CoolSiC™ MOSFETs - Revolution to rely on

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Product Marketing Manager at Industrial Power Control division
Outline

1. Power market trends and role of SiC
2. SiC at Infineon – positioning and general approach
3. Reliability as fundamento
4. Performance and usability for broad adoption
5. Summary
Megatrends call for new and efficient ways to generate, transmit and consume energy

### Global megatrends

- Climate change & scarce resources
- Demographic & social change
- Urbanization
- Digital transformation

### Power market trends

- Renewable energy, transmission & storage
- Energy efficient consumption
- eMobility & traction
- Industrial automation & robotics
Increasing demand for electrical energy is driving the need for energy efficiency

Shaping the electrical energy chain

1) Source: BP 2018 Energy Outlook
The use of SiC MOSFETs to improve conversion performance or implement system innovation

- Cuts charging time in half
- Cutting losses by 50% for extra energy from the battery
- Cutting energy losses in half in 24/7 operation
- Fanless drive in industrial automation
- Compact integration of inverter and motor
- Doubling inverter power at same inverter weight
One 1200 V SiC MOSFET better than two 650V Si switches

Si based solution:
AC/DC: Vienna PFC 650 V IGBTs + 1200 V diodes
DC/DC: 2x full-bridge LLC 650 V SJ MOSFETs

1200 V CoolSiC™ MOSFET solution:
AC/DC: B6
DC/DC: 1x full-bridge LLC

AC-DC: B6
DC-DC: 1x full-bridge LLC

~98.5% efficiency thanks to DC-DC stage’s 50% less switches and resulting loss reduction by 50%

Example: 15 kW building block with 450 W losses

15 kW building block with 150 W losses, or 30 kW building block with 450 W losses
... and bi-directional charging gets efficient, simple and energy saving!

Si based solution:
DC/DC: 2x full-bridge LLC 650 V SJ MOSFETs

1200 V CoolSiC™ MOSFET solution:
DAB (Dual Active Bridge)

~2% efficiency improvement during charging
~2% efficiency improvement during grid support

~2% less battery bank
MOSFET characteristics in 1200 V class brings lower conduction losses than the IGBT

- High torque (current) in acceleration and breaking period
- Low torque (current) in constant speed period
- Typically 90% time in low torque operation

### Output characteristic comparison

CoolSiC™ MOSFET 1200 V 45 mΩ vs. IGBT 1200 V 40 A @ 25°C & 175°C

### Conduction loss comparison vs IGBT

<table>
<thead>
<tr>
<th>Mode</th>
<th>SiC Reduce</th>
<th>Approximate Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Speed</td>
<td>65% ~ 83%</td>
<td></td>
</tr>
<tr>
<td>Acceleration</td>
<td>8% ~ 47%</td>
<td></td>
</tr>
<tr>
<td>Braking</td>
<td>7% ~ 40%</td>
<td></td>
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</tbody>
</table>

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...and lower switching losses even at the same EMC (~5 V/ns) as IGBT solution

**Low Q\textsubscript{rr} and No tail current**

![Graph showing I(t) vs. t for MOSFET and IGBT]

**Temperature independent switching losses**

![Graph showing I(t) vs. t for MOSFET and IGBT at 25°C and 150°C]

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**CoolSiC™ MOSFET 1200 V 45 mΩ vs. IGBT 1200 V 40 A @ 150 °C**

**Total switching loss at 150°C, acceleration and braking (20 A)**

- At the same dV/dt, SiC reduce 50% ~ 60% loss
- w/o dV/dt limitation, SiC reduce up to 90% loss

![Bar chart showing comparison of switching loss at 5 V/ns, 10 V/ns, and 50 V/ns]

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**Total switching loss at 25°C, constant speed operation (5 A)**

- At the same dV/dt, SiC reduce 20% ~ 35% loss
- w/o dV/dt limitation, SiC reduce up to 60% loss

![Bar chart showing comparison of switching loss at 5 V/ns, 10 V/ns, and 50 V/ns]

(IGBT is unable to achieve high fsw)
Up to 80% system loss reduction enables next generation servo drive

