Building-in Reliability into Power Modules

Chemnitzer Seminar 2019

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Trends in Power Electronics

Power density | Junction temperature | Reliability demand

Source: Infineon

Source: Infineon
Automotive applications – life time expectation

- 14 years life time
- 3000 max temperature cycling
- 15,000 starts (w/o start-stop)
- 200,000 max. accelerations
- 3,000,000 hard transistor switching
Life time expectation for modern applications

- How to verify the 20-25 years of service life required by the wind-energy industry for a liquid cooled power module setup
Two ways to improve the reliability in power module

- Better cooling
  - Lowering the Tj

- Better packaging technology
  - Bonding and joining
Power Module under Construction

- Wire bond interconnection frame to substrate
- Wire bond interconnection chip-chip & chip substrate
- Die soldering on substrate
- Wire bond interconnection substrate to substrate
- Solder layer, joining of substrate and base plate

Frame with terminals
Substrates DBC (Al₂O₃, AlN, Si₃N₄)
Cooler, forced air

Liquid Cooler ShowerPower®
Shower Power® direct liquid cooling for lowest Rth

• Shower Power® is a direct cooling technology for large power modules
• Eliminating the thermal interface material
• Offering high performance homogenous cooling at a low pressure drop
Power Module under Construction

Wire bond interconnection frame to substrate

Wire bond interconnection chip-chip & chip substrate

Die soldering on substrate

Wire bond interconnection substrate to substrate

Solder layer, joining of substrate and base plate

Frame with terminals

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Liquid Cooler ShowerPower®
First Solution: Sintering Technology

- operation temperature at least 200°C
- high reliability
- excellent electrical and thermal conductivity
- no liquid phase at joining process
- high mechanical strength
- lead-free technology
- pressure sintering 10 – 30 MPa

**Graph:**
- Liquidus [°C]
- Heat conductivity [W/mK]
- Electrical conductivity [MS/m]
- Tensile strength [MPa]

**Source:** Ch. Mertens

**TEM picture of sintered layer**

**Source:** Böttge IWM Halle
Large Area Sintering vs. Large Area Soldering after Temperature Cycling (-40°C – 125°C)

<table>
<thead>
<tr>
<th>Sintering</th>
<th>SAM-analysis</th>
<th>Soldering</th>
</tr>
</thead>
<tbody>
<tr>
<td>layer thickness</td>
<td>Cycles passed</td>
<td>layer thickness</td>
</tr>
<tr>
<td>50µm</td>
<td>500 cycles</td>
<td>100µm</td>
</tr>
<tr>
<td>50µm</td>
<td>1500 cycles</td>
<td>100µm</td>
</tr>
<tr>
<td>50µm</td>
<td>2000 cycles</td>
<td>100µm</td>
</tr>
<tr>
<td>200µm Solder</td>
<td>200 cycles</td>
<td>400µm Solder</td>
</tr>
<tr>
<td>200µm Solder</td>
<td>400 cycles</td>
<td>400µm Solder</td>
</tr>
<tr>
<td>200µm Solder</td>
<td>600 cycles</td>
<td>400µm Solder</td>
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</table>
Power Module under Construction

Frame with terminals
Substrates DBC ($\text{Al}_2\text{O}_3$, AlN, $\text{Si}_3\text{N}_4$)
Cooler, forced air

Wire bond interconnection frame to substrate
Wire bond interconnection chip-chip & chip substrate
Die soldering on substrate
Wire bond interconnection substrate to substrate
Solder layer, joining of substrate and base plate

Liquid Cooler ShowerPower®
Power Cycling Test – Solder and Ag-Sintering

Weibull data calculated from experimental results

Graph showing fail probability against cycles until 10% temperature rise or EOL:
- Green line: Sintering
- Blue line: Solder

Conditions:
- 50V – MOSFet
- 20mm², 140µm thick Si-die
- Ag sinter
- const. power
- Temp. 20°C/120°C
- 1s on / 5s off

Factor of about 2 better reliability for sintered die
Lower Tj with Ag-Sintering Layers

Simultaneous thermography of soldered and sintered chips

**Calculated Rth**

<table>
<thead>
<tr>
<th>Material</th>
<th>SnAg</th>
<th>Sinter.</th>
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</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>0.048</td>
<td>0.048</td>
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<tr>
<td>Solder NTV</td>
<td>0.026</td>
<td>0.002</td>
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<tr>
<td>Copper</td>
<td>0.010</td>
<td>0.01</td>
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<tr>
<td>AL2O3</td>
<td>0.165</td>
<td>0.166</td>
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<tr>
<td>Copper</td>
<td>0.007</td>
<td>0.007</td>
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<tr>
<td>Solder NTV</td>
<td>0.024</td>
<td>0.003</td>
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<tr>
<td>Copper</td>
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<td>Rth</td>
<td>0.350</td>
<td>0.309</td>
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<tr>
<td>ΔRth</td>
<td></td>
<td>13%</td>
</tr>
</tbody>
</table>

Current @ 90A

Time @ 1s
Power Module under Construction

- **Wire bond interconnection frame to substrate**
- **Wire bond interconnection chip-chip & chip substrate**
- **Die soldering on substrate**
- **Wire bond interconnection substrate to substrate**
- **Solder layer, joining of substrate and base plate**

**Frame with terminals**

**Substrates DBC**

\( \text{Al}_2\text{O}_3, \text{AlN, Si}_3\text{N}_4 \)

**Cooler, forced air**

**Liquid Cooler **

ShowerPower®
Combination of Sinter Technology and Cu Wire Bonding Leads to DBB® Technology

- **Al**-wire soldered die
- **Al**-wire sintered die
- **Cu**-wire on bond buffer sintered die
- **wire lift off**
- **solder degradation and wire lift off**

**reliability**

**technology improvements**
Cross Section – Silicon Die with DBB® Technology

- DBB foil
- Sinter layer
- Si die
- Cu wire
- Cu buffer
- Sinter layer
- Cu DCB

Pressure sintering process
Power cycling reliability @ $\Delta T = 130\text{K}$

Test parameter:
$\Delta T = 130\text{K}$
$T_{\text{min}} = 20°C$
$P = \text{const}$
$t_{\text{on}} = 1\text{s}$
$t_{\text{off}} = 10\text{s}$

Limit for standard technology
Coffin Manson Diagramm - DBB Results

Outstanding power cycling capability
Factor of 20 better reliability than standard technology

<table>
<thead>
<tr>
<th>Type</th>
<th>DBB 130</th>
<th>DBB 100</th>
<th>ST 130</th>
<th>ST 100</th>
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<tbody>
<tr>
<td>ton [s]</td>
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<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>toff [s]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Ipulse [A/cm²]</td>
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<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Tj,min [°C]</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
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<td>Tj,max [°C]</td>
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<td>120</td>
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<tr>
<td>DT [K]</td>
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<td>100</td>
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<tr>
<td>Tm [°C]</td>
<td>85</td>
<td>70</td>
<td>85</td>
<td>70</td>
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</table>
Conclusions

- Better cooling systems increase the reliability of power modules
- Better bonding and joining technology increase the reliability of power modules
- Extended lifetime is achieved by using sintering technique between silicon die and DBC substrate
- Heavy copper wires reduce the electrical resistance and improve the life time of power modules
- Combination of sintering technology and Cu wire bonding increases the reliability and leads to better products
Thank you for your attention