Designing and Building Microwave Circuits in LTCC

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What is Low Temperature Co-Fired Ceramic (LTCC)

- Extension of Thick Film Multilayer Technology
- Versatile to build Microwave Components & Circuits
- Ease of developing 3-D structures
- Called Low Temp as firing temperature is about 900°C as opposed to HTCC—1800°C firing temperature
- Comes in 2/5/10 mil thick tape
- “Green Tape”—ends up Blue for DuPont material & White for Ferro & Heraeus
LTCC Process Steps

- Sheets can be mounted in frames or go frameless
- Vias Punched / Metallized for Interconnects
- Desired resistors/CAPs/conductors/dielectric patterned on each layer
- Align layers/laminate under pressure/Co-fire
- Dice/Separate Circuits
Table 1: LTCC Material Data

<table>
<thead>
<tr>
<th></th>
<th>DuPont 951-AX</th>
<th>Ferro A6-S</th>
<th>DuPont 9K7</th>
<th>Heraeus CT 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dielectric Constant</strong></td>
<td>7.8</td>
<td>5.9 ± 0.15</td>
<td>7.1 ± 0.2</td>
<td>9.1 ± 0.1</td>
</tr>
<tr>
<td><strong>Green thickness (µm)</strong></td>
<td>254</td>
<td>127</td>
<td>127</td>
<td>99</td>
</tr>
<tr>
<td><strong>Fired thickness (µm)</strong></td>
<td>205</td>
<td>99</td>
<td>105</td>
<td>77</td>
</tr>
<tr>
<td><strong>Tan δ</strong></td>
<td>0.0055 (&gt;1 GHz)</td>
<td>0.001 (&gt;1 GHz)</td>
<td>0.001 (&gt;1 GHz)</td>
<td>0.0027 (&gt;1GHz)</td>
</tr>
<tr>
<td><strong>Insulation Resistance</strong></td>
<td>&gt; 10(^{12})Ωcm (100 VDC)</td>
<td>&gt; 10(^{14})Ωcm (bulk resistivity)</td>
<td>&gt; 10(^{12})Ωcm (bulk resistivity)</td>
<td>&gt; 10(^{13})Ωcm (bulk resistivity)</td>
</tr>
<tr>
<td><strong>Breakdown Voltage</strong></td>
<td>&gt;1000V/25µm</td>
<td>&gt;5000V/93µm</td>
<td>&gt;1100V/25µm</td>
<td>&gt;1000V/25µm</td>
</tr>
<tr>
<td><strong>Color</strong></td>
<td>blue</td>
<td>white</td>
<td>blue</td>
<td>white</td>
</tr>
<tr>
<td><strong>Thermal Conductivity</strong></td>
<td>3 W/mK</td>
<td>2 W/mK</td>
<td>4.6 W/mK</td>
<td>3 W/mK</td>
</tr>
<tr>
<td><strong>Thermal Expansion</strong></td>
<td>5.8 ppm/K (25...300)°C</td>
<td>7 ppm/K (25...300)°C</td>
<td>4.4 ppm/K (25...300)°C</td>
<td>8.5 ppm/K (25...300)°C</td>
</tr>
<tr>
<td><strong>Shrinkage: z-axis</strong></td>
<td>(15 ± 0.5)%</td>
<td>27%</td>
<td>(11.8 ± 0.3)%</td>
<td>14%</td>
</tr>
<tr>
<td><strong>x-, y-axis</strong></td>
<td>(12.7 ± 0.2)%</td>
<td>(15.5± 0.2)%</td>
<td>(9.1 ± 0.3)%</td>
<td>11.5%</td>
</tr>
</tbody>
</table>
# Characteristics of Material Set