![Diagram showing system loss reduction with CoolSiC™ MOSFET and IGBT]

- **Enhance pulse current capability**
- **Same frame higher current**
- **Passive cooling**
- **Inverter motor integration**

**System loss reduction**

- **Constant speed**
- **Acceleration & braking**

<table>
<thead>
<tr>
<th>Device Type</th>
<th>IGBT Model</th>
<th>MOSFET Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 V IGBT</td>
<td>IKW40N120H3</td>
<td>1200V CoolSiC™ MOSFET IMZ120R045M1</td>
</tr>
</tbody>
</table>

- **Enhance pulse current capability**
- **Same frame higher current**
- **Passive cooling**
- **Inverter motor integration**

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A new degree of flexibility for system improvements

CoolSiC™

- Power density
- Efficiency
- Reliability
- CAV
- Servo drives
- Solar inverter
- Traction
- UPS
- Energy storage
- EV charging
<table>
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<th>Outline</th>
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<td>3</td>
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<td>4</td>
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<tr>
<td>5</td>
</tr>
</tbody>
</table>
Silicon Carbide (SiC) is a key topic for Infineon: one of four key areas of differentiation and innovation

1. Unique 300 mm thin wafer power semiconductor manufacturing
2. Compound semiconductors SiC and GaN
3. Digitalization of the power control loop
4. Functional integration
Infineon will complement each leading edge silicon solution with a wide bandgap technology

silicon-based power semiconductors

- IGBT modules (TRENCHSTOP™)
- high-voltage MOSFETs (CoolMOS™)
- discrete IGBTs (TRENCHSTOP™)
- mid-voltage MOSFETs (OptiMOS™)
- low-voltage MOSFETs (OptiMOS™)

WBG technology

- CoolGaN™
- SiC MOSFET today
- SiC MOSFET 2020
- GaN HEMT today
- SiC MOSFET 2020
- CoolSiC™

Note: for SiC, Schottky diodes 650 V and 1200 V come in addition to this view showing only transistors
Reliability and robustness assurance in SiC strongly linked to silicon mainstream technologies

Infineon is a leading supplier when it comes to

› High power
› High reliability
› High robustness

With this experience we set tough SiC MOSFET requirements

* PV = photovoltaic inverter; ** OBC = onboard charger
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The designed lifetime of a device has to be far beyond the lifetime of the actual application.

FIT rates in high-power Si devices mostly governed today by cosmic ray effects.

In SiC MOSFETs also gate oxide fails define the FIT rate for catastrophic (field) failures.

Gate oxide stability + Cosmic ray efficiency = Target FIT rate

Effective screening of defectivity

Design measures to control high electric fields
What is the gate oxide (GOX)?

DMOS (planar)

Source  Gate  Drain
n-  e  p

Trench

Source  Gate  Drain
n-  e  p

No matter whether planar or trench MOSFET design:

- **Gate oxide is the isolation layer between gate and source**
- Formed by SiO$_2$ (quartz, glass)
- By applying an electric field across the gate oxide ($V_{GS} >> 0$ V) a **conductive channel** is formed between Source and Drain
The GOX always fails at its weakest link

Why are extrinsic defects in the GOX so critical?

Extrinsic defects are any distortion in the GOX (substrate defects, particles, process variations) can be described as a local oxide thinning.

The thinner the GOX, the higher is the electric field at a certain gate bias and the lower is the time to breakdown, i.e. targeted lifetime cannot be reached.

GOX screening for extrinsic defects converts potential reliability risk into yield loss before product shipment.
CoolSiC™ MOSFET GOX screening builds on solid and long year in-house silicon experience

- **Dedicated GOX screening process** for CoolSiC™ MOSFET in place to detect any weak devices, valid for all Infineon's Si power technologies as well
- **Screening efficiency** increases with decreasing electric field across the GOX, under nominal Vgs turn-on use conditions
- **GOX thickness matters**, even nano meters!
Multiple levers for a SiC MOSFET must match

