Microsemi SiC Products

James Kerr
Director of Marketing
Power Discrete Products
Microsemi Power Products

**MOSFETs (100V-1200V) Highest Performance**
- SiC MOSFETs 1200V
- MOSFETs
- FREDFETs (MOSFET with fast body diode)
- COOLMOS™ (Superjunction MOSFET)

**IGBTs (600V-1200V) Lowest Cost**
- PT (Punch-Thru) – short tail current
- NPT (Non Punch-Thru) – low switching losses and easy to parallel
- Field Stop – low conduction losses

**Diodes**
- SiC Schottky Diodes 650V, 1200V, and 1700V
- Si Fast Recovery Epitaxial Diodes “FRED” (200V-1200V)
- Si Schottky, low $V_F$ and fast switching (200V)
Silicon Carbide (SiC) Manufacturing
Microsemi SiC Wafer Fab located in Bend, Oregon USA

- Complete In-house process capability since 2007
- Current capacity of 200 wafers/week (100mm)
- 12 Issued SiC technology patents
- Over 1,000,000 SiC Schottky Diodes produced
- SiC MOSFETs and SiC Schottky Diodes
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>SiC vs. Si</th>
<th>Results</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Breakdown Field</td>
<td>10x Higher</td>
<td>Lower On-Resistance</td>
<td>Higher efficiency</td>
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<tr>
<td>Band Gap</td>
<td>3x Higher</td>
<td>Higher operating temperature</td>
<td>Improved cooling</td>
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<tr>
<td>Thermal conductivity</td>
<td>3x Higher</td>
<td>Higher power density</td>
<td>Higher current capabilities</td>
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<tr>
<td>Positive Temperature coefficient</td>
<td>-</td>
<td>Self regulation</td>
<td>Easy paralleling</td>
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<tr>
<td>Temperature Independent</td>
<td>-</td>
<td>Stable high temperature performance</td>
<td>Lower losses</td>
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<tr>
<td>switching behavior</td>
<td></td>
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<tr>
<td>Almost no Reverse Recovery</td>
<td>-</td>
<td>Lower switching losses</td>
<td>Higher performance</td>
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<td>Charge</td>
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<td>Higher switching capabilities</td>
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# Target Markets for SiC

<table>
<thead>
<tr>
<th>Markets</th>
<th>Applications</th>
<th>High Temp.</th>
<th>High Freq.</th>
<th>Small, Light System</th>
<th>Low Loss, Efficiency</th>
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<td>Aux. Power Supplies</td>
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<td>Fast Battery Charger</td>
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<td>UPS, SMPS</td>
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<td>Induction Heating</td>
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<td>Medical</td>
<td>MRI power supply</td>
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<td>X-Ray power supply</td>
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Microsemi SiC Schottky Diodes

### 650V SiC Schottky Diodes

<table>
<thead>
<tr>
<th>Volts</th>
<th>$I_{F(avg)}$ Amps</th>
<th>$V_F$ Volts</th>
<th>Part Number</th>
<th>Package</th>
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<tbody>
<tr>
<td>650</td>
<td>10</td>
<td>1.5</td>
<td>APT10SCD65K</td>
<td>TO-220</td>
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<tr>
<td></td>
<td>20</td>
<td>1.5</td>
<td>APT20SCD65K</td>
<td>TO-220</td>
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<tr>
<td></td>
<td>30</td>
<td>1.5</td>
<td>APT30SCD65B</td>
<td>TO-247</td>
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<tr>
<td>2 x 10</td>
<td>1.5</td>
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<td>APT10SCD65KCT</td>
<td>TO-220</td>
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### 1200V SiC Schottky Diodes

