Short Circuit Tests with 4th Generation SiC MOSFETs in a Power Module for xEV Main Inverters

An Application Example for xEV applications

Since the benefits of SiC power semiconductors for electric powertrains are proven, SiC power semiconductors are quickly attracting attention as a next-generation technology. Higher efficiency of SiC MOSFETs compared to Si IGBTs lead to longer driving distances or smaller high voltage batteries, bringing benefits to the consumer. ROHM is one of the SiC pioneers and announced its 4th generation of SiC MOSFETs for multiple applications this year.

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ROHMs 4th generation in xEV

Since ROHM obtained qualification under the AEC-Q101 automotive standard for SiC in 2012, the company has built a track record for SiC MOSFETs, primarily in automotive chargers and DC/DC converters. ROHM presented the 1st trench based SiC MOSFET already in 2015. The experience in process and field design helped to create the newest generation with a 40% reduced Rdson compared to the previous trench-based generation.

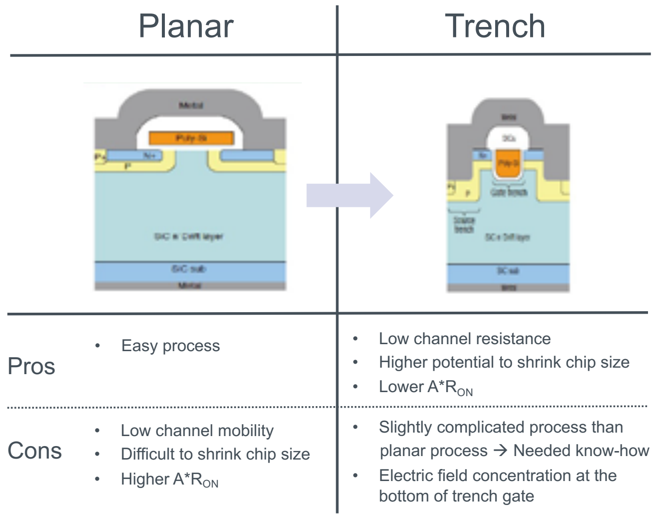


Figure 1: Planar vs. Trench

ROHM's latest 4th Gen SiC MOSFETs deliver low ON-resistance per unit area through advanced technology utilizing a trench gate structure. At the same time parasitic capacitance, the source of switching loss, has been reduced. This translates to a 40% performance improvement in drift layer resistance and 50% lower switching loss compared with 3rd Gen SiC MOSFETs. Switching loss in particular account for more than 70% of the losses generated by SiC MOSFETs in traction inverter applications, so minimizing this can contribute to significantly improved efficiency. [Tamegai]

Incidentally, superior response enables higher frequency operation, leading to smaller heatsink, capacitors, and other components used to smooth out the waveforms of voltage and current. And as the size of these components greatly affect the size of the inverter, they also contribute to greater miniaturization. SiC's high temperature resistance is also advantageous to downsizing. Compared to silicon power semiconductors, SiC enables stable performance at temperature exceeding 100°C (actually up to 175°C but the package and wiring cannot withstand this), allowing the cooling structure to be simplified by changing from water to air cooling and reducing the size of the heat sinks. [Tamegai]

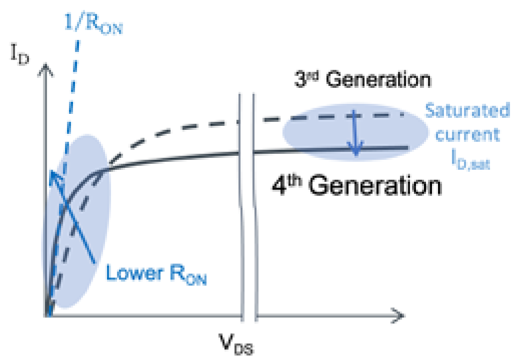


Figure 2: Optimized Short Circuit behavior

Short Circuit Tests

ECPE's guideline AQG 324 describe two short circuit scenarios which should be qualified on power module level [AQG 324]:

1. A Short circuit when no current was flowing before a.k.a. Short Circuit Type 1
2. A failure under load a.k.a. Short Circuit Type 2

Due to their high short circuit current and lower short circuit withstand time in comparison with Si-IGBTs, SiC MOSFETs require a fast and precise short circuit detection method. For this purpose, experimental short circuit detection and protection results of a newly developed power module using the conventional drain source monitoring method (a.k.a. DESAT) are presented at [PCIM 22].
The device under test used for this investigation was a power module for e-powertrain applications equipped with ROHM's newest generation of SiC trench MOSFETs.

Expectations 4th Gen in SC

ROHM's latest 4th Gen SiC MOSFETs reduce loss without compromising durability and reliability (short-circuit withstand time). Together with a low inductive power module design this promise an ideal solution for e-vehicle traction inverters.

