ST SiC MOSFET
Perspectives of WBG in renewing power applications

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Key Topics

• ST SiC MOSFET at a glance
  • Development status
  • Electrical characteristics and packaging

• A revolution in Power electronics switches arena
  • Advantages vs Standard Silicon
  • A look to the diode
  • Opening new frontiers: new fields of application for FETs

• SiC MOSFET in a 5kW Step-up converter
  • Driving possibilities
  • Comparison vs Si IGBT
ST SiC Power MOSFET: SCT30N120

1200V SiC MOSFET Schedule:
- Samples available
- Full production by Q4 2013

BV > 1,200 V
In = 45 A
Ron(typ) < 80 mΩ
Qg(typ) < 105 nC
Gate Driving Voltage = 20 V
HiP247 Package: Tjmax = 200 °C
ST SiC Power MOSFET
On-Resistance vs. Temperature (SiC vs. Silicon MOSFETs)

Highest benefits at higher temperatures
ST SiC Power MOSFET: $I_{DSS}$ leakage

$I_{DSS}$ increase: less than 10uA @ 200°C, 1200V

**SCT30N120 vs Temperature**

- **SCT30N120 25°C**
- **SCT30N120 200°C**
TO247-4L: under evaluation with FETs

**Features**
- Kelvin Source PIN to separate power path from driving signal
- Increased creepage between PINs

**Benefits**
- higher efficiency
- Lower working temperature
- Higher insulation standards

4th pin for source sensing for switching losses saving
A revolution in Power electronic switches arena
ST SiC MOSFET

Benefits vs. alternative 1200V Silicon Technologies

- **MOSFET 1.2 kV**

  The newest ST SUPERMESH5 Super Junction technology still exhibits much higher Ron*A values at 1200V with consequently big impact on dynamic performances and drive power losses (still high Gate charge values).

<table>
<thead>
<tr>
<th>Part number</th>
<th>BV</th>
<th>Package</th>
<th>Ron (mΩ)</th>
<th>Ron<em>A (mΩ</em>cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT30N120 (ST SiC MOSFET)</td>
<td>1200V</td>
<td>HiP247</td>
<td>80</td>
<td>11.5!</td>
</tr>
<tr>
<td>STx*</td>
<td>1200V</td>
<td>TO 247</td>
<td>320*</td>
<td>220</td>
</tr>
<tr>
<td>IGBT 25A (Vcesat=2.1V@25°C)</td>
<td>1200V</td>
<td>TO 247</td>
<td>84</td>
<td>20</td>
</tr>
<tr>
<td>STx20N95K5</td>
<td>950V</td>
<td>TO220</td>
<td>330</td>
<td>114</td>
</tr>
</tbody>
</table>

*Simulated R\text{ON} value of SUPER MESH5 technology at 1200V in TO247

- **IGBT 1.2 kV**

  The best in class IGBTs (trench field stop technology) have Ron*A values comparable with the SiC MOSFET but show much higher power switching losses.
### SiC MOSFET vs. Best in Class IGBT
Results measured on first samples (1200V/30A/80mΩ\textsubscript{typ})

<table>
<thead>
<tr>
<th>Device</th>
<th>(V\text{on,typ,(V)}) \text{(}25^\circ\text{C, 20A)}</th>
<th>(V\text{on,typ,(V)}) \text{(}175^\circ\text{C, 20A)}</th>
<th>(E\text{on,(\mu J)}) \text{(}20A, 900V, 25^\circ\text{C/175^\circ,C)}</th>
<th>(E\text{off,(\mu J)}) \text{(}20A, 900V, 25^\circ\text{C/175^\circ,C)}</th>
<th>Chip size</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC MOSFET</td>
<td>1.6</td>
<td>1.9</td>
<td>725/965(*)</td>
<td>245/307</td>
<td>0.45</td>
</tr>
<tr>
<td>IGBT</td>
<td>1.95</td>
<td>2.35</td>
<td>2140/3100</td>
<td>980/1850</td>
<td>1</td>
</tr>
</tbody>
</table>

\(\ast\) Eon measured by using the SiC intrinsic body diode

+ 30 % at 175°C

+ 90 % at 175°C

**Huge switching energy difference**

**Much higher switching frequency is now possible**
ST SiC MOSFET
Benefits vs. alternative 1200V Silicon Technologies

**SiC MOSFET vs SI IGBT**
- STATIC COMPARISON -

*THE AREA OF ADVANTAGE OF SiC MOSFET VS IGBT MOVES UP TO 35A AT 175°C*

**SiI GBT vs SiC MOSFET**
Output characteristics @25°C, 175°C

**SiC MOSFET SHOWS BETTER STATIC PERFORMANCES vs. IGBT**
BELOW 25A @25°C
What about SiC MOSFET Body Diode?

THE SiC MOSFET IS THE ONLY SiC ALTERNATIVE OFFERING AN INTRINSIC BODY DIODE, WITH ALMOST NEGLIGIBLE RECOVERY CHARGE.