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<th>Volts</th>
<th>$I_{F(avg)}$ Amps</th>
<th>$V_F$ Volts</th>
<th>Part Number</th>
<th>Package</th>
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<tbody>
<tr>
<td>1200</td>
<td>10</td>
<td>1.5</td>
<td>APT10SCD120B</td>
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<td></td>
<td>1.5</td>
<td>APT10SCD120K</td>
<td>TO-220</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.5</td>
<td>APT20SCD120B</td>
<td>TO-247</td>
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<td></td>
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<td>1.5</td>
<td>APT20SCD120S</td>
<td>D³</td>
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<td>30</td>
<td>1.5</td>
<td>APT30SCD120B</td>
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<td>1.5</td>
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<td>2 x 10</td>
<td>1.5</td>
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<td>APT10SCD120BCT</td>
<td>TO-247</td>
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### 1700V SiC Schottky Diodes

<table>
<thead>
<tr>
<th>Volts</th>
<th>$I_{F(avg)}$ Amps</th>
<th>$V_F$ Volts</th>
<th>Part Number</th>
<th>Package</th>
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<tr>
<td>1700</td>
<td>10</td>
<td>1.5</td>
<td>APT10SCE170B</td>
<td>TO-247</td>
</tr>
</tbody>
</table>

### Future products

650V, 1200V, and 1700V 20A & 50A single chip design

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**Microsemi Advantages**

**Superior Passivation Technology**
leads to higher reliability. Microsemi thin film passivation applied in the wafer fab vs. competitors’ spin on passivation applied post wafer fab.

**Patented Technology**
Junction barrier structure has a lower $V_F$ than any equivalent die size (*due to larger Schottky area and buried P-Wells*).

**Microsemi SiC Wafer Fab**
SiC MOSETs are Designed and Manufactured at Microsemi’s SiC Wafer Fab in Bend, Oregon.
Customer Case Study – SiC Diode for Solar

Application
Solar Inverter – 3 level inverter, full bridge

Design Goal
Improve system reliability with new generation SiC Schottky Diode

Customer Options
- Microsemi’s New 1200V 10A SiC Schottky Diode
- Competitor's Incumbent 1200V 10A SiC Schottky Diode

Customer Solution
Microsemi’s New SiC Schottky Diode!

Microsemi Advantages
- Improved reliability in field trial. 5,000 tested in 6 month field trial with zero failures vs. previous supplier 2% per year failure rate
- Competitive price
- Strong customer support
SiC MOSFETs vs. IGBTs
Transistor Power Loss Comparison

(30kHz, 50% duty cycle, I_{LOAD}=15A, V_{OFF}=800V, T_{CASE}=80°C, T_{J}=125°C)

- **TFS IGBT**
  - Turn-off Losses
  - Turn-on Losses
  - Conduction Losses

- **PT IGBT**
  - Turn-off Losses
  - Turn-on Losses
  - Conduction Losses

- **NPT IGBT**
  - Turn-off Losses
  - Turn-on Losses
  - Conduction Losses

- **SiC MOSFET**
  - Turn-off Losses
  - Turn-on Losses
  - Conduction Losses

T_{J}=150°C
Max Switching Frequency vs. Current

(50% duty cycle, $V_{OFF} = 800V$, $T_{CASE} = 80^\circ C$, $T_J = 125^\circ C$)
Total Transistor Power Loss vs. Current

(30kHz, 50% duty cycle, $V_{OFF} = 800V$, $T_{CASE} = 80^\circ C$, $T_J = 125^\circ C$)

- SiC MOSFET ($T_J = 150^\circ C$)
- NPT IGBT
- TFS IGBT
- PT IGBT

Power Loss [W] vs. $I_{LOAD}$ [A]
Normalized Total Power Losses versus Current

(30kHz, 50% duty cycle, $V_{OFF}=800V$, $T_{CASE}=80^\circ C$, $T_J=125^\circ C$)
Microsemi SiC MOSFETs
# Microsemi SiC MOSFETs

