ST SiC MOSFET & Diode product and application

Lay LV
Power Discrete & Sub-Analog
AP Region, STMicroelectronics
1. SiC benefits
2. SiC markets
3. SiC application case study
4. ST SiC technology overview
5. ST SiC product profile
SiC benefits
Wide bandgap materials figure of merit

<table>
<thead>
<tr>
<th>Property</th>
<th>Si Silicon</th>
<th>SiC Silicon Carbide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Field (V/cm)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Electron Saturation Velocity (x10^7 cm/s)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Melting Point (℃)</td>
<td>3</td>
<td>3K</td>
</tr>
<tr>
<td>Bandgap (eV)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Higher breakdown voltage</td>
<td>x10</td>
<td></td>
</tr>
<tr>
<td>Lower ON resistance &amp; losses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher temperature (operation &amp; endurance)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced cooling requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Si Silicon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Higher switching frequency</td>
<td>3K</td>
<td></td>
</tr>
<tr>
<td>Lower switching losses</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
SiC is closest to an ideal switch

Only SiC MOSFETs combine all 3 desirable features of an ideal switching device (with the highest max. junction temperature)

<table>
<thead>
<tr>
<th></th>
<th>SiC MOSFET (planar)</th>
<th>Silicon MOSFET</th>
<th>Silicon IGBT</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDS(on)xArea</td>
<td>1</td>
<td>30</td>
<td>3 (10 at low current)</td>
</tr>
<tr>
<td>Switching energy loss</td>
<td>1</td>
<td>&gt;10</td>
<td>7</td>
</tr>
<tr>
<td>Max Junction temperature [°C]</td>
<td>&gt;200</td>
<td>150</td>
<td>175</td>
</tr>
</tbody>
</table>

SiC MOSFET for:
- The Lowest Ron
- The Highest Speed
- The Highest Operating Temperature
Key benefits of SiC MOSFETs

- **Extremely low energy losses and low $R_{ON}$ especially at very high $T_j$**
  - Higher operating frequency for smaller and lighter systems

- **Easy to drive**
  - Fully compatible with standard gate drivers

- **Thermal performance**
  - High operating temperature ($T_{jmax} = 200°C$)
  - Reduced cooling requirements & heat-sink
  - Increased life time

- **Very fast and robust intrinsic body diode**
  - More compact inverter
Key benefits of SiC Diode

Energy savings generated by sustainable technology

- **Power Losses**
  - **SiC-based diodes**
  - **Si-based ultrafast diodes**

- **Conduction Losses**
  - SiC diode
  - STPSCxH065
  - 600V ultrafast silicon based

- **Switching performance comparison**
  - Switching losses
  - Recovery losses
  - Conduction losses

- **Eliminate Recovery Losses**
  - More efficient power conversion

- **Reduced Dimensions**
  - 60%

- **More efficient power conversion**
  - +20% @ low load
SiC markets
SiC MOSFET market applications

- **Rated Voltage**
  - 600V
  - 900V
  - 1200V
  - 1700V

- **Power**
  - 1 kW
  - 5 kW
  - 10 kW
  - 30 kW
  - 50 kW
  - 100 kW
  - 350 kW

- **Applications**
  - **HEV / BEV**
  - **Home appliances**
  - **NETCOM Server**
  - **Rail traction, Smart Power Grid, Wind mills**
  - **Photovoltaic, Industrial drives, Power supply / ups, Energy storage, Charging station**
SiC diode market applications

- Highly reliable products with high performance and robustness
- Different solutions able to cover a wide range of applications

Motor drives
- Telecom power
- PC power
- Server power
- Motor drives

Automotive
- Power supplies
- UPS

Industrial
- Lighting
SiC application case study
Benefits in single-switch applications Boost PFC

Thanks to its exceptional $R_{DS(on)}A$, the SiC MOSFET solution for 3.6kW PFC can be housed in SMD packages, while Silicon needs Through-hole TO-247.