NOTE: THE SiC MOSFET BODY DIODE IS ABLE TO WORK AS FREEWHEELING DIODE IN ANY POWER CONVERSION SYSTEM. IT'S SUGGESTED TO USE IT IN THE INVERTERS FOR SHORT TIME INTERVALS (I.E. DEAD TIME IN SYNC RECTIFICATION TECHNIQUES).
The SiC MOSFET is the only SiC alternative offering an intrinsic body diode, with almost negligible recovery charge.

The SiC MOSFET shows very hard switching losses reduction.

The SiC MOSFET shows very important conduction losses at low and medium load due to its output characteristics – no PN junction drop as in the IGBT.

It is the first time you can use FETs in motor control applications and inverters in general without any trick*.

* i.e. Blocking MOSFET body diode by means of additional shotthky diode and using external freewheeling diode thus increasing complexity and decreasing performances.
SiC MOSFET - Application Landscape
Key Market Drivers

- Photovoltaic Inverters (Boost & DC-AC Inverters)
- Server Power Supply
- HEV/EV & Traction
  - Main DC-AC Inverters, Chargers

Value Propositions: Solution cost effectiveness, Power Density, Efficiency Gain
SiC MOSFET in a 5kW Step-up converter
The SiC MOSFET has been tested in a DC/DC Boost 5KW, developed on purpose for internal evaluation only.

**BOOST SPECS:**

\[ V_{IN} = 600V, \quad V_{OUT} = 800V, \quad CCM, \quad \text{DUTY CYCLE} \approx 27\%, \quad \text{Output Power} = 5KW. \]

**BOOST DIODE:**

2x1200V 6A ST SiC DIODES (STPSC6H12B) in parallel

**BOOST INDUCTOR:** L=1mH@100KHz developed on purpose with low parasitic capacitance to minimize its impact on MOSFET turn on losses.
# Devices under comparison

<table>
<thead>
<tr>
<th>DEVICES, PACKAGE</th>
<th>BV, I</th>
<th>Typ Ron/Vcesat</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiC MOSFET, HIP247 (prototype)</td>
<td>1.2kV, 34A@100°C</td>
<td>80mΩ @ 20V, 25°C — 100 mΩ @ 20V, 200°C</td>
</tr>
<tr>
<td>SI IGBT TO247</td>
<td>1.2kV, 25A@100°C</td>
<td>2.1V @ 15V, 25A (84mΩ equiv@15V, 25A) 2.7V @ 15V, 25A, 175°C</td>
</tr>
</tbody>
</table>

4kW boost converter DEMO prototype based on SCT30N120 (by Applications IPG Products EMEA-Prague)
SiC MOSFET on board
How to drive the SiC MOSFET

SiC MOSFET can be simply driven by a standard IGBT Gate Driver

PROS:
• VERY SIMPLE IMPLEMENTATION OF THE DRIVING STAGE ALLOWED

NEEDS:
• HIGH SOURCE AND SINK CURRENT CAPABILITY.
• WIDE OPERATING VOLTAGE RANGE, MINIMUM 25V

CONS:
• NO PROTECTION FEATURES IMPLEMENTED.
• EXTERNAL ISOLATION BETWEEN CONTROL PART AND POWER STAGE REQUIRED (if needed).
• NO NEGATIVE GATE DRIVE ABILITY
SiC MOSFET on board
How to drive SiC MOSFET

The standard and well known ST TD350 driver can be used:
just an external push pull may be necessary to increase the current capability

A galvanically isolated driver with several control and diagnostic features and high source/sink current capability

PROS:
- MATURE AND COST EFFECTIVE TECHNOLOGY OF THE GATE DRIVER
- SEVERAL PROTECTION FEATURES INCLUDED.
- NEGATIVE GATE DRIVE ABILITY