## Table 2: Material Options

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>DuPont</th>
<th></th>
<th>Ferro</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process</strong></td>
<td><strong>#51</strong></td>
<td><strong>#K7</strong></td>
<td><strong>A6-M/S</strong></td>
<td></td>
</tr>
<tr>
<td>Inner Layer Au</td>
<td>734</td>
<td>TC502 (export control)</td>
<td>LL505</td>
<td>30-025</td>
</tr>
<tr>
<td>Via Fill Au</td>
<td>738</td>
<td>FC501 (export control)</td>
<td>LL502</td>
<td>30-078</td>
</tr>
<tr>
<td>Wirebond Co-Fire Au</td>
<td>742 (Al wire)</td>
<td>734 (Au wire)</td>
<td>FC502 (export control)</td>
<td>LL507 (1 &amp; 2 mil Au wire) LL505 (1 mil Au wire, transition to bond ledge)</td>
</tr>
<tr>
<td>Wirebond Post-Fire Au</td>
<td>771 (Al and Au wire)</td>
<td>771 (Al and Au wire)</td>
<td></td>
<td>30-068 (Al wire)</td>
</tr>
<tr>
<td>Solderable Au</td>
<td>739 (Pt/Au)</td>
<td>LL509 (Pt/Au)</td>
<td></td>
<td>36-020 (Pt/Au)</td>
</tr>
<tr>
<td>Photoimageable Au</td>
<td>989</td>
<td></td>
<td></td>
<td>4002</td>
</tr>
<tr>
<td>Brazing Material (AUSn, AuGe Braze)</td>
<td>5062D/5063D</td>
<td>5062D/5063D</td>
<td></td>
<td>4007</td>
</tr>
<tr>
<td>Inner Layer Ag</td>
<td>d142D (Signal)</td>
<td>d148 (Power, Grid)</td>
<td>LL612 (Signal) LL602 (Power, Grid)</td>
<td>33-398</td>
</tr>
<tr>
<td>Via Fill Ag</td>
<td>6141 (Ag)</td>
<td>6138 (Pd/Ag)</td>
<td>LL601 (Ag) LL701 (Au/Ag)</td>
<td>33-343 (Ag) 39-005 (Pd/Ag)</td>
</tr>
<tr>
<td>Solderable Co-Fired Ag</td>
<td>6146 (Pd/Ag)</td>
<td>LL627 (Pd/Ag)</td>
<td></td>
<td>33-391</td>
</tr>
<tr>
<td>Solderable Post-Fired Ag</td>
<td>6135 (Pd/Ag)</td>
<td>LF171 (AgPt)</td>
<td></td>
<td>3350</td>
</tr>
<tr>
<td>Co-Fired Resistors</td>
<td>CF Series</td>
<td></td>
<td>Ag System HFB12, 20 Ω/square HFB22, 200 Ω/square Au System E114065-108, 25 Ω/square E114065-109, 100 Ω/square E114065-123, 1000 Ω/square</td>
<td>87 Series</td>
</tr>
<tr>
<td>Post-Fired Resistors</td>
<td>1000 Series (Ag)</td>
<td>1900 Series (Au)</td>
<td></td>
<td>82 Series</td>
</tr>
<tr>
<td>Co-Fired Dielectric</td>
<td>9615R</td>
<td></td>
<td>9615R</td>
<td>38-088</td>
</tr>
<tr>
<td>Post-Fired Overglaze</td>
<td>9615R</td>
<td></td>
<td>9615R</td>
<td>NCAa</td>
</tr>
<tr>
<td>Photo Imageable Dielectric</td>
<td></td>
<td></td>
<td></td>
<td>NCAa</td>
</tr>
</tbody>
</table>
Important Features

- High Dielectric Constant/Low Loss
- Thermal conductivity is good
- Shrinkage is an issue—
  - But predictable
  - New “No-shrink” tapes available
  - Z-direction shrinkage still present
- Multi-layered structures possible
  - NATEL has built up to 70 layers
  - Generally—5-30 layers is common
Typical Features

- **Line width/spacing**—Typically 6 mils or more
  
- **Vias**
  - Used for electrical interconnect
  - Thermal management
  - 10 mil vias common—3 via diameter spacing between
  - For microwave/RF circuits may need to place vias parallel to controlled line for better performance