3.6kW BOOST PFC (CCM)

Devices
- $S_1/S_2 =$ ST SIC Mosfet 650V/55mohm/H2Pack
- $S_1 / S_2 =$ ST M5 Series SI Mosfet: 650V/24mohm/TO247
- $S_1 / S_2 =$ ST M5 Series SI Mosfet: 650V/41mohm/TO247

Efficiency @ fsw

Test conditions
- $P_{out}$ = 3.6 kW
- $I_{in\,rms}$ = 16A
- $V_{out}$ = 400 V
- $F_{sw}$ = 70/130 kHz
- $V_{in}$ = 220V ac
Totem-pole bridgeless PFC
Ideal reverse recovery diode benefits

Test conditions
- $P_{out} = 3.6$ kW
- $I_{in\,rms} = 16$ A
- $V_{out} = 400$ V
- $F_{sw} = 100$ kHz
- $V_{in} = 220V_{ac}$

Devices
- $S_1 / S_2 = $ ST SIC Mosfet 650V/55mohm/H2Pack
- $S_1 / S_2 = $ ST SI Mosfet: 650V/24mohm/TO247
- $S_1 / S_2 = $ ST 650V 40A IGBT
- $D_1/D_2 = $ 650V 30A Si rectifiers

SiC MOSFET outperforms both Si solutions

<table>
<thead>
<tr>
<th>$S_1, S_2$ position</th>
<th>Conduction losses [W]</th>
<th>Switching losses [W]</th>
<th>$S_1 + S_2$ losses [W]</th>
<th>Efficiency*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIC MOS</td>
<td>7.61</td>
<td>3.7</td>
<td>11.3</td>
<td>99.68%</td>
</tr>
<tr>
<td>Si MOS</td>
<td>12.56</td>
<td>34</td>
<td>46.56</td>
<td>98.7%</td>
</tr>
<tr>
<td>IGBT</td>
<td>15.6</td>
<td>40.7</td>
<td>56.1</td>
<td>98.44%</td>
</tr>
</tbody>
</table>
Benefits in LLC DC/DC secondary stage

Comparing efficiency in an 11 kW LLC DC/DC

Test conditions
- $P_{out} = 11$ kW
- $I_{Mos-rms} = 12.7$ A
- $V_{bus} = 800$ V
- $F_{sw\_min} = 100$ kHz (at max load)

600V Silicon MOSFET can challenge 1200V SiC one. In fact a 1200V Si would have much higher RDS(on) and therefore dramatically worse performance.

<table>
<thead>
<tr>
<th>DUT</th>
<th>$P_{cond_DC/DC}$ [W]</th>
<th>$P_{sw_DC/DC}$ [W]</th>
<th>$P_{tot_DC/DC}$ [W]</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST SIC MOS 1200V 70mohm</td>
<td>62.15</td>
<td>48</td>
<td>110.15</td>
<td>98.98</td>
</tr>
<tr>
<td>ST SI MOS 650V 80mohm</td>
<td>202.4</td>
<td>28</td>
<td>230.4</td>
<td>97.87</td>
</tr>
</tbody>
</table>
SiC Diode performance in CCM PFC

480W BOOST PFC (CCM)

SiC delivers:
❖ Best switching performances (fast and soft)
❖ Best efficiency in hard-switching applications thanks to best turn-off performance

Devices
- D1= ST Ultrafast diode: 8A/600V R series
- D1= ST Tandem G1: 8A/600V
- D1= ST Tandem G2: 8A/600V
- D1: ST SIC Diode: 6A/650V H series

I_i=8A ; dl/dt=400A/µs ; V_R=400V ; T_j=125°C 2A/div ; 10ns/div

Reverse characteristics

Capacitive current independent of T_j

Ultrafast diode

Tandem G2

Tandem G1

SiC 600/650V diode

Power losses

SiC PFC 480 W

V_IN = 90 V, F = 100 kHz, T_j = 125 °C, dl/dt = 400 A/µs

Ultafast diode △η = +0.4%
Tandem G1 △η = +0.8%
Tandem G2 △η = +1.4%
20 years of experience with SiC

April 1998
1st contract on SiC with CNR-IMETEM (Dr. V. Raineri)

May 2004
Schottky Diode Demonstrator (ST line)

November 2003
First ST internal product request

February 2003
ETC Epitaxial reactor prototype installed in ST

October 2007
1st Gen Diode Start Production

December 2005
Schottky Diode Mat 20

March 2009
Power MOSFET 3” Demonstrator

May 2012
2nd Gen Diode Start Production

June 2014
3rd Gen 3 Diode Start Production

June 2017
2nd Gen MOSFET AG 6” Start Production

June 1996
Collaboration with Physics Dept. (Prof. G. Foti)