Device under Test and Test setup

In ROHMs Power lab in Willich/Germany short circuit tests with 4th Gen were performed and presented at [PCIM 22]. A Power module from Semikron was used and a Gate driver testboard based on ROHMs Gate Driver BM6112 (20A output DESAT detection and Advanced Soft turn off) was developed to perform the tests.

The device under test (eMPack module from Semikron) was equipped with 4th Gen SiC MOSFET dies. It includes six switches (three half bridges) and was specifically developed for automotive traction inverters [4]. Blocking voltage of the semiconductors is 1200 V, the module's rated current is 780 A. A very low stray inductance has been realized through an innovative internal assembly and connection method to the DC-link capacitor. [PCIM 22]

To detect a Short Circuit the short circuit desaturation detection (DESAT) method was used. After DESAT is triggered, the so called Advanced Soft Turn Off (ASTO) is used to turn off the device quickly and safely.

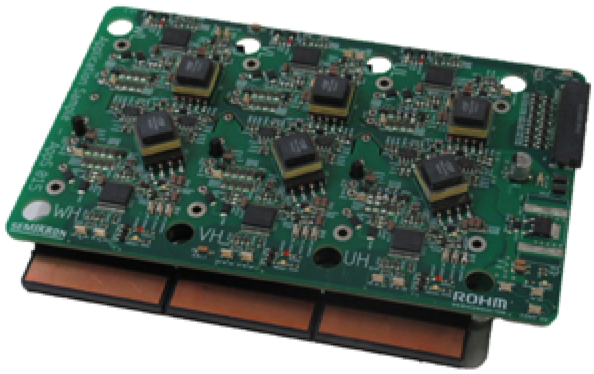


Figure 3: Testboard BM6112 for eMPack: "EMPACK6CHGD-EVK-301" with six GDIC BM6112FV for IGBT and SiC MOSFET, Vgson/off: 18V/0V

Test results

Before we present our results, we like to explain the Gate driver settings. Even if ROHMs 4th generation SiC MOSFETs are designed to withstand higher short circuit withstand times, we defined our goal based on market typical requirements. The market trend for DESAT detection circuits is to turn off a short circuit within 1.5-2µs.

Per definition the short circuit time is between the 10% of ISC during turn on and 10% of IC during turn off.

There are in general two gate driver design criteria which play a role in managing the short circuit time:

1. DESAT detection time
   Goal: tradeoff between detection speed and sensitivity
   Parameters: R1, R2, R3, D1 (pic. 4, left)
2. Turn off slope:
   Goal: tradeoff between turn off time and overvoltage due to parasitic L * di/dt
   Parameters: ASTO feature: R_PROOUT1 for ~160ns after DESAT is detected and R_PROOUT for the rest of the turn of slope (pic. 4, right)

We adjusted the gate driver board (picture 3 and 4) in a way that we first evaluated the DESAT with a hard short circuit (like type 1). We tested different soft turn off scenarios:

STO: Soft turn off
(R_PROOUT1=10Ω, R_PROOUT2=open)

ASTO: Advanced Soft Turn off
ASTO1: fast turn off
(R_PROOUT1=10Ω, R_PROOUT2=1.2Ω)
ASTO2: optimized ASTO
(R_PROOUT1=10Ω, R_PROOUT2=2.7Ω)

With ASTO1 design, the shortest t_{SC} was archived. However, the peak voltage upon turn off is with 1156 V which provides a low safety margin for a 1200V rated power device.

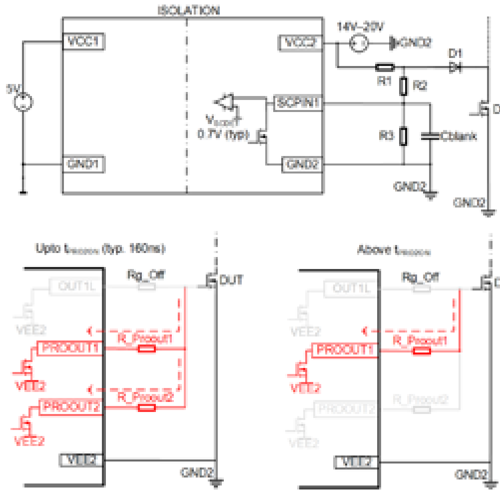
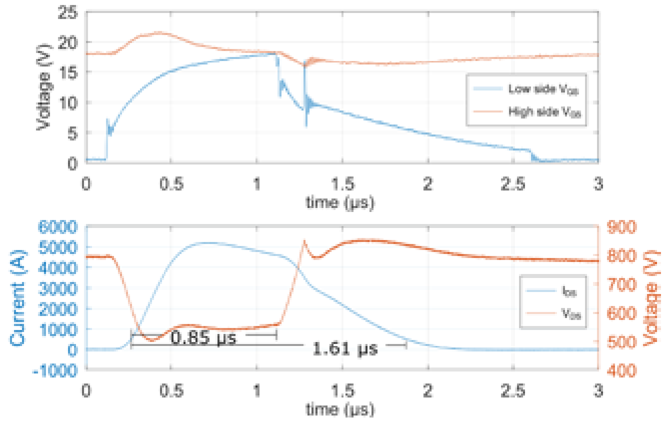


