E-MOBILITY FORUM

SVEN KLAKA, MAY 09, 2019

SiC Power Semiconductor Modules for 250 kW Converters

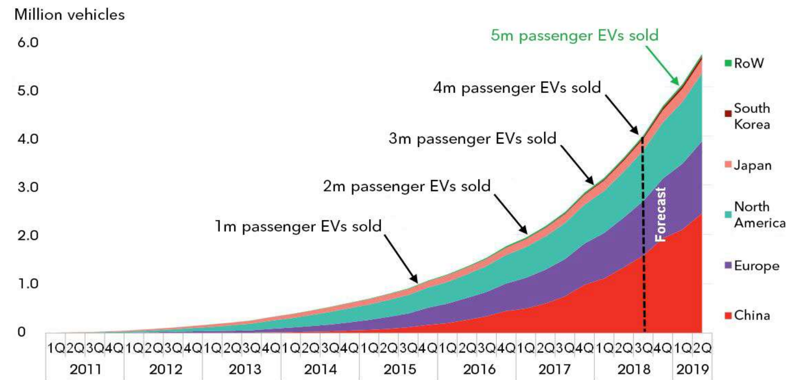
The next generation of e-mobility

ABB Switzerland, Semiconductors

Market expectations

Strong demand

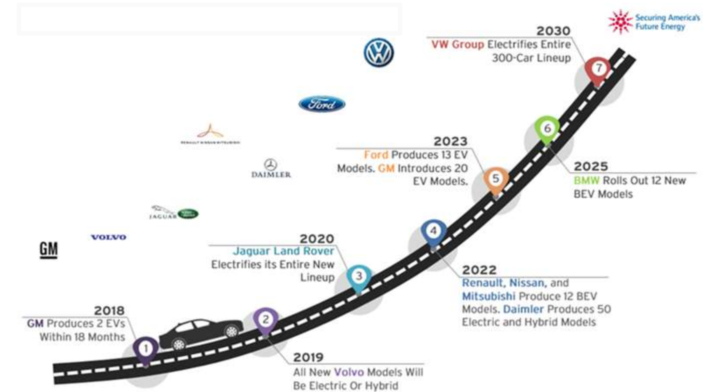
Sales of electric vehicles are accelerating – despite of a still unfavorable cost situation.



Source: Bloomberg NEF

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.

Wide range of requirements to be covered by a module platform

Environment

Temperature and humidity

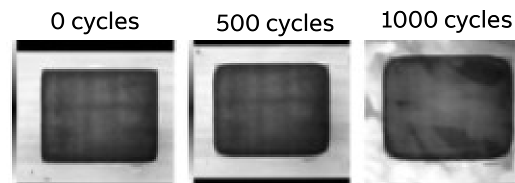
Temperature Changes

- 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

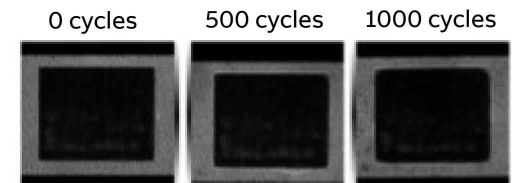
Cu baseplate

0 cycles 500 cycles 1000 cycles



AlSiC baseplate

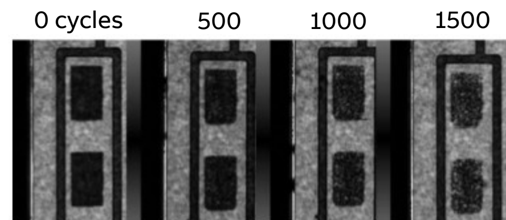
0 cycles 500 cycles 1000 cycles



Chip joints

Die attach

0 cycles 500 1000 1500



Top plate

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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 compund

Low stress to prevent delaminations

- Criteria: CTE mismatch x Youngs modulus

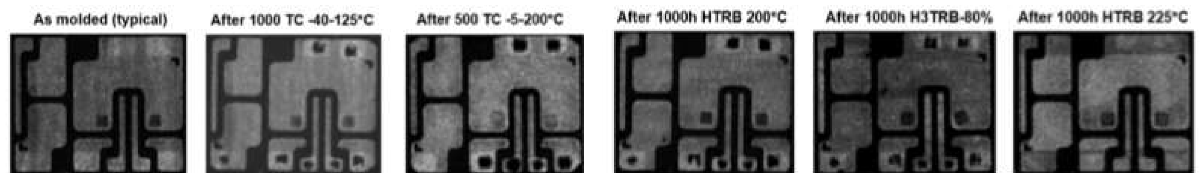
Molded structure after 1500h storage at 200°C:

- Oxidized layer not to reach active areas

Results

Test structures after cycling

After storage



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Lifetime

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

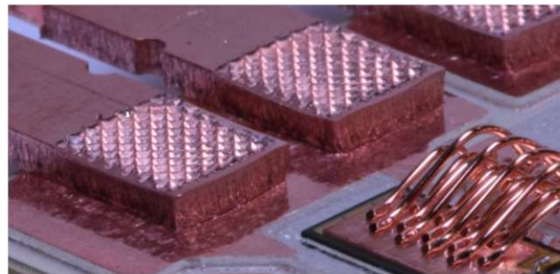
Die sintered to Cu-SiN substrate.

