FAQ
SiC MOSFET

Description

This document introduces the Frequently Asked Questions and answers of SiC MOSFET.

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1. What is SiC ?

Compared with commonly used Si products, SiC products can achieve low power loss due to low on-resistance and high-speed switching, especially in the high-voltage range. It is a semiconductor material that is expected to expand because it can also operate at high temperatures, among power devices expected to grow.

Silicon carbide (SiC) comprises silicon (Si) and carbon (C) atoms. Each atom is surrounded by four different atoms in the form of a regular tetrahedron. SiC is a compound semiconductor with the densest tetrahedral arrangement. SiC has many crystalline structures called polytypes that exhibit different physical properties because of periodic differences in the overlap of tetrahedrons. Compared to silicon, SiC has a wider energy gap where no electron states can exist (called a bandgap) between the valence band (i.e., an energy band filled with valence electrons) and the conduction band (i.e., an empty energy band in which electrons can be present). A wide bandgap provides a strong chemical bond among atoms and therefore a high electric breakdown field. SiC has an electric breakdown field roughly ten times that of silicon. And SiC is a power device with high withstand voltage and low voltage drop can be realized. In the case of the same ithstand voltage, the on-resistance per unit area can be reduced compared with that of Si. In addition, while Si MOSFET is generally commercialized only up to about 1000V, SiC MOSFET is commercialized up to about 3300V because it can keep on-resistance low even at high withstand voltages.

SiC can realize MOSFET, the unipolar device that operate only with electronics even in high-voltage products, and the turn-off loss is smaller than bipolar devices because no tail current is generated. For this reason, SiC MOSFET is attracting attention because it can operate in the high switching frequency, which was difficult for Si IGBT, and has a great advantage of contributing to the miniaturization of passive components, making it ideal for power converting applications that require miniaturization and low-loss.

For example, it is widely used for OA and industrial switching power supplies, EV power supply equipment, welders for FA, and photovoltaic power generation applications. (Figure 1)

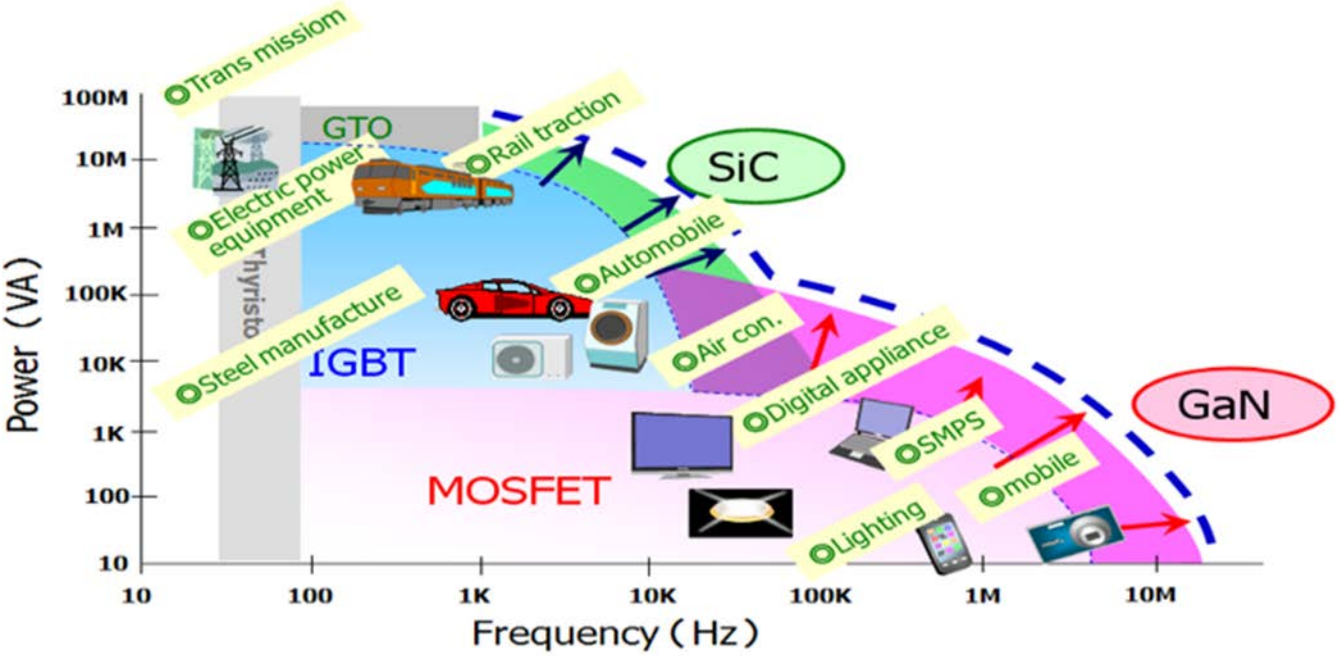

Figure 1. Application Use Case

2. Is it possible to connect multiple SiC MOSFETs in parallel?

SiC MOSFET can be connected and used in parallel in the same way as Si MOSFET.

