IV. 2 Frequently Asked Questions for Printed Circuit Board fabricators: Answers from 3M

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Describe thin core product

Physical:
- Dielectric Material: Epoxy loaded with barium titanate
- Dielectric Thickness: 8 um (0.3 mils) (standard)
- Dielectric Thickness Uniformity: 10%
- Copper Thickness: 35 um (1.4 mils) (standard)
- Copper Thickness Uniformity: 5%
- Material Width: Up to 18.5 inches

Electrical:
- Capacitance/Unit Area: 10 nF/in$^2$ +/- 10% (25C/1 kHz)
- Dissipation Factor: 0.005 (25C/1 kHz)
- Frequency: >5 GHz
- Breakdown Voltage: >50 Volts
- DC Leakage Current: <10 nanoamps/in$^2$ (at ≤15V)
- Operating Temperature: -40°C – 125°C (“X7R” behavior over this range)

Experience

Volumes run to date: Pilot Scale

Yield data: Not Optimized (Pre-Commercial)

Lessons learned: Proprietary

Obstacles to implementation:
- Design tools, simulation ability, major OEM qualification, regulatory (UL) qualification, established test standards and PCB processes
**Key schedule milestones**

Availability; Time to:

Samples for Engineering/Verification: 
Currently available

Small runs: Based on sample feedback and completion of business model

Volume: Based on sample feedback and completion of business model

**Anticipated cost per square foot (delivered price to PCB fabricator)**

Near future, Intermediate, Longer term:
Business model to be determined

**Reliability testing results (materials):**

Tests Performed on C-Ply Printed Circuit Boards:

ENVIRONMENTAL/RELIABILITY

Thermal Shock/Thermal Cycle
Elevated Temperature and/or Humidity*
Temp, Humidity, Bias (THB)*
ESD

ADHESION

Multiple Solder Reflow
Solder Shock/Solder Stress
TMA 260C
Mechanical (Bend Test)

No significant issues with any of the above tests
*(C-Ply is epoxy based and absorbs a low level of water similar to FR-4 materials)*

**Agency or regulatory approvals:**

Necessary: UL Recognition at laminate level for flammability and maximum operating temperature (MOT)

Complete: Testing for flammability (V-0 results); Testing for Provisional MOT (~130C test results)

**Formal UL recognition:** Flammability - Q1 2002; Final MOT - Q2 2002
3M Embedded Capacitor Material

This presentation will focus on the advantages of embedded capacitor materials and in particular, the advantages of 3M’s embedded capacitor material.

The benefits of embedding a capacitor layer into a printed circuit board or other electronic package are: 1) increased packaging density (or correspondingly a decrease in size and/or number of layers); 2) improved electrical performance (lower power bus noise and EMI) due to lower inductance; and 3) improved reliability due to a reduction in solder joints. When the above benefits are coupled with a reduction in the costs of the capacitors and their placement, the overall goal of a more reliable, better performing, cost-effective capacitor material should be the result.

3M’s embedded capacitor material (3M C-Ply) consists of an epoxy/ceramic dielectric sandwiched between two layers of copper. The dielectric is solution coated very thin (for high capacitance) on copper foil (typically 1.4 mil in thickness). The coating is done in a high-speed roll-to-roll process. Two sheets of coated material are then laminated (dielectric-to-dielectric) to produce the final product.

The embedded capacitor material properties include high capacitance (10 – 20 nF/in²), low loss, an operating frequency of at least 5 gigahertz and an operating temperature of up to ~125C (“X7R” behavior over this range). It has been successfully incorporated into printed circuit boards (rigid and flex) and can be easily incorporated into other electronic packages. It has been found to be compatible with all PCB processing including laser ablation. It has been shown to greatly reduce power bus noise, much better than discrete decoupling capacitors or existing embedded capacitor materials. It has also been shown to reduce EMI.

Outline

• Material Technology and History
• PCB Processing
• Basic Electrical and Material Properties
• Environmental Data
• High-Frequency Electrical Data
• Summary
### Thin-Film Capacitor Technology

<table>
<thead>
<tr>
<th>Electrode (Cu)</th>
<th>Dielectric (k)</th>
<th>Thickness (t)</th>
<th>Electrode (Cu)</th>
</tr>
</thead>
</table>

- Capacitance per unit area (C/A) is proportional to \( k \) and inversely proportional to \( t \)
- 3M uses a very thin layer (<25 microns) of a precision coated loaded polymer
- Vary C/A by varying thickness (t)

### History of Embedded Capacitors at 3M

- **1996 - 1999** DARPA Program
- **1998 - 2000** NCMS Embedded Decoupling Capacitance (EDC)
- **1999 -** NIST ATP Embedded Passives
PCB Processing

Pattern Capacitors

Supply panels up to 18.5” wide

Laminate into PCB

C-Ply layer

Board Cross Section

Material Property Goals

<table>
<thead>
<tr>
<th>Attribute</th>
<th>8 micron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacitance/area</td>
<td>10 nF/in²</td>
</tr>
<tr>
<td>Adhesion (1” peel)</td>
<td>&gt;4 lbs.</td>
</tr>
<tr>
<td>T260 Life</td>
<td>&gt;5 mins.</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>16</td>
</tr>
<tr>
<td>Freq., Volt., Temp.</td>
<td>meet X7R</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>~130 V/mm</td>
</tr>
<tr>
<td>Breakdown</td>
<td>&gt;50 V</td>
</tr>
<tr>
<td>Tolerances</td>
<td>10%</td>
</tr>
<tr>
<td>Copper Thickness</td>
<td>35 μm</td>
</tr>
</tbody>
</table>

Focus is currently on an 8 micron dielectric although other thickness’ can be produced
### Environmental Testing

<table>
<thead>
<tr>
<th>Test</th>
<th>Property</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Temp (125°C)</strong></td>
<td>Capacitance</td>
<td>No Change (1000 hrs)</td>
</tr>
<tr>
<td><strong>Thermal Cycle</strong></td>
<td>Capacitance</td>
<td>No Change (1000 cycles)</td>
</tr>
<tr>
<td><strong>High Humidity (85°C/85% RH)</strong></td>
<td>Capacitance</td>
<td>5-15% Increase*</td>
</tr>
<tr>
<td></td>
<td>Dissipation Factor</td>
<td>0.4% to 0.9%*</td>
</tr>
<tr>
<td><strong>TMA (T260)</strong></td>
<td>Life</td>
<td>&gt;5 minutes**</td>
</tr>
<tr>
<td><strong>THB</strong></td>
<td>Life</td>
<td>&gt;1000 hrs (15 V)</td>
</tr>
<tr>
<td><strong>ESD</strong></td>
<td>Short Capacitance</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No Change</td>
</tr>
<tr>
<td><strong>UL Approval</strong></td>
<td>Various</td>
<td>In Process</td>
</tr>
</tbody>
</table>

*Returned to pre-test level after 125C bake

### Power Bus Noise (UMR data)

(Time Domain - 50 MHz)

Data from NCMS Embedded Decoupling Capacitance Project Report - 12/00
Power Bus Noise on Test Vehicle (UMR)

- Traditional decoupling capacitors are not effective at frequencies above 1 GHz
- C-Ply layer has excellent performance to 5 GHz

Data from NCMS Embedded Decoupling Capacitance Project Report - 12/00

3M Embedded Capacitor Material

- Builds on the experience and interaction gained from three industry consortia (DARPA, EDC and AEPT)
- Performs well as a distributed power/ground layer, also can produce singulated and isolated capacitors
- Passes basic environmental tests
- Cost effective for high component density, high speed, and size constrained designs