## Product Roadmap

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Current</th>
<th>$R_{DS(ON)}$</th>
<th>Part Number</th>
<th>Package</th>
<th>Availability</th>
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</thead>
<tbody>
<tr>
<td>1200V</td>
<td>40A</td>
<td>80mΩ</td>
<td>APT40SM120B</td>
<td>TO-247</td>
<td>Available Now!</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APT40SM120S</td>
<td>D3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>APT40SM120J (32A)</td>
<td>SOT-227</td>
<td></td>
</tr>
<tr>
<td>1200V</td>
<td>20A</td>
<td>160mΩ</td>
<td>APT20SM120B</td>
<td>TO-247</td>
<td>December 2014</td>
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<td>APT20SM120S</td>
<td>D3</td>
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<tr>
<td>700V</td>
<td>50A</td>
<td>40mΩ</td>
<td>APT50SM70B</td>
<td>TO-247</td>
<td>December 2014</td>
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<td>APT50SM70S</td>
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<td>APT50SM70J</td>
<td>SOT-227</td>
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<td>1200V</td>
<td>80A</td>
<td>40mΩ</td>
<td>APT80SM120B</td>
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<td>February 2015</td>
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<td>APT80SM120S</td>
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<td></td>
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<td>APT80SM120J</td>
<td>SOT-227</td>
<td></td>
</tr>
<tr>
<td>1700V</td>
<td>5A</td>
<td>800mΩ</td>
<td>APT5SM170B</td>
<td>TO-247</td>
<td>April 2015</td>
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<td></td>
<td></td>
<td></td>
<td>APT5SM170S</td>
<td>D3</td>
<td></td>
</tr>
</tbody>
</table>

## Microsemi Advantages

- Best in class $R_{DS(ON)}$ vs. Temperature
- Low Switching Losses
- Low Conduction Losses

- Short Circuit Withstand Rated
- Superior Stability
- Patented SiC MOSFETs

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Power Matters
Best in Class $R_{DS(ON)}$ vs. Temperature

Microsemi Advantage vs. Competition

Normalized $R_{DS(ON)}$ (to 25°C) vs. $T_j$ [°C]

- Competitor 1: 80mΩ
- Competitor 2: 80mΩ
- Microsemi APT40SM120B: 80mΩ
- Microsemi APT50SM120B: 50mΩ
Ultra Low Gate Resistance
Minimized Switching Energy Loss & Higher Switching Frequency

Oscillation-free with minimal external $R_G$

APT50SM120B 50mΩ
APT40SM120B 80mΩ
Competitor 2
Competitor 1

Microsemi Low $R_G$
Competition High $R_G$
Switching Energy Benchmark
Microsemi Advantage vs. Competition

>30% less switching loss translates to cooler dynamic operations and capability for higher switching frequencies

\[ T_c = 25^\circ C; \ V_{DD} = 900V \]
Dynamic performance breakaway enablers:

- Superior $E_{ON}$ ($t_{on}$) due to high $g_{m}$, ultra low $R_{G}$
- Superior $E_{OFF}$ due to extremely low $R_{G}$ (yet oscillation free with very low external $R_{G}$)
- Low $R_{DSON}$ at high temperatures extends switching frequency and current capability

$T_{j}=150^\circ C; T_{c}=75^\circ C$
Superior Short Circuit Withstand
Microsemi Advantage vs. Competition

Microsemi’s 80mΩ SiC MOSFET demonstrates 25% longer short circuit capability
Summary – Microsemi SiC MOSFETs

Microsemi’s **Best-in-Class** SiC MOSFETs enable customers to design ultra efficient high power electronics

**Microsemi Advantages**

- Best-in-class $R_{\text{DS(ON)}}$ vs. Temperature
- Ultra Low Gate Resistance
- Low Conduction Losses
- Low Switching Losses
- Short Circuit Withstand Rated
- Reliable Technology Platform
SiC in Electric Vehicles
SiC in Electric Vehicles

