HIGH PERFORMANCE COOLING AND LOW-INDUCTANCE BUSBAR-CAPACITOR SOLUTIONS FOR SiC INVERTER

PowerAmerica Annual Meeting – Raleigh, NC - Feb 2020
Mersen Solutions for SiC electronics

February 2020

Mersen in Brief
A France-headquartered traded company. Mersen USA Corp. in Rochester-NY

Sales
€950M

Staff
7,000

Geographies
- 33% North America
- 34% Europe
- 33% Asia and RotW

Advanced Materials
- Anticorrosion Equipment
- Graphite Specialties
- Power Transfer Technologies

Electrical Power
- Electrical Protection & Control
- Solutions for Power Management

*As of December 31, 2019
**Introduction:** Mersen is active all over the SiC value-chain

**Crystal Growth, Epitaxy and Power Conversion**

- **Crystal Growth:** Sublimation PVT reactors
- **Wafering Polishing:** SiC ingot “boule”
- **Epitaxy:** SiC Wafer
- **Wafer carriers:** SiC epi-wafer

**Graphite insulation & components**

**Front-End**

- Lithography, deposition, etching, implantation, metallization...
- Bare-die “chip” Diode, MOSFET, J-FET
- **Binning, pick-and-place** packaging, housing
- **Discrete** power module
- **Power Converter**

**Applications**

- Busbar, Cooling, Capacitors, Fuses....
Mersen has a comprehensive range of graphite and insulation solutions for SiC production

**Graphite crucible**
- contributes to the chemical composition of the single crystal
- controlled CTE, controlled reactivity with the gases, controlled thermal conductivity
- extreme purity (7N) of the graphite

**CALCARB® insulation**
- spatial consistency,
- low thermal conductivity at 2,400°C
- ability to be precision machined
- high purity

<table>
<thead>
<tr>
<th>Running temperature</th>
<th>Cycle duration</th>
<th>Ingot weight</th>
</tr>
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<tbody>
<tr>
<td>2,400°C +/- 2°C</td>
<td>3-5 days</td>
<td>5-10 kg</td>
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INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS

- **Full SiC @ 100kHz**
  - High power density specific cooling
  - Ultra-low induct. Busbar
  - Ultra-low induct. Fuses
  - High T° busbar & film caps

- **Full SiC @ 48kHz**
  - Advanced small dimension cooling
  - Low induct. Busbar
  - Low induct. Fuses
  - Film caps

- **Full SiC @ 24kHz**

- **Full SiC @ 16kHz**

- **Hybrid Si IGBT + SiC diode @ 16kHz**
  - Standard cooling
  - Cables or busbars
  - Standard caps
  - Standard fuses

- **Reference: Full Silicon: Si IGBT + Si diode @ 16kHz**

- **Small dimension cooling**
  - Laminated busbars
  - Advanced fuses
  - Advanced caps (film or elect.)

**Credit: ABB**
Addressing SiC Applications with Mersen Line of Products

- Low inductance [cap-bus bar] connection: Fischerlink™
- Cooling solutions for SiC applications
- High temperature Capacitors
- High temperature bus bar, 130°C and 180°C, Low Partial discharge, creepage and clearance up to 10kV. Mhi-Txx™ series
**Embedded Heat-Pipe: Pushing the limits of air cooled heat-sink**

~30% reduction in $T^\circ$ rise compared to standard Al heat-sink

- A heater block, simulating a power module, has been placed at the same location on 3 different heat sinks (Al+MeHP, Al and Cu) with same geometry. $T^\circ$ rise is measured at the heater location as a function of air velocity.

![Diagram showing temperature rise over ambient temperature for different materials](image)

<table>
<thead>
<tr>
<th>Material</th>
<th>Average $T^\circ$ rise</th>
<th>Cost comparison</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al blank</td>
<td>Ref = 1</td>
<td>Ref = 1</td>
<td>x 3.5</td>
</tr>
<tr>
<td>Cu blank</td>
<td>-23%</td>
<td>x 4</td>
<td>1</td>
</tr>
<tr>
<td>Al + MeHP</td>
<td>-30%</td>
<td>x 1.25</td>
<td>1</td>
</tr>
</tbody>
</table>
IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

NO HOT-SPOT ANYMORE!

BLANK HEATSINK

EMBEDDED HEAT PIPE MeHP

(INserted inside the Baseplate)
**IsoMAXXTM: THE ULTIMATE LIQUID COOLING SOLUTION FOR MODULES**

**No ΔT module-to-module, no ΔT chip-to-chip**

- **AN INNOVATING COUNTER-FLOW “WAVY SPIRAL” DESIGN, HAS BEEN DEVELOPED FOR IMPROVING THERMAL MANAGEMENT OF LATEST GENERATION OF Si & SiC POWER MODULES. IT OFFERS:**
  - **Better thermal performances:** $R_{th} \sim 6 \, ^\circ\text{C}/\text{kW}$
    (EG 50%, 250 mm modules, 3kW power losses and 5 liter/min per component.)
  - **Lower pressure drop** than all existing designs (~600mbar)
  - **Thermal homogeneity** chip-to-chip (all chips at the same $T^\circ$) and module-to-module on a multi-module cooling plate
  - **Compact design:** distance between modules can be optimized $\rightarrow$ Inverter size reduction
  - **Modular solution:** covers all PrimePACK™ types, whatever the number of modules on the plate
  - **Cost competitive** compared to others efficient designs

Homogeneity: < 2°C ΔT chip-to-chip
Pressure drop: 565 mbar

Homogeneity: no ΔT module-to-module

Homogeneity: no ΔT module-to-module
**Recent Trends in WBG Power Conversion**

_How to Reduce Stray Inductance While Increasing Overall Power Density and Junction $T^o$?_

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**New module design**

Power module makers are working on new designs for their power modules in order to stay competitive against press-packs for high-voltage devices. The most popular solution is reducing the distance between internal connections.