NEEDS:
- EXTERNAL PUSH PULL REQUIRED TO REACH VERY FAST TURN ON AND TURN OFF

CONS:
EXTERNAL ISOLATION BETWEEN CONTROL PART AND POWER STAGE REQUIRED (if needed)

...a galvanically isolated driver with several control and diagnostic features and high source/sink current capability
SiC MOSFET Operation – Overall (4kW)

25kHz

+20V  Vgs  Vds  -4V  Id

100kHz

+20V  Vgs  Vds  -4V  Id

Measure value status
P1 area(F2) -3.0310348 ml
P2 area(C1)
P3 freq(C4)
P4 area(M3)
P5 ---
P6 ---
SiC MOSFET - Dynamic Comparison vs IGBT turn-off (5kW)

SiC MOSFET $E_{off}=188 \, \mu J$

IGBT $E_{off}=734 \, \mu J$

Test conditions for both switches:

Pin=5KW, Vin=600V, Vout=800V, fsw=25Khz, D=27%, $R_{gon}=R_{goff}=2.2\Omega$, $V_{g(e/s)}=4V$
SiC MOSFET on board
DC/DC Boost converter @ 25KHz

SiC MOSFET & SI IGBT DRIVING CONDITIONS: $R_{gon}=R_{goff}=2.2\Omega$, $V_{goff}=-4V$
SiC MOSFET on board
DC/DC Boost converter @ 25KHz

Efficiency SiC vs SI @25KHz

At 25kHz the IGBT still represents a cost effective solution despite the high turn-off energy

SiC MOSFET & SI IGBT DRIVING CONDITIONS: Rgon=Rgoff=2.2\,\Omega, \ Vgoff=-4V
SiC MOSFET on board
DC/DC Boost converter @ 100KHz

Efficiency SiC vs Si @100kHz

At 100kHz the Si IGBT is not a viable solution. SiC MOSFET represents the main alternative.

SiC MOSFET & Si IGBT DRIVING CONDITIONS: $R_{gon}=R_{goff}=2.2\Omega$, $V_{goff}=-4V$
SiC MOSFET on board
DC/DC Boost converter @ 100KHz

Case temperature SiC vs Si @100kHz

Tc=90°C has been considered as the maximum case temperature allowed for the IGBT@Tamb=25°C during its operation. The board has been stopped after few minutes beyond this maximum T\textsubscript{case} value.

Tc=115°C has been considered the maximum value allowed for the SiC MOSFET during its operation.
SiC MOSFET on board
SiC advantage in numbers

1.2 kV SiC MOSFET IS ABLE TO GUARANTEE SIMILAR EFFICIENCY LEVELS THAN 1.2 kV SI IGBT AT $f_{SW} = 4$ TIMES HIGHER THAN IGBT!!

FURTHER EFFICIENCY INCREASE IS STILL POSSIBLE BY USING A MOSFET AS BOOST DIODE AND LET IT CONDUCTING IN THE THIRD QUADRANT (SR PRINCIPLE)
And….Above 100kHz
DC/DC Boost converter @ 125KHz

Efficiency SiC MOSFET @125kHz

Still very high efficiency also above 100kHz
Case temperature SiC MOSFET @125kHz

![Graph showing the relationship between output power (P_{out}) and case temperature (T_{case}) for a DC/DC Boost converter at 125kHz.](image)

- **Maximum value of T_{case} for the SiC MOSFET**

T_{c}=115°C has been considered the maximum value allowed for the SiC MOSFET during its operation.

There's still big room to further increase either maximum power or switching frequency.
## Summary: Key benefits of SiC solutions

<table>
<thead>
<tr>
<th>Key features</th>
<th>Key benefits</th>
<th>Impact</th>
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<tbody>
<tr>
<td>Higher operating frequency</td>
<td>Reduction of bulky passive components</td>
<td>Size</td>
</tr>
<tr>
<td></td>
<td></td>
<td>System cost (passive)</td>
</tr>
<tr>
<td>Lower power losses with temperature &amp;</td>
<td>Reduction of cooling requirements &amp; heatsink size</td>
<td>Size</td>
</tr>
<tr>
<td>Higher operating temperature</td>
<td></td>
<td>System cost (heatsink)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reliability</td>
</tr>
<tr>
<td>Easy to drive</td>
<td>Lower components Count</td>
<td>System cost</td>
</tr>
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</table>
Grazie
Thanks
谢谢