High Frequency Packaging
and RF Devices

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Quantum Leap Packaging, Inc
September 16, 2008
Outline

- Company Background
- Current Packaging Material Technology
- Enabling Material and Packaging Technologies
- Performance & Reliability Data
- Next Generation Film
- Summary
Company Background

- Founded December 2002
- Headquartered in Wilmington, Massachusetts
  - 32,000 sq. ft. manufacturing facility in Wilmington, MA
  - 20,000 sq. ft. manufacturing facility in Poway, CA
- Venture Capital:
- Strategic Investor:
- Strategic Partnerships
  - DuPont
  - CMC Interconnect Technologies
  - Customer Joint Development
- Materials Company with first products in semiconductor packaging
High Frequency Power Amplifiers
LDMOS Base Station Transistors

Design Trends:
- Increased Power > 300 W
- Higher Frequencies up to 6 GHz
- Device Integration

Drive:
- Greater Thermal Performance
- Lower Dielectric Constant
- Multi-component, multi-lead Package

- Other Applications: Driving frequencies up to 100Ghz
LDMOS Base Station Transistors
Current LDMOS Packaging

- Ceramic Lid and Body
- Heat Sink/Flange Alloy:
  - Match CTE to ceramic body
  - Minimize stress with ceramic body and Si device
- Highly Reliable Construction
  - MIL-STD-883E
  - Gross Leak
- Key Limitations:
  - Thermal Conductivity
  - Multi-lead Device Integration
  - Cost

<table>
<thead>
<tr>
<th>Package</th>
<th>Material</th>
<th>CTE (ppm)</th>
<th>Thermal (Wm/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body &amp; Lid</td>
<td>Ceramic</td>
<td>5.7 – 8.1</td>
<td>~</td>
</tr>
<tr>
<td>Heat sink/Flange</td>
<td>CuW</td>
<td>6.5 – 7.2</td>
<td>180 - 200</td>
</tr>
<tr>
<td></td>
<td>CuMoCu (CMC)</td>
<td>5.7 – 9.5</td>
<td>210 – 220</td>
</tr>
<tr>
<td></td>
<td>CuCuMoCu (CPC)</td>
<td>7.2 – 9.0</td>
<td>220-240</td>
</tr>
</tbody>
</table>
Alternative Packaging Solutions

- **Organic Body**
  - LCP ➔ anisotropic, low temp (not capable of eutectic die attach), poor adhesion to metal
  - Epoxy ➔ non-linear, poor moisture resistance
  - Others: PTFE, PEEK ➔ Limitations on temperature, adhesion.

- **Flange Materials**
  - Cu ➔ Stress @ die level
  - AlSiC, Metal Carbon Fiber composites ➔ cost
QLP Approach

Enabling Technologies

- **Material**: solves limitations of previous materials
  - Adhesion directly to copper
  - High Temperature, > 400°C die attach
  - Isotropic properties

- **Copper Technology**
  - High Thermal conductivity
  - Manages stresses between Si-Cu
  - Flatness control

- **Full Body package**
  - Injection molded
  - Leads/flange molded in simultaneously
  - Eliminates Assembly Steps & Improves Flatness

- **Lid**
  - B-stage epoxy (provided as drop-in)
    - Gross Leak
  - Improved → Ultrasonic welding
    - Fine Leak

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IMAPS ATW on RF and Microwave Packaging
Extension to Multiple Leaded Packages—Enables Integration

Multi-Lead QFN
New Molecular Structure:
- Isotropic Properties
- High Temperature Stability (500°C)
- Ability to Manipulate Material Properties
  - Control of Mechanical Properties, CTE
  - Tailored Electrical Properties
- Excellent Adhesion to Metal Leadframes and Flanges
- Outstanding Moisture Resistance
- Injection moldable and Extrudedable
• Traditional LCPs are Anisotropic
  • CTE MD~8 ppm/°C, CTE TD >80 ppm/°C

**Flow Direction**

**Cross-Flow Direction**

<table>
<thead>
<tr>
<th>Clte</th>
<th>-30 to 30</th>
<th>-30-100</th>
<th>Pts</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLTE</td>
<td>1.07E-05</td>
<td>1.21E-05</td>
<td>1.19E-05</td>
</tr>
</tbody>
</table>
Permeability Comparable to Glass
High Temperature Stability
AuSi Die Attach 430°C