May 2003
Schottky Diode Demonstrator (CNR line)

June 2003
2” ST line

June 2006
3” ST line

June 2011
4” ST line

June 2016
6” ST line

May 2002
Schottky Diode Demonstrator (ST line)

June 1996
Collaboration with Physics Dept. (Prof. G. Foti)

February 2003
ETC Epitaxial reactor prototype installed in ST

May 2004
Schottky Diode Demonstrator (ST line)

October 2007
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SiC MOSFET Technology Roadmap

**Planar Technology**

<table>
<thead>
<tr>
<th>Gen</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1200 V</td>
<td>(0-300kHz)</td>
</tr>
<tr>
<td></td>
<td>1700 V</td>
<td>(0-300kHz)</td>
</tr>
<tr>
<td>2nd</td>
<td>650 V</td>
<td>(0-500kHz)</td>
</tr>
<tr>
<td>3rd</td>
<td>1200 V</td>
<td>(0-&gt;500kHz)</td>
</tr>
<tr>
<td></td>
<td>750 V</td>
<td>(0-&gt;500kHz)</td>
</tr>
<tr>
<td>4th</td>
<td>1200 V</td>
<td>(0-&gt;1MHz)</td>
</tr>
<tr>
<td></td>
<td>750 V</td>
<td>(0-&gt;1MHz)</td>
</tr>
</tbody>
</table>

**Trench Technology**

<table>
<thead>
<tr>
<th>Gen</th>
<th>Voltage</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>750 V</td>
<td>(0-&gt;1MHz)</td>
</tr>
</tbody>
</table>

**Mass production**

- 2014
- 2018
- 2020 (Q4)
- 2022 (Q2)

**Continuous scale-down**

- [Ron x area] x2 shrinkage
- [Ron x area] x4 shrinkage
- [Ron x area] x5 shrinkage

**ST’s planar technology is the state-of-art but still susceptible to be improved with G4 iteration:**

- About 15% better on-resistance than G3
- Operating frequency set to approach 1 MHz mark
- Well-established and robust process
  - Throughput, design simplicity, reliability, experience …
  - High production rates for Automotive
  - Short time-to-market (less than 2 years from Gen3)

**ST Trench technologies: a long-term approach**

- ST to maintain and consolidate leadership
- Major process modifications vs. existing structures
- Critical steps under optimization and refinement

**FOM improvements vs. Technology Evolution**

- R_DS(on) x area (mΩ x cm²)
- R_DS(on) x Qg (mΩ x nC)

- Competitive R_DS*A and R_DS*Qg FOM

* Normalized
ST SiC Diodes
Over 10 Years Experience

- 2008: SiC 600V 1st Gen, STPSCxx06x
- 2012: SiC 650V H series, STPSCxxH065x
- 2014: SiC 650V H series Automotive Grade, STPSCxxH065x-Y
- 2016: SiC 650V Low V_F, STPSCxx065x
- 2017: SiC 1200V Industrial & Automotive Grade, STPSCxxH12x
- 2018: Introduction of new packages, STPSCxxH12x-Y
- 2019 & Onwards: Module, Die Form, New ratings

Timeline:
- 2008
- 2012
- 2014
- 2016
- 2017
- 2018
- 2019 & Onwards
## SiC MOSFET package overview

