LTCC Packaging & Smart System Integration
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LTCC
Low Temperature Co-fired Ceramics

APPLICATION AREAS:
• telecom & wireless
• automotive
• sensor & opto packaging
• medical
• high speed signal processing
• military & space

BENEFITS:
• high density, fine-line
• Good high frequency properties
• radiation / crosstalk management
• reliability & stability
• 3D - capability
Low temperature cofired ceramics (LTCC)
Process Flow

Glass/ceramic sheet blanking → Via punching → Via metallisation → Conductor printing → Layer alignment & lamination → Sintering → Optional green cutting → Circuit separation

Standard process:
X,Y shrinkage 10…15% +/- 0.2%

Zero-shrink process:
X,Y shrinkage 0…0.3 % +/- 0.03%
LTCC Material Systems

- Several manufacturers: Du Pont, Heraeus, Ferro, CeramTec, NEC…
- LTCC tape is glass which is cast with organic additives on a polyester backing
- Different tape thicknesses can be used in the same substrate
- Metallization pastes for vias and conductors are matched to each tape
- Pure silver (Ag) is the mainly used low cost, high conductivity metallisation (Rs = 1…3 mohm/square, surface roughness Ra = 0.6 μm)
- Ag/Pd or Ag/Pt is used for solderable conductors (Rs = 20 mohm/sq.)
- Au conductors are used for bondable conductors (Rs = 5 mohm/sq.)
## LTCC Tape Systems

<table>
<thead>
<tr>
<th>TAPE</th>
<th>Fired thickness [μm]</th>
<th>Permittivity Er</th>
<th>Tan δ [%]</th>
<th>TCE [ppm/K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferro A6M</td>
<td>100, 200</td>
<td>5.9</td>
<td>0.12 (2.5 GHz)</td>
<td>&gt;8</td>
</tr>
<tr>
<td>DuPont 951</td>
<td>40, 90, 130, 200</td>
<td>7.8</td>
<td>0.15 (10 MHz)</td>
<td>5.8</td>
</tr>
<tr>
<td>DuPont 943</td>
<td>105</td>
<td>7.4 (40GHz)</td>
<td>0.2 (40 GHz)</td>
<td>6.0</td>
</tr>
<tr>
<td>Heraeus CT2000</td>
<td>77</td>
<td>9.1</td>
<td>0.2 (2 GHz)</td>
<td>8.5</td>
</tr>
<tr>
<td>Heraeus HL2000</td>
<td>89</td>
<td>7.4</td>
<td>0.26 (2.5 GHz)</td>
<td>6.1</td>
</tr>
<tr>
<td>Heraeus CT 800</td>
<td>-</td>
<td>8.4</td>
<td>0.18 (1 kHz)</td>
<td>8.4</td>
</tr>
<tr>
<td>Heraeus CT707</td>
<td>105</td>
<td>6.4</td>
<td>0.46 (2.5 GHz)</td>
<td>8.1</td>
</tr>
<tr>
<td>Heraeus CT765</td>
<td>84</td>
<td>65</td>
<td>0.17 (2.5 GHz)</td>
<td>9.1</td>
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<tr>
<td>Heraeus CT702</td>
<td>-</td>
<td>5.3 (30GHz)</td>
<td>&lt;0.2 (30 GHZ)</td>
<td>-</td>
</tr>
<tr>
<td>Heraeus CT703</td>
<td>-</td>
<td>7.0 (30GHz)</td>
<td>&lt;0.2 (30GHZ)</td>
<td>-</td>
</tr>
</tbody>
</table>

Thermal conductivity 2…4 W/mK for all LTCC materials.
Characterisation of novel LTCC materials for μ-wave and millimeter-wave frequencies

Mixed K LTCC resonator
Q=150 (2 GHz)

Characterisation of Ferrite LTCC
Heralock self-constraining tape system
( "Zero-Shrink")

Heralock clad substrate uses CT800 tape outer layers

+ X, Y shrinkage only 0.3%
+ Shrinkage tolerance 0.03% enables fine-pitch component assembly
+ Excellent substrate flatness
+ Clad system enables Ni/Au plating (reliability of interconnections)
- Cavities are difficult to make
- Number of tape layers limited to 8 - 10
LTCC design limits

<table>
<thead>
<tr>
<th>FEATURE</th>
<th>Production State-of-the art</th>
<th>Special applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of tape layers</td>
<td>&gt;20</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Substrate max. thickness</td>
<td>4mm</td>
<td>&gt;4mm</td>
</tr>
<tr>
<td>Printed conductor line width / spacing</td>
<td>50 μm / 70 μm</td>
<td>40μm / 60 μm</td>
</tr>
<tr>
<td>photo-patterned line width / spacing</td>
<td>40μm / 50 μm</td>
<td>40μm / 50 μm</td>
</tr>
<tr>
<td>Via diameter</td>
<td>80 μm… 200 μm</td>
<td>50 μm</td>
</tr>
<tr>
<td>via pitch</td>
<td>2.5 x via diameter</td>
<td>2 x via diameter</td>
</tr>
<tr>
<td>layer alignment tolerance</td>
<td>15 μm</td>
<td>10 μm</td>
</tr>
<tr>
<td>shrinkage tolerances (x, y)</td>
<td>typical +/- 0.1%</td>
<td>0.03% (zero shrink)</td>
</tr>
<tr>
<td>Thickness tolerance (z)</td>
<td>typical +/- 2%</td>
<td>typical +/- 2%</td>
</tr>
</tbody>
</table>

