SKiN: Double side sintering technology for new packages

Peter Beckedahl/Kevork Haddad
SKiN: Double side sintering technology

- Introduction
- SKiN Assembly Process
- Test Results
- Summary
Market Drivers for Power Modules

**Industry**

- Drives: Lower Cost
- Elevator: Reliability
- Power Supply: Efficiency

**Renewables**

- Size, Reliability

**Vehicles**

- Cost, Robustness, Weight, Size
Challenges for Power Module Packaging

- Higher operating temperatures
  - Better cooling
  - New materials
- New Chip Technologies
  - Wide Bandgap Devices
  - RC IGBT
  - Next gen. IGBT
- Reliability
  - Bond wires
  - Solder fatigue
- Integration
  - Electronics inside
Replace Solder by Diffusion Sintering

Pressure
Temperature

Chip
Ag layer
Substrate with gold flash surface

Ag sinter layer between chip and substrate

Si-Chip
Sinter layer
Substrate

20 µm

Ag layer before after sintering
Sinter Technology

<table>
<thead>
<tr>
<th>properties</th>
<th>solder layer SnAg(3)</th>
<th>Ag diffusion sinter layer</th>
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</thead>
<tbody>
<tr>
<td>melting temperature</td>
<td>°C</td>
<td>221</td>
</tr>
<tr>
<td>thermal conductivity</td>
<td>W/mK</td>
<td>70</td>
</tr>
<tr>
<td>electrical conductivity</td>
<td>MS/m</td>
<td>8</td>
</tr>
<tr>
<td>layer thickness</td>
<td>μm</td>
<td>~90</td>
</tr>
<tr>
<td>CTE</td>
<td>ppm/K</td>
<td>28</td>
</tr>
<tr>
<td>tensile strength</td>
<td>Mpa</td>
<td>30</td>
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</table>

@ 150 °C operating temperature

Unable to bear engineering loads
Creep area
Mechanical stable

Adhesion test
SKiN device cross section

- Flexible Circuit Board
- Via
- SMD
- DBC Substrate
- Power Chip
- Heatsink
- Sintering
SKiN: Die sintering to substrate

DBC, 5" x 7", plated

Ag paste, stencil printed

IGBTs & FWDs, sintered
SKiN device assembly

- DC / AC terminals
- IGBT FWD
- Ag paste
- chip position
- sensor
- gate
- Heat sink top side w/ Ag paste
- SKiN device
Assembled SKiN device

AC terminal

auxiliary terminals

DC terminals

IGBTs FWD

sintered SKiN on pin-fin cooler

SKiN Base Unit
# SKiN ® Half Bridge Modules

<table>
<thead>
<tr>
<th></th>
<th>1700V</th>
<th>1200V</th>
<th>650V</th>
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<tbody>
<tr>
<td>IGBT voltage</td>
<td>1700V</td>
<td>1200V</td>
<td>650V</td>
</tr>
<tr>
<td>DC link voltage</td>
<td>1300V</td>
<td>900V</td>
<td>450V</td>
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<tr>
<td>Current Rating</td>
<td>180A</td>
<td>200A</td>
<td>400A</td>
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<tr>
<td>ISO test voltage</td>
<td>5.6KV DC</td>
<td>4.2KV DC</td>
<td>3.5KV DC</td>
</tr>
<tr>
<td>IGBT</td>
<td>2 x 100mm²</td>
<td>2 x 100mm²</td>
<td>2 x 100mm²</td>
</tr>
<tr>
<td>Diode</td>
<td>1 x 120mm²</td>
<td>1 x 120mm²</td>
<td>1 x 120mm²</td>
</tr>
<tr>
<td>Heatsink</td>
<td>74 mm x 56 mm</td>
<td>74 mm x 56 mm</td>
<td>74 mm x 56 mm</td>
</tr>
</tbody>
</table>

![Diagram of SKiN ® Half Bridge Modules](image)
SKiN Process Line
SKiN Development Status

- Switching performance and inverter tests
- Inverters test @ 300V, 300A (110 kVA)
- Low stray inductance, no clamping, no snubber

Turn-off waveform of the BOT IGBT at 400V DC, 500 A. The peak voltage is 528 V

Measurement Setup
Electrical Test Results

3-Phase Inverter, 20 kW/dm³ Power Density
Thermal Test Results

- Chips are thermally decoupled
- Homogenous temperature distribution
- $R_{thja} = 0.44 \text{ Kcm}^2/\text{W}$ (35% less than conv.)