Cu – top plate sintered to chip

Cu – bondwires (emitter)

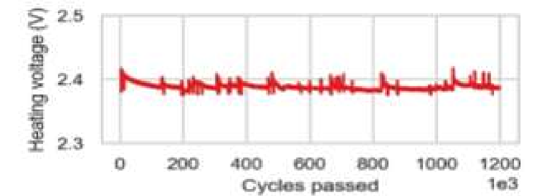
Al – bondwires (gate)

Ultrasonic welded Cu terminals



Results

> 1 M cycles passed



>careful optimization of bond and interconnect processes to avoid SiC cracks

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Driving experience

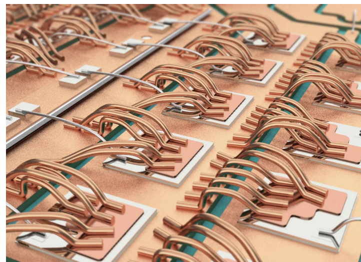
Fast switching

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 dI/dt = 30 kA/µs a 6 nH commutation inductance causes 180 V peak overvoltage. Sustainable for 750V chips and 400V battery voltage.

	Gen 2	RoadPak
Main self-inductance	6.2 nH	5.6 nH
HS gate inductance	17 nH	16 nH
LS gate inductance	23 nH	22 nH

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.

	M_{chip}	$V_{GS,ext}$	module dI/dt	Distortion	$V_{GS,chip}$
Chip 1	M_1 = -120 pH	15 V	30 kA/µs	-3.6 V	$V_{GS,1}$ = 11.4 V
Chip 2	M_2 = +10 pH	15 V	30 kA/µs	+0.3 V	$V_{GS,2}$ = 15.3 V

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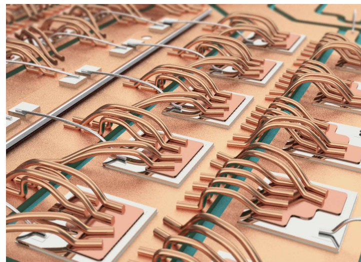

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- **The lower the commutation inductance the higher the current the module footprint can provide.**

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- **The lower the coupling inductances (and the more even they are distributed) the higher the current the module footprint can provide.**

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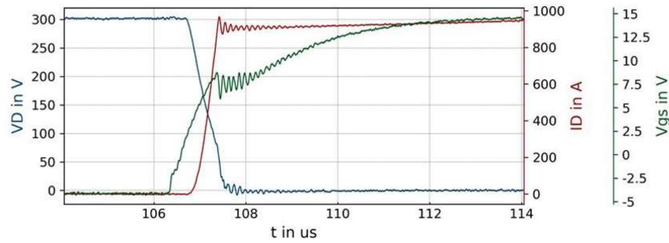
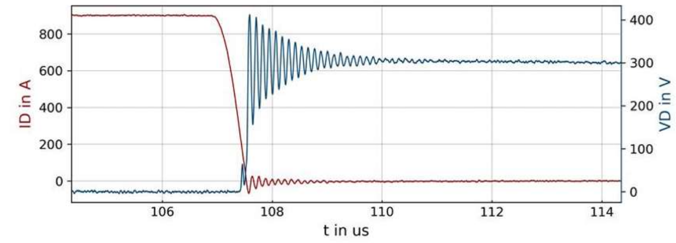
Driving Experience