General design guidelines on VTT web pages
LTCC Patterning

• Screen printing is the main fabrication method
  - co-fireable conductors, resistors and overglaze
  - post-fireable conductors printed on fired substrate

• Photoimageable thick film pastes
  - limited to special applications (higher cost)
  - co-fired Ag, post-fired Ag, Au, glass
  - HF- properties comparable to printed conductors

• Etching of post-fired thick film or thin film metallization
  - 25 μm line and space is feasible.
  - limited to special applications (higher cost)

• Electroless Ni/Au plating of thick film conductor
  - Improved wire bond and solder joint reliability
  - Requires a plateable Ag paste

Printed line width 50μm, via 80μm

Ni/Au plating on LTCC
Fine-line screen printing

Typically minimum line width and spacing is >100 μm in volume production.

Fine-line screen printing (50...70μm) is possible in LTCC production using:

- advanced screen technology
- fine-line ink (only a few types are available)
- optimized layout design
- careful process control (cleanliness etc.)

Printed inductor 35 μm line / 55 μm space

Trampoline Screen
mesh 500, 15 μm wire
Photoimaged conductors

- Minimum line width 40 μm, minimum space 50 μm
- Improved edge resolution
- Line width tolerance: +/- 2 μm (with high quality exposure mask)
- Complicated process compared to screen printing
Thermal Management
Thermal vias

- LTCC dielectric thermal conductivity is 3...5 W/mK (FR-4: 0.2 W/mK)
- Ag via thermal conductivity is typically 300 W/mK
- 24% area fraction of vias can be readily achieved
- thermal resistance reduced by 1/20

POWER DIE
In/Pb SOLDER
Ag THERMAL VIAS
(diam 0.2 ; 24% area fraction )
Cu heat sink , 50mm x 50mm x 3mm attached using thermal grease

adhesive 20 μm
Thermal Management
water cooling

- Efficient cooling method
- Difficult to arrange pumping for portable equipment
Thermal Management
Thermal plug

Up to diameter 0.9mm hole can be filled with thermal plug paste
- Firing at 850°C
- Suitable for alumina and LTCC

Cross-section of diam. 0.9mm Ag plugs for LED array
Chip assembly on LTCC

FLIP-CHIP
Solder bump on the chip side is recommended, if available
- Au metallization on LTCC for Au/Sn or bumps (without flux)
- Ag/Pd metallization on LTCC for Pb/Sn bumps (with flux)

Gold stud bumps for prototyping
- Bumps can be made on the chip (>3mmx3mm) or on the LTCC
- Typical bump diameter 75 μm (25 μm wire), height 30 μm
- joining by thermocompression, ultrasonics or adhesive

CHIP&WIRE
- A well proven and reliable technology on thick film and LTCC
- The chip is usually die bonded using conductive or non-conductive epoxy
- Thin gold or aluminium wire (typically 25μm) is used
- Alternatively Au ribbon for MMIC’s
LTCC
Sealing & hermeticity

• LTCC substrate itself is hermetic, stable and reliable
• Local hermetic sealing (Au/Sn solder) is possible
• Non-hermetic glob-top sealing
• Under fill support for flip-chip components
  - due to small TCE mismatch, underfill is often not needed
Why LTCC in RF- and Microwave Applications

- Low loss materials up to 100 GHz
- Controlled impedance (3-D design, precise geometry)
- Low Tf (Temperature coefficient of resonant frequency)
- Radiation / crosstalk management
- Integrated passive components
  - Inductors -> 200 nH/layer (+/- 5%)
  - Capacitors -> 10 pF (+/- 5%)
  - Resistors -> 10 Ω - 10 MΩ, buried +/- 30%, surface +/- 1%
  - Filters, antennas, resonators
LTCC
Antenna demonstrators

Patch antenna array with air cavity
Communications Research Centre, Canada

24GHz dielectric resonator
Carleton University, Canada

Patch antenna array (60GHz)
LTCC MEMS packaging

LTCC technology meets the technical requirements for MEMS packaging

- Good high frequency properties
- Reliability (good TCE match to Si, stability, hermeticity)
- 3D microstructures, fluidistics

MEMS switch in LTCC package

Pressure transmitter
MEMSPACK- project
Zero- and First level Packaging of RF- MEMS

Packaging concepts for RF-MEMS

Critical packaging issues for RF- MEMS
• good RF- behaviour
• reliability
• low cost
Thin-film RF-MEMS switches on LTCC platform were successfully demonstrated.

LTCC is readily suitable for high frequency but surface quality is not good enough for the most demanding thin-film post-processing, such as RF-MEMS.