- Toyota approximates that 20% of HV total electrical power loss occurs in the power semiconductors.
- One key to improving fuel efficiency is to improve power semiconductor efficiency.
- Compared to silicon, SiC MOSFETs operate with 1/10 the power loss and switching frequency can be increased by a factor of ten.
- Increased fuel efficiency and smaller PCUs.
- Aim to leverage the benefits of high frequency and high efficiency to enable PCU downsizing of 80%.
- **Over 5% fuel efficiency improvement** confirmed with SiC MOSFETs under JC08 test cycle.
- **GOAL:** Toyota is aiming for a 10% improvement in fuel efficiency with SiC MOSFETs.

Source: Toyota-Denso presentation, Automotive Engineering Exposition in Japan May 2014

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SiC in Electric Vehicles
Total Inverter & Battery Cost Reduction with SiC

5% Cost Reduction with SiC MOSFETs!

- 350V Battery
- 225kW 3-Phase Inverter
  - 84 Si IGBT solution (IXGX72N60B3H1)
  - 60 SiC MOSFET solution (40mΩ, 700V)

Si IGBT

6.5%
1.4%
4.3%
2.2%
86%

SiC MOSFET

6.0%
1.0%
2.2%
6.2%
80%

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SiC in Electric Vehicles

Semiconductor % Efficiency Loss versus Load

350V Battery
225kW 3-Phase Inverter
- 84 Si IGBT solution (IXGX72N60B3H1)
- 60 SiC MOSFET solution (40mΩ, 700V)

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SiC in Electric Vehicles
SiC MOSFET versus IGBT Summary

- **5% reduction** in Inverter & Battery cost using SiC MOSFETs
- **7% improvement** in fuel efficiency using SiC MOSFETs
  - Lower switching losses
  - Higher switching frequency
  - Higher temperature capable
  - Better current sharing when paralleled
  - No need for anti-parallel diode
SiC Power Modules Advantages
# Microsemi SiC Power Modules

NEW PRODUCTS

## Low Profile and Industry standard packages

Great design flexibility to offer modified versions!

<table>
<thead>
<tr>
<th>Technology</th>
<th>Topology</th>
<th>Voltage</th>
<th>Current Tc=80°C</th>
<th>Rdson max. per switch Tj=25°C</th>
<th>Package - Height</th>
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<tbody>
<tr>
<td>APTMC120TAM12CTPAG</td>
<td>3-Phase leg + Parallel diode</td>
<td>1200V</td>
<td>150A</td>
<td>12mΩ</td>
<td>SP6P – 12mm</td>
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<tr>
<td>APTMC120TAM17CTPAG</td>
<td>3-Phase leg + Parallel diode</td>
<td>1200V</td>
<td>100A</td>
<td>17mΩ</td>
<td>SP6P – 12mm</td>
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<td>APTMC120TAM33CTPAG</td>
<td>3-Phase leg + Parallel diode</td>
<td>1200V</td>
<td>60A</td>
<td>33mΩ</td>
<td>SP6P – 12mm</td>
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<tr>
<td>APTMC120AM25CT3AG</td>
<td>Phase Leg + Parallel diode</td>
<td>1200V</td>
<td>80A</td>
<td>25mΩ</td>
<td>SP3 – 12mm</td>
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<tr>
<td>APTMC120AM16CD3AG</td>
<td>Phase Leg + Parallel diode</td>
<td>1200V</td>
<td>100A</td>
<td>16mΩ</td>
<td>D3 – 30mm</td>
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<td>APTMC120AM12CT3AG</td>
<td>Phase Leg + Parallel diode</td>
<td>1200V</td>
<td>150A</td>
<td>12mΩ</td>
<td>SP3 – 12mm</td>
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<td>APTMC120AM09CT3AG</td>
<td>Phase Leg + Parallel diode</td>
<td>1200V</td>
<td>200A</td>
<td>9mΩ</td>
<td>SP3 – 12mm</td>
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<td>APTMC170AM60CT1AG</td>
<td>Phase Leg + Parallel diode</td>
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<td>40A</td>
<td>60mΩ</td>
<td>SP1 – 12mm</td>
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<tr>
<td>APTMC170AM30CT1AG</td>
<td>Phase Leg + Parallel diode</td>
<td>1700V</td>
<td>80A</td>
<td>60mΩ</td>
<td>SP1 – 12mm</td>
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</table>
SiC MOSFET and Module Packaging

Packaging choice will help to emphasize the best of SiC performance for the application.