TGA
Stability to 500°C

DMA (-200°C – 500°C)
Enabling Technology: Quantech™ Adhesion

Adhesion to Metal

Cohesive attachment of LCP—Copper
Traditional LCPs don’t bond to metals

Adhesion to Glass

IMAPS ATW on RF and Microwave Packaging
Reliability Lead Pull Tests
RF Power Amplifier

Instron Testing

- Withstand 100 lb RF Test Fixture
- Withstand assembly loads
- Lead Deflection testing
- Bolt Down
- MSL1 –for lead free solder
## Reliability

**Lead pull force and Comparison**

<table>
<thead>
<tr>
<th>Material</th>
<th>Max pull load</th>
<th>Visual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generic LCP</td>
<td>32 lbs</td>
<td>No LCP to Cu adhesion</td>
</tr>
<tr>
<td>Quantech</td>
<td>100 lbs</td>
<td>Excellent LCP to Cu adhesion</td>
</tr>
</tbody>
</table>

No Degradation after aging (1000 L-L cycles)

<table>
<thead>
<tr>
<th>T = 0</th>
<th>T = 1000 Cycles</th>
</tr>
</thead>
</table>

**Images:**
- Commercial LCP: NO Cu to LCP adhesion
- Cohesive Quantech LCP Cu bond

**Graphs:**
- Load vs. Extension curves for different temperatures.

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IMAPS ATW on RF and Microwave Packaging
Enabling Interface Technology
Hermeticity – Enables Multi-leads

Traditional LCP Issues:
Adhesion and Hermetic Properties

QLP Quantech™ Package

- No dye leakage @ Interface
- No Leakage @ Lead Interface
Quantech™ LDMOS Package
Enabling Technology: Copper Flange

- Organic Lid and Body
  - Quantech™ Matched CTE to Cu

- Cu Heat Sink/Flange
  - Higher Thermal Conductivity
  - Proprietary Low Stress Layer to manage Si-Cu stress

- Robust & Reliable Construction
  - MIL-STD-883E
  - Gross Leak & Fine Leak

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**Comparison Table**

<table>
<thead>
<tr>
<th>Package</th>
<th>Material</th>
<th>CTE (ppm)</th>
<th>Thermal (Wm/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body &amp; Lid</td>
<td>Quantech™</td>
<td>15 - 17</td>
<td>~</td>
</tr>
<tr>
<td>Heat sink/Flange</td>
<td>Cu</td>
<td>17</td>
<td>360 - 390</td>
</tr>
</tbody>
</table>

>70% Thermal Improvement

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**Thermal Conductivity (Wm/K)**

- CuW
- CMC
- CPC
- Cu

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IMAPS ATW on RF and Microwave Packaging
Managing Cu-Si Stress
QLP Proprietary Cu Technology

- Si-Cu CTE Mismatch
  - Si Device = 2.8 ppm/°C
  - Cu = 17 ppm/°C
- Die Crack and Failure
- Poor Reliability Performance

QLP “Low Stress” Cu Flange Technology
- Manages stresses
- Maintains flange convexity
- Enables Higher Thermal Conductivity
- Maintains Long Term Reliability
- 15 points measured across back side of flange

- Positive flatness values indicate convex part

- Summary of Flatness Measurements
  - Little change through processing
  - Final flatness - favors bolt down and good contact between heat sink and board

<table>
<thead>
<tr>
<th></th>
<th>Before die attach</th>
<th>After die attach</th>
<th>After ceramic lid attach</th>
<th>After LCP lid attach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center</td>
<td>1.6</td>
<td>1.5</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>Left ear</td>
<td>-0.5</td>
<td>-0.6</td>
<td>-1.0</td>
<td>-0.9</td>
</tr>
<tr>
<td>Right ear</td>
<td>-0.7</td>
<td>-0.8</td>
<td>-1.1</td>
<td>-0.9</td>
</tr>
</tbody>
</table>
## Reliability

### Military Power Package

#### Customer A

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Result</th>
<th>MIL-STD-883E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Parts</td>
<td>49</td>
<td>1014.9</td>
</tr>
<tr>
<td>Initial Gross Leak Test</td>
<td>49/49 Pass</td>
<td></td>
</tr>
<tr>
<td>Initial Fine Leak Test (&lt;5 x 10^{-8} atm cc/s)</td>
<td>47/47 Pass*</td>
<td></td>
</tr>
<tr>
<td>500 Temp Cycles (-40°C to +125°C)</td>
<td>45/45 Pass*</td>
<td></td>
</tr>
<tr>
<td>1000 Temp Cycles (-40°C to +125°C)</td>
<td>21/21 Pass</td>
<td></td>
</tr>
</tbody>
</table>

