CoolSiC™ power MOSFETs – new additions to the portfolio

Fanny Björk, Laura Keuper, Andre Lenze, Karsten Schoo, Peter Friedrichs
Overview

1. SiC & Infineon - Positioning
2. Current application targets and related portfolio
   - Role of SiC diodes
   - MOSFET portfolio expansion
3. Outlook
Overview

1. SiC & Infineon - Positioning

3. Current application targets and related portfolio

- Role of SiC diodes
- MOSFET portfolio expansion

3. Outlook
SiC is a key topic for Infineon

Core innovations by Infineon presented by CEO at IFX Day mid of 2018

- Unique 300 mm thin wafer power semiconductor manufacturing
- Compound semiconductors SiC and GaN
- Digitalization of the power control loop
- Functional integration in IGBT
Device opportunities for WBG power

Diodes (SiC only)
- Schottky
- PN

Transistors
- HEMT
- MOSFET
- SJ MOSFET/ IGBT
- IGBT

Blocking voltage (V):
- Si
- SiC
- GaN

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SiC and GaN enable higher efficiency through faster switching at lower losses than Si

SiC is expected to complement silicon in many applications and to enable new solutions.

GaN is expected to enable new horizons in power supply applications and audio fidelity.

* PV = photovoltaic inverter; ** OBC = onboard charger
Overview

1. SiC & Infineon - Positioning

3. Current application targets and related portfolio
   - Role of SiC diodes
   - MOSFET portfolio expansion

3. Outlook
CoolSiC™ Schottky diode 650 V
G5 + G6 for a granular and complete portfolio

<table>
<thead>
<tr>
<th>Ampere [A]</th>
<th>TO-220 R2L</th>
<th>DDPAK</th>
<th>TO-247</th>
<th>D²PAK R2L</th>
<th>ThinPAK 8x8</th>
<th>TO-247 dual die</th>
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</thead>
<tbody>
<tr>
<td>2A</td>
<td>IDH02G65C5</td>
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<td></td>
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<td>IDW20G65C5B*</td>
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<td>24A</td>
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<td>IDW30G65C5</td>
<td>IDW32G65C5B*</td>
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<tr>
<td>40A</td>
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<td></td>
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<td>IDW40G65C5B*</td>
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</table>

*Common cathode

G5 Diode technology also implemented in power modules
1200V CoolSiC™ Schottky Diode G5 Portfolio
Now in TO247-2pin package

<table>
<thead>
<tr>
<th>Continuous Forward Current, $I_F$</th>
<th>TO-252 (DPAK real 2-leg)</th>
<th>TO-220 (real 2-leg)</th>
<th>TO-247-3</th>
<th>TO-247-2</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>8A</td>
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<td>IDH08G120C5</td>
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</tr>
<tr>
<td>10A</td>
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<td>IDWD10G120C5</td>
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<td>15-16A</td>
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<tr>
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<td>IDWD40G120C5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

G5 Diode technology also implemented in power modules

"B" in product name refers to common-cathode configuration:
1200V CoolSiC™ G5 Schottky diode

System improvements?
› Reach new efficiency targets
› Higher power density
› Upgrade designs towards higher output power
...while maintaining reliable system!

Easily enabled by SiC Schottky diodes

Benefit of TO247 2pin package
✓ Expanded creepage distance
✓ Suitable for high pollution environments
✓ Easy exchange of commonly used Si ultrafast diodes
Charging station: 1200V CoolSiC™ diode for high efficiency and high output power

Three-Phase Vienna PFC
2x Full-bridge LLC DC/DC Converter

AC input

Battery

Comparison at 48 kHz

SiC vs. Si diode:
- +0.8% higher efficiency
- Increased output power
Easy Hybrid Modules with CoolSiC™ Schottky Diodes G5

Key Features

› System efficiency improvement for reduced cooling requirements
› Enabling higher frequency to Increase Power density
› Reduction of IGBT turn-on loss
› Reduced EMI
› Switching loss independent from load current, switching speed and temperature