- High stray inductances will lead to higher oscillation and voltage spikes
- Not efficient paralleling will compromise reliability of the system
- Built-in internal series gate resistor for easy paralleling

62mm package – 30mm height
30nH stray inductance

62mm package – 17mm height
15nH stray inductance

62mm package – 12mm height
5nH stray inductance
## SiC Module advantages vs. Discrete

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Higher power density</td>
<td>Size and cost reduction</td>
</tr>
<tr>
<td>Isolated and conductive substrate</td>
<td>Excellent thermal management</td>
</tr>
<tr>
<td>Internal wiring</td>
<td>Less external hardware</td>
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<tr>
<td>Minimum parasitic</td>
<td>Higher performance and efficiency</td>
</tr>
<tr>
<td>Minimum output connections</td>
<td>Reduced assembly time</td>
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<tr>
<td>Mix &amp; match components</td>
<td>Optimized losses</td>
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### System improvement

<table>
<thead>
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<th>Performance</th>
<th>Reliability</th>
<th>Size</th>
<th>Cost</th>
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Reduced size and cost of magnetics and heatsink

SiC COST
## SiC Module = Higher Power Density

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Microsemi APTGLQ300A120G</th>
<th>Microsemi APTMC120AM20CT1AG</th>
<th>Comparison SiC vs Si</th>
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<tbody>
<tr>
<td>Semiconductor type</td>
<td>Trench4 IGBT</td>
<td>SiC Mosfet</td>
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<tr>
<td>Ratings @ Tc=80°C</td>
<td>300A/1200V</td>
<td>108A/1200V</td>
<td></td>
</tr>
<tr>
<td>Package type</td>
<td>SP6 – 108x62mm</td>
<td>SP1 – 52x41mm</td>
<td>3x smaller</td>
</tr>
<tr>
<td>Current @ 30kHz Tc=75°C, D=50%, V=600V</td>
<td>130A</td>
<td>130A</td>
<td>-</td>
</tr>
<tr>
<td>Current @ 50kHz Tc=75°C, D=50%, V=600V</td>
<td>60A</td>
<td>115A</td>
<td>~2.0x higher</td>
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<tr>
<td>Eon+Eoff @ 100A Tj=150°C, V=600V</td>
<td>16.0mJ</td>
<td>3.4mJ</td>
<td>4.7x lower</td>
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**MORE POWER in SMALLER VOLUME**
Parallel diode to SiC MOS: to Be or not to Be?

<table>
<thead>
<tr>
<th></th>
<th>Si MOSFET</th>
<th>SiC MOSFET</th>
<th>SiC ADVANTAGE</th>
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<tbody>
<tr>
<td>Intrinsic Body diode</td>
<td>Poor Reverse Recovery Characteristics Low Vf</td>
<td>Good Reverse Recovery Characteristics. Higher Vf</td>
<td>Low SiC diode switching losses</td>
</tr>
<tr>
<td>Additional</td>
<td>Blocking diode mandatory to avoid slow body diode to conduct</td>
<td>No Need for blocking diode</td>
<td>Less components count and less conduction losses</td>
</tr>
<tr>
<td>Fast Series &amp; Parallel diode</td>
<td>No advantage: Current flow would go to body diode only</td>
<td>Mandatory to reduce high conduction losses of body diode</td>
<td>Allows full SiC-MOS performance without limitation of body diode losses</td>
</tr>
</tbody>
</table>

