Power products commercial roadmap for SiC from 2012-2020 – Jeff Casady

Power products rel data & pricing forecasts for 650V-15kV SiC power modules, MOSFETs & diodes – John Palmour

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Power Products Commercial Roadmap from 2012-2020
Cree SiC MOSFET Portfolio Beginning in 2011

1200V MOSFETs (Bare Die)
- CPM2-1200-0025 (25mΩ; 60A)
- CPM2-1200-0040 (40mΩ; 40A)
- CPM2-1200-0080 (80mΩ; 20A)
- CPM2-1200-0160 (160mΩ; 10A)

1200V MOSFETs (TO-247)
- C2M0025120D (25mΩ; 60A)
- C2M0040120D (40mΩ; 40A)
- C2M0080120D (80mΩ; 20A)
- C2M0160120D (160mΩ; 10A)
- C2M0280120D (280mΩ; 7A)

1700V MOSFETs
- C2M1000170D (1Ω; 3.0A) TO-247
- CPM2-1700-0040 (40mΩ; 50A) Bare Die

>13 products and growing

New 1700 V MOSFETs needed for PV inverters with 1.0-1.5 kV bus voltages
Cree All-SiC Power Module Portfolio Beginning in 2012

50 mm Platform Half-Bridge Configuration
- CAS100H12AM1 (1200V, 100A)
- XAS125H12AM2 (1200V, 125A)
- XAS125H17AM2 (1700V, 125A)

45 mm Platform 6-Pack Configuration
- CCS050M12CM2 (1200V, 50A 6-pk)
- CCS020M12CM2 (1200V, 20A 6-pk)

62 mm Platform Half-Bridge Configuration
- CAS300M12BM2 (1200V, 300A)
- CAS300M17BM2 (1700V, 250A)

1700V ½ bridge released!

Cree confidential information protected under NDA

> 7 products and growing
Cree 1700V, 8mΩ, ½ bridge power module available NOW

Full commercial release – September 2014

Available globally – Digikey, Mouser, Richardson/Arrow (right), … ~ $850 single unit

Gate drivers, app notes available

2 channel; 1.2/1.7 kV 62 mm module gate driver direct mount
Section –

SiC MOSFET Roadmap
SiC current ratings are much less than Si

300 Amp SiC More Capable than 600 Amp Si IGBTs!

- System cost reduction of 20% using 1200V SiC
  - Increased frequency reduces size and weight of magnetics
  - Lower losses reduce system cooling requirements
  - Amperage rating for SiC less than half required for Si IGBTs

Si Amps are *not* SiC Amps

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SiC voltage ratings are much less than Si?

6.5 kV Si IGBT used for 3.6 kV drives (100 cosmic ray FIT rate)

4.5 kV SiC MOSFET used for 3.6 kV line?

10 kV SiC MOSFET used for 7.2 kV?

- Medium Voltage SiC MOSFET roadmap must respond to application
  - 10X higher switching frequency, lower thermal dissipation possible
  - Cosmic ray, other reliability metrics may be 100X better
  - All requirements, eg. short circuit, surge must be understood
10X higher switching for SiC MOSFET than Si IGBT

Dramatic Reduction in System Weight and Complexity compared to Silicon

- 7.2 x 7.2 mm² Gen 3 6.5 kV MOSFET
  - Nominally 25 A

- 7.2 x 7.2 mm² Gen 3 10 kV MOSFET
  - Nominally 15 A

- 6.5 kV Si IGBT
  - (5SMX 12M6501 - ABB)

Switching Frequency (kHz) vs. Amperes
3rd Generation SiC MOSFETs

Gen 2 DMOS
Commercially released in 2013

Same high reliability DMOS Structure, but optimized to dramatically reduce die size

Gen 3 DMOS

- Smaller pitch
- Optimized doping
3.3 kV, 40 mΩ, “40 A” MOSFET Engineering Samples
10 kV, 300 mΩ, “20 A” MOSFET Engineering Samples

Available under NDA
10 kV SiC MOSFETs in Boost Converter (Fraunhofer ISE)

Box is 36 cm x 30 cm

Efficient, “transformer-less” power distribution to medium voltage grid

- Fraunhofer DC-DC converter used 10kV SiC MOSFETs from Cree
- 30 kW DC voltage converter with 3.5 kV input voltage, 8.5 kV output voltage, 98.5% efficient
- 8kHz switching frequency 15X higher than possible with conventional silicon devices in the same voltage range.