Target Applications

Solar

UPS

<table>
<thead>
<tr>
<th>Product</th>
<th>I&lt;sub&gt;c&lt;/sub&gt;</th>
<th>Voltage</th>
<th>Topology</th>
<th>Technology</th>
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<tr>
<td>FS3L40R07W2H5F_B11</td>
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<td>TRENCHSTOP™ 5</td>
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<td>650 V</td>
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<td>Highspeed 3</td>
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<td>Booster</td>
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<td></td>
<td>Highspeed 3</td>
</tr>
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Overview

1. SiC & Infineon - Positioning

3. Current application targets and related portfolio
   - Role of SiC diodes
   - MOSFET portfolio expansion

3. Outlook
SiC MOSFET will be adopted by various applications depending on the achievable cost performance level.

Application Driving forces:

- **Photovoltaics**: Reduction of system cost and size
- **EV charging**: Faster charging cycles
- **Traction**: Lower system cost and higher efficiency
- **UPS/SMPS**: Higher efficiency, reducing TCO
- **Drives**: System size and TCO reduction
- **eMobility**: Higher reach per charge and smaller systems

Note: 1) UPS = uninterrupted power supply; SMPS = Switched-mode power supply; TCO = total cost of ownership
System integration and energy savings will be a key lever for power electronics.

Best in class switching frequency, conduction losses and radically improved efficiency.

<table>
<thead>
<tr>
<th>Component</th>
<th>Si-IGBT &amp; Si-diode</th>
<th>Si-IGBT &amp; SiC-diode</th>
<th>SiC-switch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery losses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn-off losses</td>
<td></td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Turn-on losses</td>
<td></td>
<td></td>
<td>80%</td>
</tr>
</tbody>
</table>
The broadest portfolio of CoolSiC™ MOSFET modules in Easy package on the market

**Key Features**

› About 80% lower switching losses compared to Si
› Low conduction losses due to linear output characteristic
› Superior gate oxide reliability
› Intrinsic body diode with low reverse recovery charge
› Highest threshold voltage of $V_{th} > 4$ V

**Target Applications**

... and more

The broadest portfolio of CoolSiC™ MOSFET modules in Easy package in the market

<table>
<thead>
<tr>
<th>Rdson [mOhm]</th>
<th>EasyDUAL™</th>
<th>Easy Booster</th>
<th>EasyPACK™</th>
</tr>
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<tbody>
<tr>
<td>45</td>
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<td>1200V Booster</td>
<td>FS45MR12W1M1_B11</td>
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<td>DF23MR12W1M1_B11</td>
<td>F4-23MR12W1M1_B11</td>
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<td>11</td>
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<td>DF11MR12W1M1_B11</td>
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<tr>
<td>8</td>
<td>FF8MR12W2M1_B11</td>
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<tr>
<td>6</td>
<td>FF6MR12W2M1_B11</td>
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</tbody>
</table>

Available

New parts recently launched ★

Available

Drain-source on resistance

45mΩ
6mΩ
Sneak preview: 62mm module with CoolSiC™ MOSFET

Experienced package with newest technology

Upcoming module product

Half bridge 2–6mOhm
- FF4MR12KM1*

*in development

Well-known robust design

Excellent temperature distribution

Less design-in effort

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1200V CoolSiC™ MOSFET: Sneak Preview: roll-out in TO-247

<table>
<thead>
<tr>
<th>On-resistance, RDSon [mOhm]</th>
<th>TO247-3</th>
<th>TO247-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>Released</td>
<td>Released</td>
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<tr>
<td>60</td>
<td>Samples in Q2 2019</td>
<td>Samples in Q2 2019</td>
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<tr>
<td>90</td>
<td>Samples in Q2 2019</td>
<td>Samples in Q2 2019</td>
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<tr>
<td>140</td>
<td>Samples in Q2 2019</td>
<td>Samples in Q2 2019</td>
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<tr>
<td>220</td>
<td>Samples in Q4 2019</td>
<td>Samples in Q2 2019</td>
</tr>
<tr>
<td>350</td>
<td>Samples in Q4 2019</td>
<td>Samples in Q2 2019</td>
</tr>
</tbody>
</table>
Sneak Preview :
HybridPACK™ Drive for automotive drive train