- SiC MOSFET Body diode is enough when operated at low duty cycle
- SiC MOSFET parallel diode required if operated at high duty cycle
- Parallel diode can be avoided if MOSFET is turned ON (Synchronous Rectification)
To minimize the diode conduction losses the SiC MOSFET should be turned ON with $V_{GS} = 20V$

Increasing Gate voltage to 20V reduces total losses by 30%

Negative gate bias further reduces losses,

Vgs voltage range should be within -5V to +20V to optimize total losses
SiC MOSFET Power module application

CUSTOMER’s OBJECTIVE
MODULE COUNT REDUCTION PER SYSTEM
IMPROVED PERFORMANCE AND RELIABILITY
LOWER SYSTEM COST

INDUCTION HEATING

APTMC120AM08CD3AG

Phase leg MOSFET Power Module

$V_{DSS} = 1200\text{V}$
$R_{D\text{son}} = 7.5\text{m}\Omega \text{ typ @ } T_j = 25\text{°C}$
$I_D = 270\text{A @ } T_c = 25\text{°C}$

10 x 1200V – 80mΩ SiC Mosfet per switch
12 x 1200V – 10A SiC schottky per switch

Practical example:

DC Voltage = 535V
Sinusoidal RMS current = 136A out
Water cooled heat sink - inlet temperature = 14°C
DC power = 61.6kW
Efficiency = 99.2% @ Fsw=217KHz ZVS
SiC MOSFET Power module application

**Phase leg**

SiC MOSFET Power Module

- $V_{DSS} = 1200V$
- $R_{DSon} = 17m\Omega$ max @ $T_j = 25^\circ C$
- $I_D = 143A$ @ $T_c = 25^\circ C$

**Practical example** in race car application

3-phase inverter – 3 modules per phase
- 100KW
- DC voltage = 900V
- $>220A$ RMS @ $T_c=75^\circ C$
- $F_{sw} >100kHz$

**CUSTOMER’s OBJECTIVE**
- SMALLER AND LIGHTER SYSTEM
- RELIABILITY
- PERFORMANCE

9 modules size 52mm x 41mm

2 x 1200V – 25mΩ SiC Most per switch
2 x 1200V – 20A SiC schottky per switch
Microsemi SiC in Aerospace

SiC Discrete Products in Aerospace

- SiC Schottky Diode
- **Parker Hannifin** custom 40A SiC Schottky Diode half-bridge
- Cooling pump module for Boeing 787
- 20,000 pcs in 2014

Key Market: Aerospace

Since 1995, sub-system for cabin air-management

2,500 systems in the field
Ongoing production
New design released

Since 2005 several modules built in commercial & military aircrafts

<table>
<thead>
<tr>
<th>SOT-227</th>
<th>A350</th>
<th>A380</th>
<th>A400M</th>
</tr>
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<tbody>
<tr>
<td>SP1</td>
<td>A350</td>
<td>A380</td>
<td>A400M</td>
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<tr>
<td>SP3</td>
<td>A380</td>
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<tr>
<td>LP8W (IPM)</td>
<td>A380</td>
<td>B787</td>
<td></td>
</tr>
</tbody>
</table>

>30K modules shipped
Development and production

**Applications:**
- Air conditioning
- Actuation systems
- Power control unit
- Suplemental cooling system
- Power generation
- Transformer rectification unit
- Cargo Winch
- Fuel pump

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Microsemi’s **Best-in-Class** SiC MOSFETs enable customers to design ultra efficient high power electronics

**Microsemi Advantages**

- Best-in-class $R_{DS(ON)}$ vs. Temperature
- Ultra Low Gate Resistance
- Low Conduction Losses
- Low Switching Losses
- Short Circuit Withstand Rated
- Reliable Technology Platform
Thank You!