- **Resistors**
  - Buried or Surface type
  - Surface Resistor inks 10Ω/sq. to 1MΩ/sq.
  - Buried Resistor inks 10Ω/sq. to 10kΩ/sq.
  - Surface Resistors can be trimmed to +/- 1-2%
  - Buried Resistors can be trimmed to +/- 20%

- **Capacitors**
  - With tape—450 pf/in^2 possible
  - With Dielectrics—3000 pf +/- 20% possible
Inductors
- Spiral/Helix
- Can use standard or ferrite tape
- 5 nH to 200 nH possible

Cavities
- Useful for microwave circuits
- Embed active components
- Reduce thermal impedance of high power components
Microwave Circuit Building Blocks

(a)
Resistor film
Metal
Metal
Semi-insulating substrate

(b)
Metal
Metal
Semi-insulating substrate

(c)
Metal
Semi-insulating substrate

Strip
Strip line

Integrated

Loop

Microstrip

Slot line

Spiral

Coplanar waveguide

Suspended microstrip
Coupled Line Structures

(a) 

(b) 

(c)
Software Packages for LTCC/Microwave

- ANSOFT—design of active and passive modules
- HFSS—3D structures, circuits/EM Simulation
- EM Simulation/HFSS Planar EM/Spicelink 3D for electrical performance
- HFSS 3D Full wave solver for high frequency complex designs and package analysis
- Other thermal/stress simulation tools for Power Handling
Typical Microwave Components/Modules in LTCC

- Resonators
- Couplers
- Filters
- Power Splitters/Combiners
- Mixers
- Amplifiers
- Matching Networks
- T/R Modules
- Sensor Modules
- Multifunction modules for Radar/EW/Communications etc.
- Automotive Radars & Vehicle Control
- GPS Units
Microwave Components in LTCC

3.4 PLANAR MICROSTRIP RESONANT STRUCTURES

(a) Linear resonator with tuning elements. (b) Equivalent circuit of microstrip resonator with tuning varactor diodes.
Microwave Components in LTCC

(a) Single-section branch-line coupler (b) circular form of branch-line coupler

Hybrid Ring.
Microwave Components in LTCC

Lange coupler

Multisection Wilkinson coupler
Microwave Components in LTCC

Tapped-line filter configurations: (a) interdigital; (b) combline; (c) hairpin line; (d) parallel coupled

Two-pole filter: (a) Schematic and (b) physical layout. Dimensions in µm.
Microwave Components in LTCC

Physical Layouts of cross-coupled microstrip filters: (a) cascaded quadruplet; (b) trisection. All dimensions are calculated for an alumina substrate $\varepsilon_r = 10.8$ and thickness of 1.27 mm.

Five-section interdigital filter.
Microwave Components in LTCC

Example of practical 12-GHz image-and-sum enhanced single-ended mixer realized in microstrip. (Courtesy of E.J. Denlinger, David Sarnoff Research Center.)
Recent Advances

Laser Ablation
- Uses UV laser to achieve high tolerance patterning process on LTCC
- 1 mil line widths/spacing, compared to 4/5 mils—screen printing
  - Significant for performance improvement
  - Allows for higher frequency operations/designs.
  - Allows passive components with unique characteristics
  - Enables flip chip attachment of MMICs—bump pitches < 6 mils.
High gold prices driving technology to use silver and other metals

- Both DuPont and Ferro have Silver Material Sets
- Concerns relate to Silver Migration, Kirkendall voiding and Silver tarnishing
- Issue minimized by encapsulation in inner layers, with Ni/Pd/Au plating on exposed silver metallization
- NATEL’s processes qualified to MIL-STD-883
  - Eliminates possibility to differential diffusion between silver and gold.
Conclusion

- LTCC is a proven technology for the fabrication of microwave components, modules and multifunction circuits
- NATEL has built circuits up to 60 GHz
- NATEL can build using any vendor material system
- As processes and material systems improve, microwave/millimeter components in LTCC will move to higher frequencies with enhanced performance