Infineon introduced SiC power module for automotive applications

- 3-phase half-bridge module
- Power density doubled compared to IGBT
- HybridPACK™ Drive compatible
- Target applications:
  - Main inverter (300 kW)
  - high-voltage DC-DC converter

More than 15 leading OEMs and tier-1s are evaluating Infineon’s SiC-based HybridPACK™ Drive power module.
HybridPACK™ Drive with SiC is part of a well adjusted portfolio enabling at customers variable designs

- Performance tuning by
  - Chipset (technology and voltage rating)
  - Cooling concept
The backbone of SiC MOSFET production today - opportunities for solar conversion systems

15-20% lower bill of material for inverter manufacturer

› Simpler topologies with less control effort
› Higher switching frequency with smaller transformers
› Same power in smaller box size results in a significant system cost reduction

Total system cost [US$]

Si IGBT reference

SiC MOSFET demonstrator

SiC-based solution

Si-based solution

other
(ex: inductor, heat sink, etc.)

semi-conductor

other

semi-conductor

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Customer value proposition for PV string Inverters: Power density increase by 2,5

Development of Kaco String Inverters

<table>
<thead>
<tr>
<th>Year</th>
<th>Power</th>
<th>Weight</th>
<th>Height</th>
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<tbody>
<tr>
<td>2008</td>
<td>100 kW</td>
<td>1129 kg</td>
<td>2.12 m</td>
</tr>
<tr>
<td>2011</td>
<td>50 kW</td>
<td>151 kg</td>
<td>1.36 m</td>
</tr>
<tr>
<td>2016</td>
<td>50 kW</td>
<td>70 kg</td>
<td>0.76 m</td>
</tr>
<tr>
<td>2018</td>
<td>125 kW</td>
<td>77 kg</td>
<td>0.72 m</td>
</tr>
</tbody>
</table>

Value Proposition

› Power density increase by factor 2,5 (50kW → 125kW)

› Reduction of number of switches (5-level to 3-level) leads to reduced risk of field failures

› SiC provides less reduction in efficiency at high operating temperatures → better efficiency (99,1% vs 98,9%)

Source:
EV charging will benefit from SiC based components regarding system simplification

› Today 15 kW-units using discrete components are state of the art, currently upgraded to 20...30 kW 19“ x 3 HU x 800 mm, forced air cooling

› New infrastructure is targeting DC-chargers exceeding 300 kW leading to two changes:
  - Liquid cooling is used in these designs
  - Power per subunit is growing to 60...75 kW in even smaller spaces

› Coming now are units exceeding 60 kW 19“ x 2 HU x 800 mm, liquid cooling ➔ possible with SiC only
EV charging will benefit from SiC based components regarding system simplification

Off-board EV charger: CoolSiC™ MOSFET simplifies the system
1200V CoolSiC™ MOSFET in Easy 2B package: excellent value proposition for online UPS systems

› Using CoolSiC™ MOSFETs in a high power UPS can save ~€40,000 over 5 years operating in electricity costs (see calculation).

› In addition: heatsinks and filters can be reduced, making size, floor footprint and enclosure smaller.

› Easy 2B CoolSiC™ MOSFET modules can be paralleled to achieve a high current SiC MOSFET solution with very low inductance!
# High Power UPS Topologies

<table>
<thead>
<tr>
<th>Si 2-Level</th>
<th>Si 3-Level NPCT</th>
<th>SiC 2-Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Years ago</td>
<td>5 Years ago</td>
<td>In 2019</td>
</tr>
<tr>
<td>3.2% losses* at 6kHz</td>
<td>2.9% losses* at 8kHz</td>
<td>1.7% losses* at 32kHz</td>
</tr>
</tbody>
</table>

*% Losses of Power Semi Devices at 300kW and 400Vac
Calculating the energy losses for a 1MW UPS operating at 50% load for 5 years

500kWhrs x 24 hours x 365 days x 5 years = 22 million kWhrs processed power through UPS

