Power module technology with extended reliability for hybrid electric vehicle applications

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Power module technology with extended reliability for hybrid electric vehicle applications

Some results of the joint project „Electric Components for Active Gears“ (EfA), with financial support by German government (BMWi)
EfA: Power electronics cooled by cooling circuit of the combustion engine

Aim:
Use combustion engine coolant (105°C, worst case 125°C)

\[ T_{j\text{max}} = 200°C, \text{sufficient power cycling capability} \]
Weak points in packaging technologies to be addressed

- **Weak point 1:** Bond connection
- **Weak point 2:** Chip solder
- **Weak point 3:** Large area solder connection
- **Weak point 4:** Thermal grease
EfA: Electric Components for Active Gears

- reference standard modules
- improved bond interconnections (doped bond wires)
- different chip thickness
  \[ V = \begin{align*}
  600V & \text{ (chip thickness 70µm)} \\
  1200V & \text{ (chip thickness 120µm)} \\
  1700V & \text{ (chip thickness 180µm)}
  \end{align*} \]

Comparison with former work (CIPS 2008)

\[
N_f = K \cdot \Delta T_J^{\beta_1} \cdot e^{\left(\frac{\beta_2}{T_J+273}\right)} \cdot t_{on}^{\beta_3} \cdot I^{\beta_4} \cdot V^{\beta_5} \cdot D^{\beta_6} \quad (T_J = T_{\text{low}} \text{ in } ^\circ \text{C})
\]
EfA results #1

End-of-Life: $R_{th}$-increase.
Root cause: fatigue of chip solder

Improved bond wires alone: no increase of reliability at these conditions.
EfA results  #2

EfA results  #2

- Diffusion soldering
- all other production steps like standard modules

Test conditions:
\[ T_{\text{min}} = 75^\circ \text{C}; \quad T_{\text{max}} = 175..187^\circ \text{C}; \]
\[ t_{\text{on}} = 1..4\text{sec}; \quad t_{\text{off}} = 3..6\text{sec}; \]
\[ I_{\text{Load per bond foot}} = 9.4..12.5\text{A} \]
EfA results #2

All failures: Bond-Wire Lift-off

Diffusion soldering leads to a significant improvement (factor 3)

* 10^3 cycles

all tests with $T_{j min} = 75^\circ C$

Improved solder layer chip to substrate

Standard 600V power modules

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EfA results  #3

EfA results  #3
- diffusion soldering
- improved bond wires
- improved chip metallization

$T_{j\text{max}}$ 175°C

(exception $\Delta T > 130$K)
EfA results #3

Metallization variant 3, $\Delta T = 94K$, $T_{j_{\text{min}}} = 83^\circ C$, $t_{\text{on}} = 0.7s$

(only sample with End-of-Life)
EfA results #4

Standard: Al
Improved wire material, modified die metallization

Si

Standard: Sn-Ag solder
improved: diffusion solder

Cu, Al₂O₃, Cu (DCB)

Standard: Sn-Ag solder
improved: silver sinter technology

Standard: 3mm Cu without PinFin
improved: 5mm Cu with PinFin
Aim: stress to the interconnection Chip - DCB as well as to DCB - base plate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{\text{water_min}}$</td>
<td>22°C</td>
</tr>
<tr>
<td>$T_{\text{water_max}}$</td>
<td>122°C</td>
</tr>
<tr>
<td>$t_{\text{heating\ (passive)}}$</td>
<td>10min</td>
</tr>
<tr>
<td>$t_{\text{cooling\ (passive)}}$</td>
<td>5min</td>
</tr>
<tr>
<td>$I_{\text{Load}}$</td>
<td>220A</td>
</tr>
<tr>
<td>$t_{\text{on\ (active)}}$</td>
<td>2s</td>
</tr>
<tr>
<td>$t_{\text{off\ (active)}}$</td>
<td>4s</td>
</tr>
<tr>
<td>No of active cycles per passive cycle</td>
<td>100</td>
</tr>
<tr>
<td>$T_{\text{jmax\ (standard-module)}}$</td>
<td>175°C</td>
</tr>
<tr>
<td>$T_{\text{jmax\ (improved module)}}$</td>
<td>173°C</td>
</tr>
</tbody>
</table>
Standard technology: failure after 2,400 long cycles, caused by base plate solder layer.

New technology: no failure after 6,500 long and 650,000 short cycles.
EfA results #5

New solder process substrate to base plate. The new solder layer contains vertical intermetallic phases.

Further: improved bond wires, diffusion soldering identical EfA results #4

Test conditions: identical EfA results #4

Test after 2100 long cycles aborted for ultrasonic analysis
EfA results #5

System solder layer

Chip solder layer

Expected lifetime of this solder layer: > 6500 long cycles
Summary

Improved bond wires alone give no longer lifetime, considering the used conditions.

Improved chip solder layer (diffusion soldering), improved bond wires and improved metallization leads to a significant longer power cycling lifetime (factor 100 possible)

Additional improved substrate solder layer leads to a very high power cycling capability

The reached power cycling capability shows potential for use of power modules in the cooling circuit of the combustion engine, with $T_{j_{\text{max}}} = 200^\circ$C.

Packages with SiC devices require improved packaging technology


