SiC Power Semiconductor Modules for 250 kW Converters
The next generation of e-mobility
ABB Switzerland, Semiconductors
Market expectations

**Strong demand**

Sales of electric vehicles are accelerating – despite of a still unfavorable cost situation.

**Strong commitment**

Increasing strong commitments from OEMs to introduce EV platforms.

Until 2030 more than 20M EVs will be sold p.a.
# Requirements

**Reliability**
Power electronic components will be exposed to harsh environmental conditions from arctic to tropic. At the heart of the propulsion system zero defects is a must.

**Lifetime**
Over the lifetime of the vehicle a very large number of power and temperature cycles needs to be achieved without altering the performance of the component.

**Driving Experience**
At all times the driver shall experience the unrivalled torque and smoothness of the electric propulsion system. ABB target is a module for 250 kW propulsion power.

**Efficiency**
Range is one of the main selling arguments for BEV. Power conversion efficiency has a substantial influence.

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*Wide range of requirements to be covered by a module platform*
**Temperature Changes**

- Full power may be required even at -40°C starting temperature – day by day.

- Special care for joining technologies. Sintering of chips and substrate where required.

- Validation: Temperature shock cycling
  - 1000x -40°C to 150°C, 5min

**Baseplate to substrate**

<table>
<thead>
<tr>
<th>Cu baseplate</th>
<th>AlSiC baseplate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cycles</td>
<td>0 cycles</td>
</tr>
<tr>
<td>500 cycles</td>
<td>500 cycles</td>
</tr>
<tr>
<td>1000 cycles</td>
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</tr>
</tbody>
</table>

**Chip joints**

<table>
<thead>
<tr>
<th>Die attach</th>
<th>Top plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cycles</td>
<td>Before cycling</td>
</tr>
<tr>
<td>500</td>
<td>After 400 cycles</td>
</tr>
<tr>
<td>1000</td>
<td>After 1000 cycles</td>
</tr>
<tr>
<td>1500</td>
<td>After 1500 cycles</td>
</tr>
</tbody>
</table>
Environment
Temperature and humidity

Humidity
- Components need to operate under humid condition
- Molded module – Careful choice of molding compound
- Validation:
  - TC: -40°C / 125°C 5 min.
  - TC: -5°C / 200°C 20 min.
  - HTRB (High Temperature Reverse Blocking) 200°C.
  - HS (High Temperature Storage) 200°C, 225°C
  - H3TRB (85°C, 85% rel. hum., 80% blocking voltage)

Careful choice of mold compound
Low stress to prevent delaminations
- Criteria: CTE mismatch x Youngs modulus
Molded structure after 1500h storage at 200°C:
  - Oxidized layer not to reach active areas

Results
Test structures after cycling
After storage

See PCIM 2019 conference paper “High-Power SiC and Si Module Platform for Automotive Traction Inverter” by Jürgen Schuderer et al.
Mission Profiles
Largely dependent on the driver and on the type of usage. The worst case has to be assumed: Short but heavy acceleration cycles followed by longer periods of low power requirements.

Validation:
Active cycling conditions (SiC version)
ton = toff = 1s, ΔT = 100K, Tjmax = 200°C

Technology
- Die sintered to Cu-SiN substrate.
- Cu – top plate sintered to chip
- Cu – bondwires (emitter)
- Al – bondwires (gate)
- Ultrasonic welded Cu terminals

Results
> 1 M cycles passed
> careful optimization of bond and interconnect processes to avoid SiC cracks
Driving experience

Why fast switching?

Fast switching allows for lower switching losses and therefore higher switching frequencies of ideally up to 20 kHz. The higher the switching frequencies the better the waveform that is provided to the motor and
• the lower the noise of the propulsion system
• the lower the cost and weight of any possibly required EMV filter

Commutation inductance

High switching speed causes overvoltages due to the commutation inductance to the new current path.
• At $\frac{dI}{dt} = 30 \text{kA/}\mu\text{s}$ a 6 nH commutation inductance causes 180 V peak overvoltage. Sustainable for 750V chips and 400V battery voltage.

