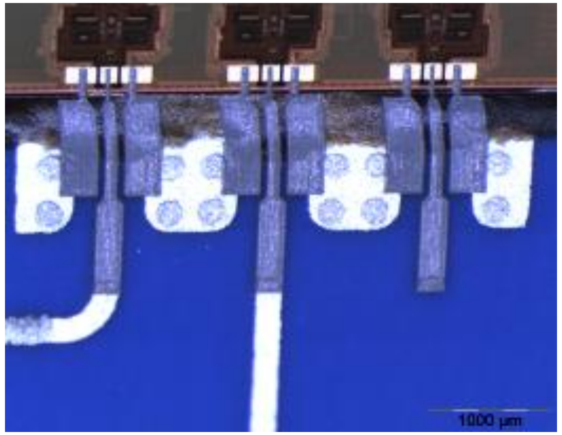


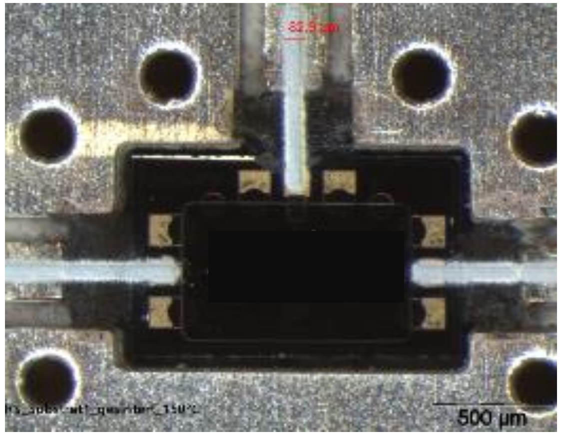


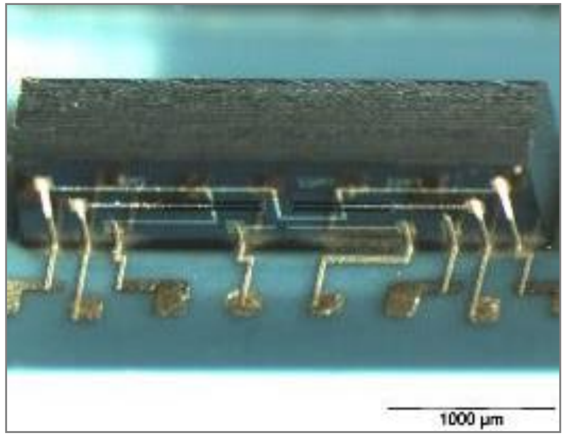
Target Technology: Surface functionalization of 3D components

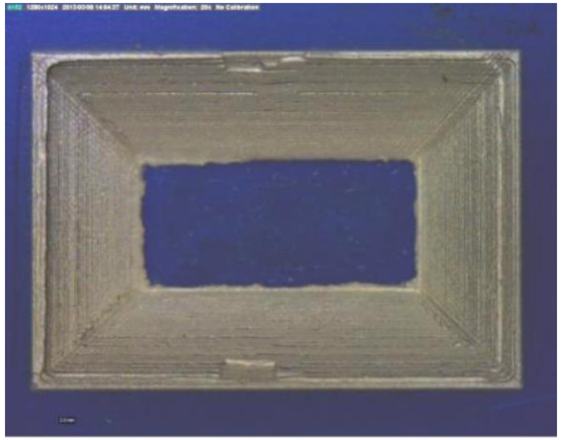
Aerosol-Jet Printing

*MMIC **	*Hybrid RF-Substrates*	*MEMS-Packages*	*3D Antennas*









MMIC *
- 3D-printing for substitution of wire bonds
- Co-planar Wave Guide (79-81 GHz)

Hybrid RF-Substrates
- Direct printing on PTFE-substrates and IC
- Sintering temperature 150°C

MEMS-Packages
- Si-MEMS (Acceleration sensors)

3D Antennas
- LTCC-based 3D cavity
- Defined directional characteristics

* MMIC Millimeter Wave IC

Conclusion

- Ceramic materials offer specific properties, thus allowing unique solutions
- Wide technological base for the processing of ceramics
- SOTA solutions
  - Thick film Technology
  - Multilayer Ceramic manufacturing
- Geometrical and functional limitations can be overcome by new technologies
  - Hybridization of conventional technologies
  - Functionalization of conventionally manufactured components by Functional printing
  - Additive manufacturing of ceramics with layer by layer technologies
- Ongoing development of printing technologies regarding productivity and printing performance
- Development of materials and semifinished components (suspensions) essential

Fraunhofer Institute for Ceramic Technologies and Systems

Winterbergstraße 28
01277 Dresden

Germany

Thank you for your attention!

Further information:

steffen.ziesche@ikts.fraunhofer.de