A Highly Efficient DC-DC-Converter for Medium-Voltage Applications
Jürgen Thoma, David Chilachava, Dirk Kranzer
ENERGYCON 2014 • May 13-16, 2014 • Dubrovnik, Croatia
Section

Power products rel data & pricing forecasts for 650V-15kV SiC power modules, MOSFETs & diodes
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Power Products Reliability Data
Cree Field Failure Rate Data since Jan. 2004 through Mar. 2014

<table>
<thead>
<tr>
<th>Product</th>
<th>Device Hours</th>
<th>FIT (fails/billion hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSDxxx60</td>
<td>426,000,000,000,000</td>
<td>0.05</td>
</tr>
<tr>
<td>C2Dxx120</td>
<td>146,000,000,000</td>
<td>0.54</td>
</tr>
<tr>
<td>C3Dxxx60</td>
<td>367,000,000,000</td>
<td>0.02</td>
</tr>
<tr>
<td>C4Dxxx120</td>
<td>26,700,000,000</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>SiC MOSFET</strong></td>
<td><strong>1,140,000,000</strong></td>
<td><strong>3.5</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>972 Billion</strong></td>
<td><strong>0.12</strong></td>
</tr>
</tbody>
</table>

- 0.12 FIT rate is 10 times lower than the typical silicon
- SiC diodes first released in 2001
- SiC MOSFETs first released in 2011
Reliability Meets All Commercial and Military Requirements

- MOSFETs have extrapolated MTTF of 30 million hours
- Gate oxides have extrapolated MTTF of 8 million hours at +20V continuous
C2M $V_{TH}$ Stability at High Temperature, +/- DC Bias

- Extremely stable for 1,000 hours under positive and negative bias
  - Accelerated beyond data sheet to see any measurable change
  - Average shift under positive bias: $\Delta V_{TH} = 0.06$ V, $\Delta R_{DS-ON} = 0.1$ mΩ
  - Average shift under negative bias: $\Delta V_{TH} = 0.01$ V, $\Delta R_{DS-ON} = 3.2$ mΩ
MOSFET Off-State Blocking Reliability

8 kV, 200°C, 1000 hr HTRB of 10 kV SiC MOSFET

8 kV Leakage Current (μA) vs. HTRB Duration (hr)

DUT Temperature = 200°C

DUT 8kV Leakage Current
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Pricing Forecasts
Vertical integration in the power semiconductor industry

### Global SiC Power Chip Supplier Rankings (2013)

<table>
<thead>
<tr>
<th>2013 Rank</th>
<th>Supplier</th>
<th>HQ Location</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Cree</strong></td>
<td>USA</td>
<td>![USA flag]</td>
</tr>
<tr>
<td>2</td>
<td>Infineon</td>
<td>Germany</td>
<td>![Germany flag]</td>
</tr>
<tr>
<td>3</td>
<td>Mitsubishi</td>
<td>Japan</td>
<td>![Japan flag]</td>
</tr>
<tr>
<td>4</td>
<td>ROHM</td>
<td>Japan</td>
<td>![Japan flag]</td>
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<tr>
<td>5</td>
<td>ST Micro</td>
<td>FR-IT</td>
<td>![FR-IT flag]</td>
</tr>
</tbody>
</table>

Top 5 suppliers (95% of market) with US supplier (Cree) No. 1 shown on left.

### Global Si and SiC Power Module Market Share (2011)

<table>
<thead>
<tr>
<th>2013 Rank</th>
<th>Supplier</th>
<th>HQ Location</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mitsubishi (inc Powerex)</td>
<td>Japan</td>
<td>Vertical, captive chip supply</td>
</tr>
<tr>
<td>2</td>
<td>Infineon</td>
<td>Germany</td>
<td>Vertical, captive chip supply</td>
</tr>
<tr>
<td>3</td>
<td>Fuji</td>
<td>Japan</td>
<td>Vertical, captive chip supply</td>
</tr>
<tr>
<td>4</td>
<td>Semikron</td>
<td>Germany</td>
<td>Foundry module vendor</td>
</tr>
<tr>
<td>5</td>
<td>Hitachi and Sanyo (tie)</td>
<td>Japan</td>
<td>Vertical and foundry mix</td>
</tr>
</tbody>
</table>

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SiC Leadership – Leveraging Vertical Integration & Scale

Vertically integrated $1.65 B business:
- Virtually all revenue based on SiC substrates
- Unmatched command of supply chain from raw materials to finished products (including power and RF devices, LEDs, light bulbs and fixtures)
- Avoiding margin stacking in supply chain provides attractive cost structure

150mm wafer capability in RTP facility
> $40M invested in RTP fab capacity expansion over 3 years
Cost reduction from volume and device refinement

Solid Lines = Actual
Dotted Lines = Projections

600V Schottky
1200V Schottky
Gen 1 Schottky
Gen 2 Schottky
Gen 3 Schottky
Gen 4 Schottky
Gen 5 Schottky
Gen 1 MOSFET
Gen 2 MOSFET
Gen 3 MOSFET

75 mm → 100 mm → 150 mm
Cree is the leader in Silicon Carbide power semiconductors.

Cree is one of world’s fastest-growing power semiconductor manufacturers.

Cree has excellent capitalization.

Cree is vertically integrated—for an efficient supply chain and product traceability.

Cree has the technology roadmap for improved SiC production and cost reduction.