<table>
<thead>
<tr>
<th>Source</th>
<th>Main self-inductance</th>
<th>HS gate inductance</th>
<th>LS gate inductance</th>
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<tbody>
<tr>
<td>Gen 2</td>
<td>6.2 nH</td>
<td>17 nH</td>
<td>23 nH</td>
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<tr>
<td>RoadPak</td>
<td>5.6 nH</td>
<td>16 nH</td>
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Coupling inductance

A large number of chips need to operate in parallel (e.g. 8 – 10 SiC chips for 900A AC current). Each gate bond represents a small transformer for the magnetic radiation resulting of the fast switching module.

<table>
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<tr>
<th>Chip</th>
<th>$M_{\text{chip}}$</th>
<th>$V_{\text{GS,ext}}$</th>
<th>module $\frac{dI}{dt}$</th>
<th>Distortion</th>
<th>$V_{\text{GS,chip}}$</th>
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<tr>
<td>Chip 1</td>
<td>$M_1 = -120 \text{pH}$</td>
<td>15 V</td>
<td>30 kA/\mu s</td>
<td>-3.6 V</td>
<td>$V_{\text{GS,1}} = 11.4 \text{V}$</td>
</tr>
<tr>
<td>Chip 2</td>
<td>$M_2 = +10 \text{pH}$</td>
<td>15 V</td>
<td>30 kA/\mu s</td>
<td>+0.3 V</td>
<td>$V_{\text{GS,2}} = 15.3 \text{V}$</td>
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Driving experience
Fast switching

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Coupling inductance
A large number of chips need to operate in parallel (e.g. 8 – 10 SiC chips for 900A AC current). Each gate contact represents a small transformer for the magnetic radiation resulting of the fast switching module.
• The lower the coupling inductances (and the more even they are distributed) the higher the current the module footprint can provide.
Driving Experience
Fast Switching

Turn On MOSFET 175°C

Turn Off (Body) Diode 175°C

Turn Off MOSFET 175°C

Turn Off MOSFET 25°C
**Driving experience**

**Output power**

**250 kW output**
- 900 A for 400V system
- 500 A for 800V system
- Tight requirement for inverter space

**Optimized PinFin cooling**
- \(< 100 \text{ mbar pressure drop}\) at 65°C, 10 l/min
- \(\Delta T_{\text{max}} < 10 \text{ K across parallel chips}\) (including chip-by-chip \(R_{\text{DSon}}\) variation)
- \(R_{\text{th}} = 0.06 \text{ K/W}\) (halfbridge module)

**Integrated heatsink**
- Target: leak tight laser welding to heatsink
- Tight process control required to avoid cracks

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*Simulated Gen 1 SiC module fluid-velocity magnitude (m/s); Coolant flow is from left to right*

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Integrated heatsink

- Target: leak tight laser welding to heatsink
- Option: sealing by gasket

See PCIM 2019 conference paper “High-Power SiC and Si Module Platform for Automotive Traction Inverter” by Jürgen Schuderer et al.
The difference between SiC- and Si- based power conversion sums up to 250 Wh while total consumption over the WLTP cycle is 5kWh. Use of SiC therefore saves 5% energy.

Depending on the incremental battery cost for long range EV the use of SiC based converters may help reducing overall system cost for a given range.

Assuming a confidence interval for future battery cost from 70 – 120 EUR / kWh, “break even” purely based on efficiency saving can be expected around 300 km range.
RoadPak e-Mobility power module platform covers a wide range of potential applications

- All standard environmental reliability requirements
- Can be operated with Silicon chipsets and SiC MOSFETs
- 250 kW output power at 400V or 800V battery voltage
- Joining techniques and materials used can be varied to best match the required mission profiles
Thanks for your attention!

**Your RoadPak**

Please collect your personal RoadPak module at our booth in Hall 9, booth no. 203

Download the presentation via [ABB PCIM event landing page](#)