Packaging and Assembly with Ceramic Circuit Boards
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Competency in Ceramics

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SYSTEMS EXPERTISE
MATERIALS DIAGNOSTICS
Reliability
Quality assurance

TECHNOLOGY EXPERTISE

MATERIALS EXPERTISE
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

State of Saxony
Hermsdorf

State of Thuringia
Pilot Plant PV
Hohenstein-Ernstthal

Dresden

- Thick-Film Technology, Functional Printing
- Microsystems/ LTCC, HTCC
- Systems Integration

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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
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

Quelle: wired.de
Quelle: american-sand.com
Quelle: Rolls-Royce plc
Quelle: spinner-wzm.de
Quelle: mcucoatings.com
Quelle: fotocommunity.de
## Ceramic Thick-Film and Multilayer Technology

<table>
<thead>
<tr>
<th></th>
<th>Ceramics/ Glass-Ceramic Substrates</th>
<th>Isolated Metal Substrates</th>
<th>Polymer Substrates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\text{Al}_2\text{O}_3$</td>
<td>SN</td>
<td>AIN</td>
</tr>
<tr>
<td>Post (DiS)/ Co-firing (ML)</td>
<td>+/-</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>$T_{\text{sinter max}}$ [$^\circ$C]</td>
<td>1600</td>
<td>1500</td>
<td>1400</td>
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<tr>
<td>CTE [$10^{-7}$/K]</td>
<td>75</td>
<td>31</td>
<td>34</td>
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<tr>
<td>Thermal Cond. [W/mK]</td>
<td>20</td>
<td>110</td>
<td>200</td>
</tr>
<tr>
<td>$\varepsilon_{\text{rel}}$</td>
<td>9,5</td>
<td>5</td>
<td>10,0</td>
</tr>
<tr>
<td>$\tan \delta \cdot 10^{-3}$ @10MHz</td>
<td>0,3</td>
<td>4,5</td>
<td>2,0</td>
</tr>
<tr>
<td>Cost factor approx.</td>
<td>1</td>
<td>&lt; 40</td>
<td>&lt; 40</td>
</tr>
</tbody>
</table>
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

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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)
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

\[
f_t = \frac{1}{2\pi} \sqrt{\frac{1}{LC} - \frac{R_L^2}{L^2}}
\]

\[
f = 3.2 \text{ MHz}
\]

\[
L_{\text{Soll}} = 1.5 \mu\text{H}, \quad Q = \frac{X_L}{R} \uparrow
\]
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

Sintered panel

Pressure sintering

Laminating and Pre-Structuring

„Laser cleaning“ process
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 😊

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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

Laminate + Core
Hybrid Ceramic Injection Moulding

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

Quelle: Fraunhofer IKTS
ADDITIVE MANUFACTURING
# Additive Manufacturing - Current Development

Technologies for 2D and 3D ceramic circuit Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binder Jetting</strong>&lt;br&gt;CerAM BJ</td>
<td><strong>Lithography-based Ceramic Manufacturing (LCM)</strong>&lt;br&gt;CerAM VPP</td>
</tr>
</tbody>
</table>

- **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
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
  - Al₂O₃, PSZ, Si₃N₄ .. further materials under development
Lithography based Ceramic Manufacturing (LCM)

- challenge: maximizing of surface for heat transfer

- $d = 30\, \text{mm}$, $h = 25\, \text{mm}$
  - $d_p = 10\, \text{mm}$, $d_w = 1\, \text{mm}$
  - surface: $> 7750\, \text{mm}^2$

- $45 \times 45 \times 10\, \text{mm}^3$
  - $d_p = 2.2\, \text{mm}$
  - surface: $> 6500\, \text{mm}^2$

- $d = 26\, \text{mm}$, $h = 13\, \text{mm}$
  - $d_p = 2.2\, \text{mm}$
  - surface: $> 3500\, \text{mm}^2$
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
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
Target Technology: Surface functionalization of 3D components
Aerosol-Jet Printing

**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

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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
Thank you for your attention!

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