For precautions on the parallel connection of MOSFET, refer to "MOSFET Application Notes _ Parasitic Oscillator, Parallel Connection" on the website of Toshiba Device & Storage Co., Ltd.
Fllowing three points must be noted for SiC MOSFET additionally.

1. $R_{DS(ON)}$ of SiC MOSFET is temperature-sensitive, so care must be taken. Since it consists of a channel resistive component with a negative temperature coefficient and a drift layer resistive component with a positive temperature coefficient, current imbalance may occur because the on-resistance is not positive temperature coefficient in low temperature range (Figure 2)

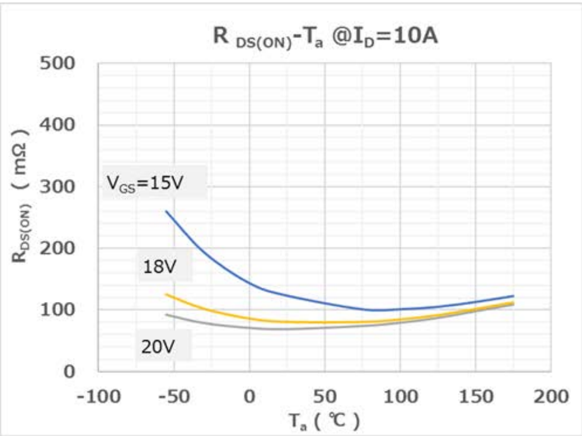

Figure 2(a). $R_{DS(ON)}$ - T_a Characteristics (10A)

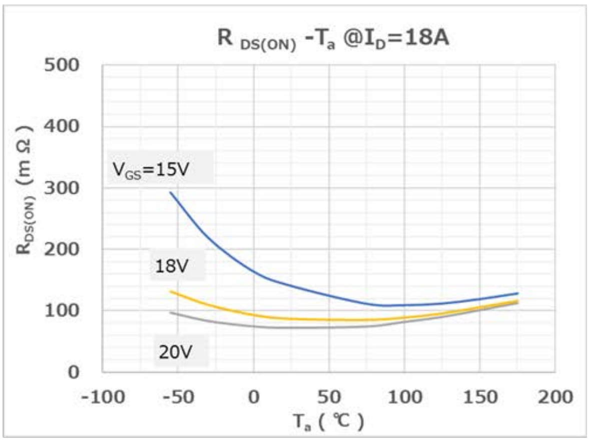

Figure 2(b). $R_{DS(ON)}$ - T_a Characteristics (18A)

2. If the gated-forward bias is below 18V, $R_{DS(ON)}$ become larger, and distribution wider. This can cause current to concentrate on a particular FET.
   Therefore, the gate forward bias design is recommended to be between 18V to 20V.(Figure 3)

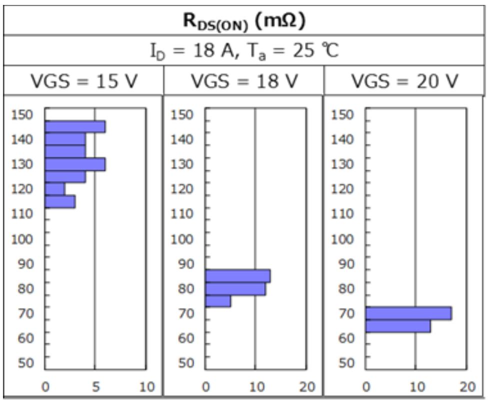

Figure 3. $R_{DS(ON)}$ Distribution map

3. Our second-generation SiC MOSFET has a built-in SiC SBD in parallel to the pn body diode, and the forward voltage of SiC SBD has a positive temperature-coefficient, which helps to ensure a stable current balance. Therefore, there is less chance of imbalance in SiC MOSFET than in Si MOSFET when current is applied from the source to the drain.

3. Is the back of the package of the SiC MOSFET insulated?

The example of packaging of our SiC MOSFET is illustrated in Figure 4.