#### Customer B

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Result</th>
<th>MIL-STD-883E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Gross Leak Test</td>
<td>40/40 Pass</td>
<td></td>
</tr>
<tr>
<td>Initial Fine Leak Rate Test (&lt;1 x 10^{-9} cc-atm/sec)</td>
<td>40/40 Pass</td>
<td></td>
</tr>
<tr>
<td>250 Temp Cycles (-50°C to +150°C)</td>
<td>5 pcs. (1 x 10^{-11} cc-atm/sec) Radioisotope Krypton 85 method by customer</td>
<td></td>
</tr>
<tr>
<td>500 Temp Cycles (-50°C to +150°C)</td>
<td>5 pcs (&lt;5 x 10^{-8} cc-atm/sec) MIL-STD-883E He Leak Test by customer</td>
<td></td>
</tr>
<tr>
<td>PIND Test</td>
<td>10/10 Pass</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MIL-STD-883E Customer</td>
</tr>
</tbody>
</table>
Package Performance

Quantech™ Cu Flange Technology

- 12°C Lower Junction Temperature vs CuW Flange
- Each °C improvement ≈ 1 year longer life
- 3 – 5% Efficiency Improvement over CuMoCu
  - Improved Reliability and Longer Life
  - Lower Current Draw
  - Greater Device Performance

<table>
<thead>
<tr>
<th></th>
<th>QLP Package (Cu Flange)</th>
<th>Standard Ceramic Package (CuW Flange)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{Flange}}$</td>
<td>70°C</td>
<td>70°C</td>
</tr>
<tr>
<td>$T_{\text{Junction}}$</td>
<td>116°C</td>
<td>128.1°C</td>
</tr>
<tr>
<td>$V_{cs}$ or $V_{ds}$</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>$I_c$ or $I_d$</td>
<td>5.1</td>
<td>5.07</td>
</tr>
<tr>
<td>$P_{\text{dis}}$</td>
<td>142.8</td>
<td>141.96</td>
</tr>
<tr>
<td>$\theta_{jc}$</td>
<td>.32</td>
<td>.41</td>
</tr>
</tbody>
</table>
- Lead frame design limitations for High Frequency
- Higher frequency and other applications require multi-layer technology

QLP materials development for multilayer organic packages.
- 100 GHz applications
- Low Dielectric Constant
- High Adhesion
- High Temp Stability
- Isotropic & Tailored CTE
## High Frequency Films

### Specifications

<table>
<thead>
<tr>
<th>Dielectric Film Properties</th>
<th>Target Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Absorption (% 1 hr, 100°C)</td>
<td>&lt; .05%</td>
</tr>
<tr>
<td>DK &gt; 10 Ghz</td>
<td>3.2</td>
</tr>
<tr>
<td>Df &gt; 1 Ghz</td>
<td>.002</td>
</tr>
<tr>
<td>Flammability Rating (bromine/Halogen free)</td>
<td>UL 94 V-0</td>
</tr>
<tr>
<td>Film and sheet thickness</td>
<td>50 ~ 500um (2 ~ 20 mils)</td>
</tr>
<tr>
<td>Film Thickness Tolerance</td>
<td>+/- 5%</td>
</tr>
<tr>
<td>CTE (X,Y)</td>
<td>Adjustable 10- 40 ppm/°C</td>
</tr>
<tr>
<td>CTE (Z)</td>
<td>&lt; 40 ppm/°C</td>
</tr>
<tr>
<td>Film HDT</td>
<td>320°C</td>
</tr>
<tr>
<td>Thermal Stability</td>
<td>Lead Free solder</td>
</tr>
<tr>
<td>Copper Peel Strength</td>
<td>&gt; 5 lb/inch</td>
</tr>
</tbody>
</table>
Multiple layer QLP substrate

0.002" Dielectric

0.5 oz Cu

IMAPS ATW on RF and Microwave Packaging
SUMMARY

- QLP Materials and Process technology enables new generation of air cavity organic packages
  - Proven higher performance
  - Improved ownership costs
  - Matched reliability
- QLP’s Roadmap targets multilayer technology and addresses high frequency applications