- **Si 2-Level at 3.2% loss** = 700,000 kWhrs x 1.2 factor* = 840,000 kWhrs
  - In EU at €.10 per kWhr = €84,000

- **Si 3-Level at 2.9% loss** = 640,000 kWhrs x 1.2 factor* = 760,000 kWhrs
  - In EU at €.10 per kWhr = €76,000

- **SiC 2-Level at 1.7% loss** = 374,000 kWhrs x 1.2 factor* = 450,000 kWhrs
  - In EU at €.10 per kWhr = €45,000

*1.2 factor reflects the energy used for air conditioning to extract heat from a building with UPS installed
Main inverter applications will account for ~80% of the overall automotive SiC market

Main Inverter SiC Penetration

- **Large and luxurious BEVs**: 100%
  - 2020

- **Compact and mid-sized xEVs**: 20-30%
  - 2024

- **Small xEVs**: >2030
  - 2020

- **As costs improve, advantages such as performance increase, range extension, and faster charging cycles will be fully adopted for premium cars**

- **The advantages of a SiC based main inverter are utilized on a use case base: e.g. form factor benefits for PHEV**

- **Si will be still more cost competitive for a long time and it is unlikely that low-range cars will be able to unfold the true potential of SiC**
The right package is key for full utilization of SiC benefits

**TO-247 with 4 pins**
- Drastically reduced switching losses due to additional source connection

![Graph showing Eoff -10% and Eon -40%](image)

**Our modules**
- Low stray inductances
- Optimized paralleling
- Easy PCB routing
- Highly symmetric strip line
Why low inductance?

Ringing between stray inductance and capacitance.

Low $L_s$ allows higher voltage utilization

Low $L_s$ reduces EMI trouble
SiC MOSFETs are fast switching AND high voltage devices, which common mode transient (CMT) can reach 50 V/ns or above

Higher switching speed requires higher gate drive current strength as well as well-matched delays and accurate timing and tight tolerances

SiC MOSFETs may need a negative gate voltage or a Miller clamp

SiC MOSFETs may need fast short circuit protection as its short circuit capability is less than traditional IGBT

To fully utilize the low Ron capability of SiC MOSFET, higher gate drive voltage is also required
Evaluation Boards
1200V CoolSiC™ MOSFET

- Complete set-up for evaluation of CoolSiC™ MOSFET switching behavior
- Configurable for continuous operation as a buck or boost converter
- Includes recommended EICEDRIVER™ IC 1EDI Compact
- Test of devices in TO-247 3pin/4pin and Easy1B Halfbridge
Overview

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   - Role of SiC diodes
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3. Outlook
Summary Key features CoolSiC™ MOSFET

SiC MOSFETs vs Si IGBT

› Low Qg & device capacitances
› Temperature-independent switching losses
› Intrinsic diode with low reverse recovery charge
› Knee voltage-free on-state

CoolSiC™ MOSFET vs Competition

› Superior gate oxide reliability
› Threshold voltage, $V_{th} > 4 \text{ V}$
› Short-circuit robustness, 2 $\mu$s
› IGBT-compatible gate driving, $+15 \text{ V}$ for turn-on
› Body diode use enabled w/o restrictions
› Safe turn off with 0V in booster
WBG‘s fast switching capability must be handled well, plug and play usually doesn´t work

3L IGBT @24kHz
State of the art solution

2L SiC @48kHz

Source: Sobe et al. PCIM 2017, "Experimental study of Si- and SiC-based Voltage Source Inverters"
Key ingredients for a successful roll out of WBG in mainstream applications

- **Extensive system expertise**
  - Extensive application system understanding and global support

- **Innovative technology and expertise in all leading power materials (Si, SiC, GaN)**

- **Unique power technology portfolio**

- **Application-dedicated products**
  - Most comprehensive power portfolio in the market ensures always best-fit

- **System**
  - Extreme high volume flexibility and reliability proven by multi million track record

- **Product**
  - Benchmark in manufacturing

- **Technology**

- **Manufacturing**
Part of your life. Part of tomorrow.