Figure 4: Top: DESAT detection in BM6112 [datasheet BM6112], bottom: ASTO [PCIM 2022]



Type of Soft turn-off	$V_{DS\,pk}$ [V]	t_d [ns]	t_{SC} [µs]	E_{SC} [J]
ASTO1	1156	850	1.34	2.88
STO	854	850	2.01	4.26
ASTO2	856	850	1.61	3.31

Figure 5: top: SC type 1 with ASTO 2, bottom: results with ASTO1: fast turn off, ASTO2: slow turn off

With STO and ASTO2 the overvoltage can be significantly reduced to an overshoot of less than 60V and thus a very good safety margin. The SC time with conventional soft turn off (STO) was around 2us with an overvoltage of 56V. ASTO2 achieve a shorter SC time (1.6us) and similar overvoltage levels as STO. Using ASTO2 is clearly a benefit since neither of SC time and overvoltage are compromised, henceforth will be used for further measurements shown in this article.

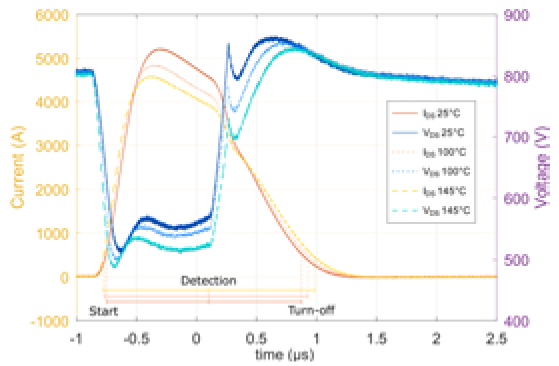


Figure 6: Short circuit Type 1

Second step was the evaluation of temperature’s influence for both, SC type 1 and 2 using ASTO2.

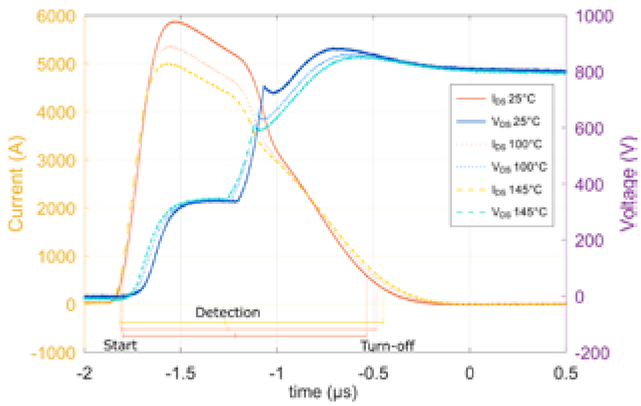


Figure 7: Short circuit type 2

Targets of the investigation:
Influence of temperature on

- td (DESAT detection time)
- tsc (short circuit time)
- Esc (short circuit energy)

Turning off the short circuit in both SC cases was possible within 2us. The gate driver detected independent of temperature, SC type I within 870ns and SC Type 2 within 550ns. The power device was also safely turned off within 1.7us in case of SC Type I and 1.3us in case of SC Type 2.

Conclusion

ROHMs newest SiC MOSFETs generation performs very well in a short circuit. The short circuit current of the 1200V MOSFET is round six times of the rated current in the device under test. A target SC time less than 2us was achievable and with an optimized Gate driver design (DESAT and ASTO) the overvoltage upon turn off was also less than 60V. With an optimized Gate Driver design (using DESAT and ASTO) it was possible to switch the short circuit off within 1.6µs by getting less then 60V overvoltage peak.

The combination of ROHMs 4th Gen SiC MOSFET in Semikron’s eMPack and ROHMs Gate Driver BM6112 are developed for automotive power train applications and bring xEV designs on the highest level of performance and robustness.

References

[Tamegai] The Impact of Silicon Power, Yoichi Tamegai, ROHM Co., Ltd., White Paper
[PCIM 22] Short circuit protection of a power module with Trench-SiC MOSFET. Can DESAT be fast enough?, Thayumanasamy; PCIM Nuremberg 2022
[AQG 324]; ECPE Guideline AQG 324, Release 03.1/2021
[4] https://www.semikron.com/products/product-lines/empack.html

Acknowledgement

It was a pleasure to collaborate with Ingo Rabl and Jürgen Engstler from Semikron on this investigation. Thanks also to our colleagues from headquarters, especially Yoichi Tamegai, Akifumo Enomoto and Naoyuki Kizu.

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