Fast Switching

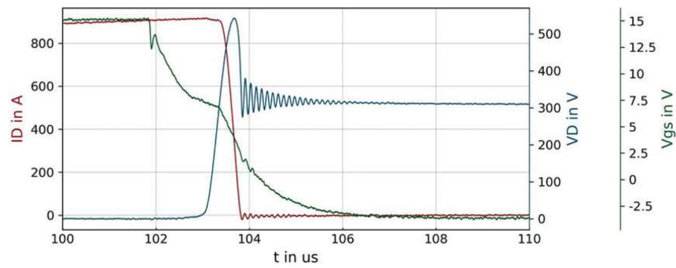
Turn On MOSFET 175°C



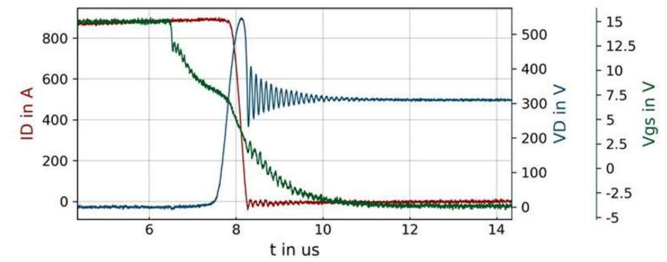
Turn Off (Body) Diode 175°C



Turn Off MOSFET 175°C



Turn Off MOSFET 25°C



Driving experience

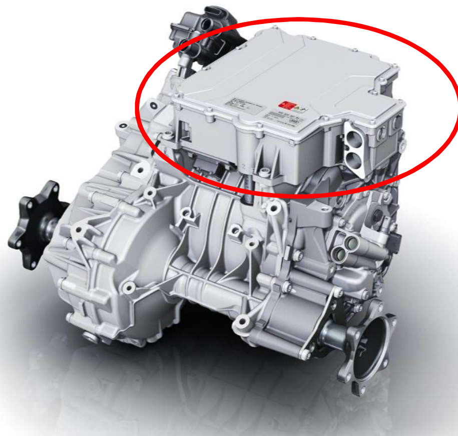
Output power

250 kW output

900 A for 400V system

500 A for 800V system

Tight requirement for inverter space

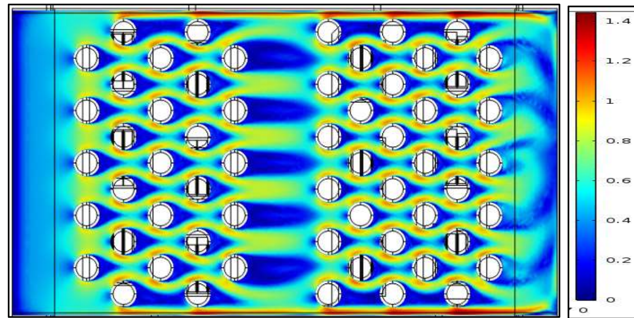


Optimized PinFin cooling

< 100 mbar pressure drop at 65°C, 10 l/min

ΔT_{max} < 10 K across parallel chips (including chip-by-chip R_{DSon} variation)

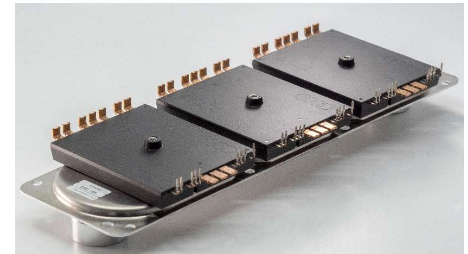
R_{th} = 0.06 K/W (halfbridge module)



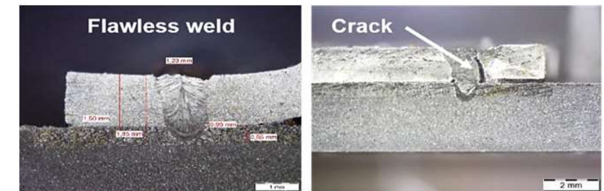
Simulated Gen 1 SiC module fluid-velocity magnitude (m/s); Coolant flow is from left to right

Integrated heatsink

Target: leak tight laser welding to heatsink



Tight process control required to avoid cracks



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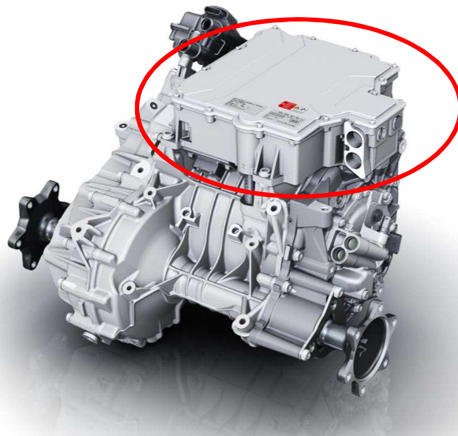