Polishing of LTCC was developed to obtain the required criteria:

- LTCC as-fired roughness Rq = 600nm reduced to Rq = 14 nm
- Pore size: < 1 μm²
- Pore depth: Rt < 200 nm
- Pore count: <30 pcs / mm²
LTCC in photonic packaging

• High packaging density, integration of high speed/low noise/high-power electronics close to photonic devices
• Accurate 3D structures - passive alignment of photonic devices and fibres (cavities, grooves, holes, channels)
• Stable and hermetic substrate material
• Good power handling capability
• Hermetic sealing - eliminates expensive metal package
• Cost effective

High-speed photo-detector array
Optical fibre passive alignment
Punched & laminated fiber groove

- Fibre groove nibbled to tape sheet with 150 μm round pin
- Lamination with low pressure
- Ag filled vias are used for laser die alignment

Laser transmitter demonstrator
Optical fibre passive alignment
Photoimaged fiber groove and alignment marks

Process:
• FODEL Photoimaged glass print- dry-print-dry, up to six layers
• UV- exposure through photo mask
• Spray development
• Firing 850 °C

Precise alignment fiducials for the laser die alignment
Optical fibre passive alignment
Passive alignment to VCSEL laser or receiver diode

Passive alignment of a 62.5/125µm multimode fibre to a VCSEL laser by the use of punched through hole in the LTCC substrate.

Hole diameter tolerance +/- 2 µm
Fibre Optic Data Link Modules

ESA ARTES-5
Intra-satellite 10Gbps fibre-optic data transceiver

Hermetic fibre pigtailed laser module with fibre passive alignment
4x 10 Gb/s Optical Coupling Demonstrator

- VCSEL / Photodiode array
- LTCC substrate
- BGA bumps
- Optical waveguides
- Micro-mirror
- Microlens array on glass substrate

Cavity for microlens array with ‘optical vias’ and alignment marks

LTCC receiver

‘optical vias’ and flip-chip pads
Fabrication of 3D LTCC Structures

Mechanical punching is the most common technique for LTCC tape structuring

- Hundreds of holes per second can be punched using customised matrix tooling
- Punching method gives the best hole quality
- Holes can be punched through several laminated layers also
- Different punch tool geometries are available

Punched 80 μm vias on 160 μm pitch

150 μm channels and cavity window nibbled to tape sheet
Laser Structuring of LTCC tape or laminate

Laser structuring of laminate and tape is fast in the un-fired state

- Narrow (<150\(\mu\)m) channels
- Complex shapes
- Laser cut edge is slightly inclined (beam shape)
CNC machining of LTCC

• Accurate holes can be drilled to very thick laminates (un-fired)
• Wear of the hard-metal drill bit due to abrasive ceramic binder
• Final hole size tolerance (after firing) mainly depends on drill tool tolerances
• Hole placement tolerance depends on drilling accuracy and LTCC firing shrinkage tolerance (typically 0.1-0.2%)

• Accurate holes can be CNC- machined to fired substrates using diamond tooling
• Minimum hole diameter is typically 2.5mm on <50x50mm LTCC part
• Hole diameter can be controlled to +/- 5μm tolerance
• Hole-to hole distance can be controlled to +/- 15μm tolerance

Drilled 2mm holes, metallised
Fabrication of surface cavities

Molded silicone inserts support the cavity structure during lamination (removed after lamination)

Typical cavity tolerance is +/- 50μm

Small inserts difficult to handle -> Insert mat can be used for lamination
Fabrication of buried cavities and channels
Lamination methods

Method 1: Lamination at very low pressure
• tape layer delamination may happen
• channel width limited to about 0.5 mm
• substrate sagging problems

Method 2: Lamination with sacrificial filler
• sacrificial material supports the structure in lamination and burns off during substrate co-firing process
• possible sacrificial materials: carbon, wax…
• substrate cracking can be a problem

Method 3: Lamination in several steps
• Standard lamination for separate sub-laminates
• Final ”cold lamination” step = gluing of parts together with a glue that burns off during co-firing
Fabrication of buried cavities and channels
Sacrificial carbon

Carbon insert 0.4 x 0.41 x 2.3 mm

Channels filled with carbon paste

Co-fired cavity
MINIGAS- Project
LTCC Platform for Miniature photo-acoustic gas sensor

Realised LTCC platform
Channel 2 x 2 x 8mm
Implant for Continuous Blood Sugar Monitoring (Lifecare AS)

LTCC IMPLANT:
- Packaging of glucose measurement system
- Microchannels for reference chamber filling and sealing
- Measurement electronics
- Inductive link for power supply and data transmission
MAC_TFC - project
MEMS Atomic Clocks for Timing, Frequency Control and Communications

• Size and power consumption of existing atomic clocks far exceed those of quartz-based clocks

• GOAL: To develop an ultra-miniaturized and low-power cesium atomic clock in LTCC package presenting:
  - Small size
  - a short-term stability of $5 \times 10^{-11}$ over 1 hour (Thermal stability important)
  - less than 200 mW power consumption

Atomic clock package concept