Schematic overview

Remove heat flexible circuit board
R\text{th}(j-a) Comparison (81mm² diode)

**SEMiX**
- R\text{th}(j-a)=1.25 K/W
- Chip + DCB + Base plate: 0.41 K/W
- Heatsink: 0.65 K/W

**SKiM**
- R\text{th}(j-a)=0.8 K/W
- Chip + DCB: 0.19 K/W
- TIM: 0.2 K/W

**SKiN**
- R\text{th}(j-a)=0.66 K/W
- Chip + DCB: 0.18 K/W
- TIM: 0.2 K/W

- Heatsink: 0.41 K/W

Pv(max) at dT(j-a)=100K:
- 80W (1 W/mm²)
- 125W (1.54 W/mm²)
- 151W (1.87 W/mm²)
Benchmark samples have identical chips and dimensions

Only difference:

Chip Top side contact sintered to flex foil

- Contact area IGBT ~50%
- Contact area Diode ~85%

Chip Top side contact with maximum amount of 300µm bond wires

- Contact area IGBT ~ 21%
- Contact area Diode ~ 21%
Thermal Resistance Measurement

- Thermal measurements 400A module samples
  - 10l/min, 70°C coolant, 50% glycol
- Excellent thermal resistance: $R_{th(j-a)} = 0.177 \text{K/W} @ 2\text{cm}^2$ chip area
- 225 W/cm$^2$ chip area losses at 150°C junction and 70°C coolant

![Differenzdruck @ 70°C, 50% Glykol](image)

![Measurement Setup](image)
Diode Surge Forward Current Measurement

- Half sine wave current surge of 10ms duration at 25°C
- $I_{FSM}$ rating of the flex layer module is 27% higher than the bond wire module
- Improvement possible due to the larger area top side contact and improved thermal spreading

$I_{FSM}$ comparison

<table>
<thead>
<tr>
<th>Sample</th>
<th>SKiN Module</th>
<th>Benchmark Module</th>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>539</td>
<td>Top 2666</td>
<td>Top 2092</td>
</tr>
<tr>
<td></td>
<td>Bot 2690</td>
<td>Bot 2108</td>
</tr>
<tr>
<td>540</td>
<td>Top 2691</td>
<td>Top 2105</td>
</tr>
<tr>
<td></td>
<td>Bot 2662</td>
<td>Bot 2096</td>
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<tr>
<td>550</td>
<td>Top 2696</td>
<td></td>
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<tr>
<td></td>
<td>Bot 2662</td>
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<tr>
<td>553</td>
<td>Top 2691</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bot 2656</td>
<td></td>
</tr>
</tbody>
</table>

|          | min 2656    | min 2092         |
|          | max 2696    | max 2108         |
|          | mean 2677   | mean 2100        |

Comparison 127% 100%
Power Cycling Test System

4 x 400Amp SKiN devices in parallel
Power Cycling Results

Test under constant power:
700 kcycles @ ΔT=110K
70 x improvement

Power cycling lifetime as a function of ΔT_j

ΔT_j [K]

cycles to failure

1E+8
1E+7
1E+6
1E+5
1E+4
1E+3

200,000

T_j,_{max} = 150°C

SKiN

SKiM

SEMITRANS

Standard
Chip Sinter
SKiN Specification
△ SKiN Test, EOL
△ SKiN Test, ongoing
Conclusions

- A Flexible Circuit Board replaces Bond Wires
- Sintering replaces all Solder / Grease Layers
- Direct Sintering to cooler: low thermal resistance
- Significant chip shrink and/or higher current
- Power Cycling capacity improves 70 x
- SKiN technology is suited for 200 °C ambient
Thank you