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**Use of external laminated busbar with low inductance connection**

Outside the module, using laminated busbar offers strong reduction of parasitic inductance.

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**Use of internal laminated busbar**

Along with the emergence of SiC, the switching frequency reaches several ten’s of kHz. Internal laminated bus bar can offer a real added-value to decrease the inductance while connecting the chips together.

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*Credit: CREE*
A PERFECT MATCHING [INSULATION – RESIN/GLUE]

- In order to perfectly match customer’s specifications, Mersen aims at selecting the right material (Insulation and Resin / Glue) with the highest Temperature, Voltage and Mechanical resistance, keeping insulation as thin as possible (to meet low inductance value requirements).

EXAMPLES OF MATERIAL SELECTION AND RELATED THICKNESS RANGE AS A FUNCTION OF MAX. OPERATING T°:

- PMMA
- PP
- PE
- PC (Lexan)
- PVDF (Kynar)
- PA6 (Nylon)
- PBI (Kapton Thick. 25 to 125 µm)
- Polyaramid (Nomex Thick. 50 to 250 µm)
- PAEK (Aptiv), PPS (Fortron), PTFE (Teflon)
- Polyester (Mylar Thick 38 to 330 µm)
- Silicone
- BMI
- Epoxy Thick. 12 to 20 µm
- Polyurethane
- Acrylic thick. 38 µm

MHi-Txx™ laminated Bus bar series: Ready for 105, 130 and now 180°C
**How to Decrease Clearance Distance in Power Module Design?**

*Conformal Bus Bar is an Enabler…*

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**Today’s Industry Standard**

*Figure 1: Top view of the bushings gap with tall insulating barrier and conformal bus bar design.*

**Step 1**

- Additional tall insulating barrier on power module housing

**Step 2**

- Removal of intermediate grooves

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**Gap between bushings can be significantly reduced → More compact module design**

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*Figure 2: Grooves for creepage distance compliance.*
**INDUCTANCE FUNDAMENTALS IN POWER CONVERTER DESIGN**

**HIGH INDUCTANCE CREATES VOLTAGE OVERSHOOT AND SURGE AT COMMUTATION**

CCL: Commutation current loop

**Turn-off waveform**

**ON**
- Short-circuit
- \( V_{ce} = 0 \text{ V} \)
- \( I_{ce} \neq 0 \text{ A} \)

**OFF**
- Open circuit
- \( V_{ce} \neq 0 \text{ V} \)
- \( I_{ce} = 0 \text{ A} \)

**Surge voltage**

\[
L_s = \text{inductance of CCL}
\]

\[
V_{CEO} = L_s \frac{di}{dt} + V_{CC}
\]
LOW-INDUCTANCE [BUS BAR-CAP] CONNECTION FOR SiC DC-LINK

**FISHERLink™**

- **Shorter connection of the cap winding to the busbar by direct connection of the winding tabs to the busbar by laser welding**
- **Up to +20% capacitance in a given volume** (e.g. from 400µF to 480µF @ 1100 Vdc | 4-cap assembly)
- **Extremely low inductance** <9nH
- **Capacitors and busbars packaged together as sub-assembly and single part #**
- **Pre-assembled and 100% tested before delivery → ready for final assembly**
INTERNAL LAMINATED BUSBAR FOR WBG POWER MODULES

SOLUTIONS TO HANDLE 180° Tj @ 100 KHz Fsw... AND BEYOND!

THE AIM:
- Get very low internal inductance by
  - laminated/symmetrical bus bar structure
  - Maximizing metallic conductor overlap
- 50% reduction in switching loss for higher switching frequency (> 20KHz)
- Safe turn-off possible at large current without snubber capacitor

THE ACHIEVEMENT
- Our bus bars can now handle up to 200°C Tj with inductance as low as 35nH and a lifetime operation of 25 years

Customer A
GaN module, 160°C Tj

Customer B
SiC 1,700 V module
150°C Tj

Customer C
SiC 1,200 V module
180°C Tj
SYNTHESIS AND CONCLUSION

- We are glad of being (finally 😊) part of Power America community!!
- Now that WBG have reached the expected maturity, at semiconductor level, it is commonly admitted that remaining issues relate to passive surrounding components (Caps, magnetics, connections, thermal management, fuse…)
- Mersen positions himself not only as a stand-alone components supplier but also as solution provider made of 2 or more components, co-designed and perfectly optimized together
- Let us know your circuit topology along with your physical, electrical, mechatronic, thermal, EMI constraints: we can definitely ease your journey in module and/or inverter design

Co-design & optimization