### Key advantages:
- Increase power density
- Reduce parasitic effects
- Target higher efficiency

<table>
<thead>
<tr>
<th>Package Type</th>
<th>Package Name</th>
<th>Voltage</th>
<th>Dimensions</th>
<th>Samples Available</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMD</td>
<td>ACEPACK DRIVE (750/1200V)</td>
<td>Samples Q3’20, 1200V</td>
<td>Traction Inverter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMD</td>
<td>POWER FLAT 650V 8x8 mm</td>
<td>Samples available</td>
<td>Small power application Kelvin pin option Suitable for IMS substrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMD</td>
<td>H2PAK 650/1200V 10x15 mm</td>
<td>Samples available</td>
<td>Bottom side cooling Suitable for IMS substrate Kelvin pin option</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMD</td>
<td>HU3PAK 650/1200V 18x14 mm</td>
<td>Samples available</td>
<td>Top Side Cooling Very high thermal dissipation Kelvin source pin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through Hole</td>
<td>ACEPAK SMIT 650/1200V</td>
<td>Samples Q4 2020, 1200V</td>
<td>Half-bridge configuration Top side cooling package Kelvin source pin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Through Hole</td>
<td>HiP247 650/1200V 18x14 mm 4L 15x14 mm 3L</td>
<td>Samples available</td>
<td>4L Kelvin pin option Vs 3L solution Lower switching losses Higher efficiency Available in Long Lead option</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SIC Diode PowerFLAT* 8x8 package benefits: 4A, 6A & 8A

PowerFLAT 8x8: a less-than-1-mm thick package

The ultimate improvement in watts

- STPSCxH065
- STPSCxH065DLF

Every mV grants efficiency toward 97%, 98%, 99%

More guard band to grid disturbances

Relative value

D2PAK

DPAK

PowerFLAT 8x8

-2.15mm

-3.58mm

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ST SiC product profile
### SiC MOSFET series overview

<table>
<thead>
<tr>
<th>Breakdown Voltage</th>
<th>Series</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>650 V</td>
<td>G2</td>
<td>45 to 119 A</td>
</tr>
<tr>
<td>1200 V</td>
<td>G1</td>
<td>12 to 65 A</td>
</tr>
<tr>
<td>1700 V</td>
<td>G1</td>
<td>6 to 25 A</td>
</tr>
</tbody>
</table>

**Focus Applications**

- Renewable energy
- Power Conversion
- Industrial drives
- Photovoltaic
- HVAC
- Street Lighting
- Charging stations
- High Voltage
- Power Supply
SiC Diode series overview

Extended range

SiC diodes | 1200V
Automotive Grade

SiC diodes | 1200V
High Surge Capability
Automotive Grade

SiC diodes | Low $V_F$
Automotive Grade

SiC diodes | H-Series
High Surge Capability

SiC diodes | Low $V_F$

$V_{RRM}$ (V) vs. $I_{F_{AV}}$ (A) range:
- 1200V: 2A to 20A
- 650V: 2A to 40A

Extended range
- 1200V: 10A
- 650V: 8A

SiC diodes | Low $V_F$
Automotive Grade

SiC diodes | H-Series
High Surge Capability

SiC diodes | Low $V_F$
Automotive Grade

SiC diodes | H-Series
High Surge Capability
Takeaways

ST is leader in the SiC market through dedicated product lines. The Ramp up of SiC Technology is faster than market expectation!

ST offers a growing SiC product line up, following industrial market trends with strong manufacturing flexibility and capacity extension.

ST SiC technology innovation (Gen 2 and next Gen 3) plus the complete industrialization of new power packages has lead to a strong product range for many power systems.

ST's expertise in Industrial markets is well recognized by customers. ST is ready to support in SMPS, Solar, UPS, Motor Control, and DC-DC converters.
Technical and promotional material

Flyers

STPOWER SiC MOSFET
The real breakthrough in high-voltage switching

Panels

Gen2 SiC MOSFETs Panels (Automotive and Industrial)

Application notes and technical papers

Webinars and e-presentations

Brochures
ST SiC MOSFET Finder

APP on SMARTPHONE with same data of ST's Web Product Selector

Parametric and By Choice Search

Download of Datasheets

STPOWER MOSFET finder mobile app for tablets and smartphones

Features
- Full range of products: both low and high voltage including SiC and Automotive products
- Parametric search on multiple criteria
- Easy access to the key product parameters
- Part number search for direct access to a specific product
- Download of datasheets for offline consulting
- Direct access to sampling and buying
- Management of favorite part numbers
- Product features sharing via e-mail or social media
- Available on Android™ or iOS™ operating systems
- Available on Wandaqapp store for Chinese users

Description
The STPOWER MOSFET Finder is a mobile application available for Android or iOS offering a user-friendly alternative to searching through the ST Power online product portfolio, driving the user along a smooth and simple navigation experience using portable devices. The parametric search engine allows the user to rapidly identify the right product that best fits its application. This app is available on Google Play, App Store and Wandaq.
Thank you