**Static behavior**
- $R_{ds(on)}$
- $R_{ds(on)}$ with temperature

**Dynamic behavior**
- Device capacitances
- Gate and body diode recovery charges

**Robustness and reliability**
- Gate oxide reliability
- IGBT or CoolMOS -like FIT rates
- Robustness against parasitic turn-on
- $V_{GS(TH)}>4\,\text{V}$
- Body diode rated for hard commutation
- Avalanche capability*
- Short-circuit capability*

**Ease of use**
- Wide $V_{GS}$ range*
- 0 V turn-off $V_{GS}$*

*depending on product configuration
The practical loss reduction

**In theory**

SiC MOSFET has very low switching loss

**In reality**

The low switching loss might be high due to capacitive turn-on

IF

the induced $\Delta V_{gs} = \Delta V_{ds} \frac{C_{dg}}{C_{dg}+C_{gs}}$ from capacitance ratio of chip is larger than threshold voltage $V_{gs(th)}$

THEN

risk of capacitive turn-on
...and the generated negative voltage spikes may be violating datasheet limits
Variations in capacitive turn-on voltage

Datasheet comparison:

Induced $V_{gs} = \Delta V_{ds} \frac{C_{dg}}{(C_{dg} + C_{gs})}$ for the case $V_{DC} = 600$ V

1200 V SiC MOSFET latest generation devices having a nominal on-state resistance of 60-80 mΩ, as per datasheets on supplier web pages September 2019
**CoolSiC™ MOSFET with a combination of high gate threshold and low capacitive turn-on voltage**

**Induced $V_{gs} = \Delta V_{ds} C_{dg}/(C_{dg} + C_{gs})$ for the case $V_{DC} = 600$ V**

Datasheet comparison:

Inherent immunity against parasitic turn-on

1200 V SiC MOSFET latest generation devices having a nominal on-state resistance of 60-80 mΩ, as per datasheets on supplier web pages September 2019
Designing to performance: CoolSiC™ MOSFET creates a benchmark in low dynamic loss

Eon measured* at $V_{gs(off)} = 0$ V, 800 V, 15 A and 150°C


1200 V SiC MOSFET latest generation devices having a nominal on-state resistance of 60-80 mΩ, as per datasheets on supplier web pages Sept-19
No parasitic turn-on of CoolSiC™ MOSFET at 0 V turn-off gate voltage

Turn on wave form for IMZ120R060M1H at 150°C, $R_g = 2.2\, \Omega$, $V_{dc} = 800\, V$

- $V_{gs\,(off)} = 0 \, V$
- $V_{gs\,(off)} = -5 \, V$
Driving a CoolSiC™ MOSFET is easy

- **6 key components** are good to provide a fully controlled CoolSiC™ MOSFET drive schematics with 0V turn-off

- No negative drive voltage, no snubber, no gate capacitor!
**CoolSiC™ MOSFET base technology now available in a comprehensive product portfolio**

### Discretes

<table>
<thead>
<tr>
<th>RDson [mΩ]</th>
<th>1200 V TO-247-3</th>
<th>1200 V TO-247-4</th>
<th>1200 V D²PAK-7</th>
<th>RDson [mΩ]</th>
<th>650 V TO247-3</th>
<th>650 V TO247-4</th>
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<tbody>
<tr>
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### Easy 1B and Easy 2B

<table>
<thead>
<tr>
<th>RDson [mΩ]</th>
<th>1200 V half-bridge</th>
<th>1200 V booster</th>
<th>1200 V H-Bridge</th>
<th>1200 V 3-level</th>
<th>1200 V SixPACK</th>
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<tr>
<td>45</td>
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Available / In pipeline: release in Q2-Q3 CY2020
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CoolSiC™ solutions

Reliability as Si power transistor by Infineon

Powerful performance for broad adoption

Comprehensive 1200 V portfolio in series delivery, 650 V portfolio coming next

This is the revolution you can rely on!

For more product information, please visit
Webpage: www.infineon.com/coolsic-mosfet
Forum: www.infineonforums.com/forums/34-Silicon-Carbide-(SiC)-Forum
A world leader in semiconductor solutions

Our vision
We are the link between the real and the digital world.

Our values
We commit
We partner
We innovate
We perform

Our mission
We make life easier, safer and greener.

Part of your life. Part of tomorrow.