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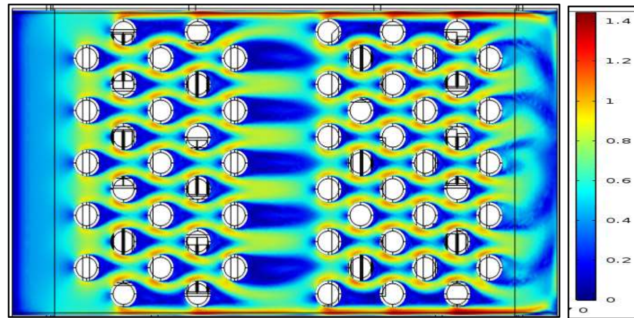

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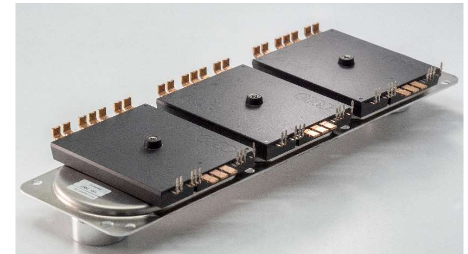
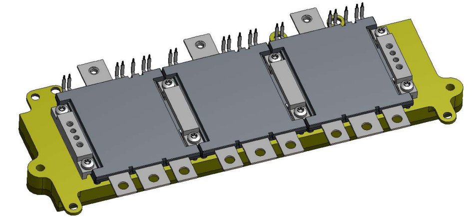


Option: sealing by gasket



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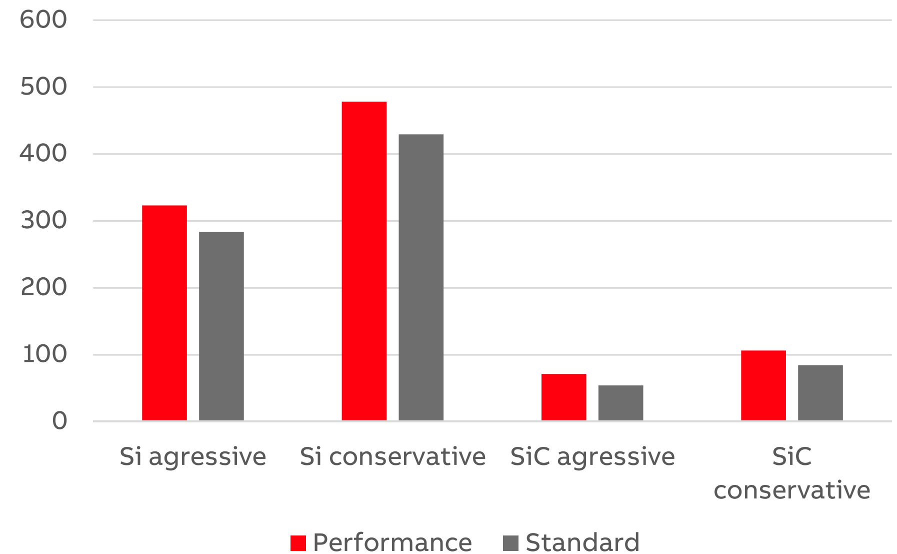
Efficiency

Power conversion vs system cost (Si or SiC ?)

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.



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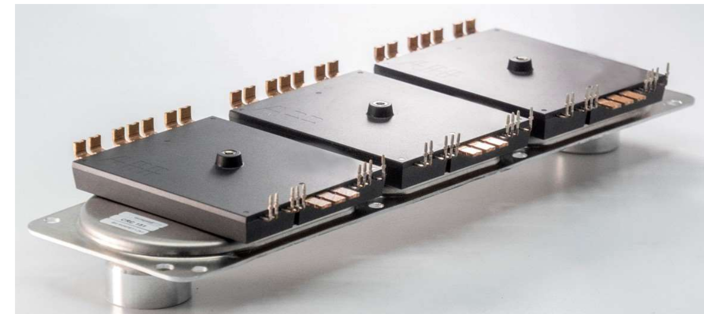
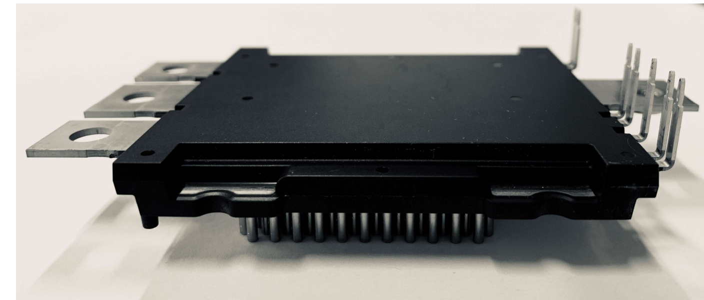
Conclusions

RoadPak e-Mobilty 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 misssion profiles





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Thanks for your attention!

Your RoadPak

Please collect your personal RoadPak module at our booth in

Hall 9, booth no. 203

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