The current packaging of our SiC MOSFET has electrodes exposed and is not insulated on the back when viewed from the marked side. The back side is connected to the drain. The drain has a high voltage. When attaching a radiator plate connected to the ground, be careful that this portion (red circular mark) does not also come into contact with the peripheral components.

To calculate the creepage distance between the radiator plate and the product or to determine the distance between the terminals, please refer MOSFET package information and application note for the installation of the radiator plate on web site below.

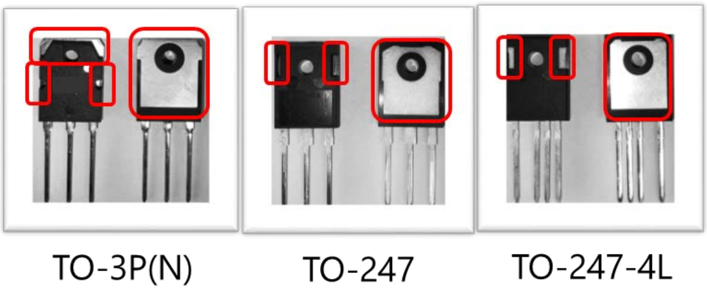

Figure 4. Example of SiC MOSFET Package

Web address

・Package & Packing Information

Japanese ：https://toshiba.semicon-storage.com/jp/design-support/package/MOSFET.html

English ：https://toshiba.semicon-storage.com/ap-en/design-support/package/MOSFET.html

・Application Note（Thermal Design and Attachment of a Thermal Fin）

Japanese ：https://toshiba.semicon-storage.com/info/docget.jsp?did=13412

English ：https://toshiba.semicon-storage.com/info/docget.jsp?did=13417

4. Please let me know the characteristic of the body diode

A typical SiC MOSFET body diode is a SiC pn junction diode. The reverse-recovery-time (t_{rr}) of this pn-junction diode is faster than that of a normal Si pn junction diode.

Our SiC MOSFET has built-in SiC Schottky barrier diodes (SBDs) between SiC MOSFET's drain-source (Figure 5) to reduce inductance due to wires and circuit boards when the SBDs are connected externally, it makes device suitable reducing losses and noises caused by high-frequency switching. In addition, conduction loss can be reduced compared to SiC MOSFET without built-in SBDs. (Figure 6)

Built-in SBDs are also effective in improving reliability, reducing the risk of characteristics change, such as threshold voltage (V_{th}) and on-resistance, due to defect that occur during long-term use. Our SiC MOSFET is designed with a built-in SiC SBD to prevent to energize pn-junction diodes, thus reducing the risk of characteristics change.

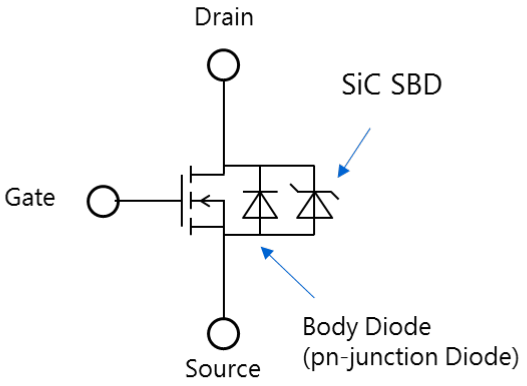

Figure 5. SiC MOSFET Equivalent Circuit

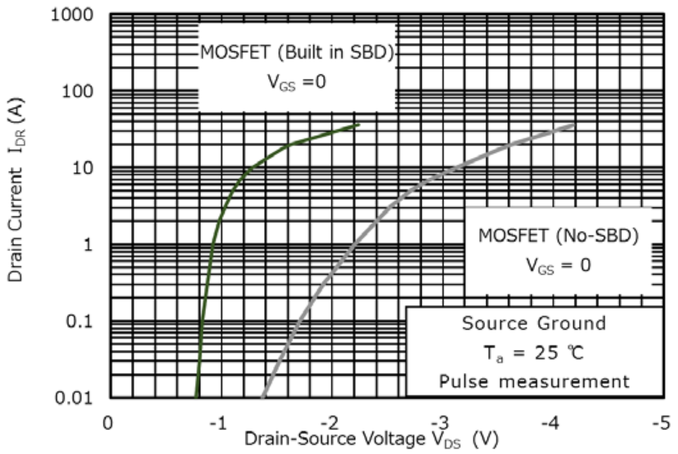

Figure 6. I_{DR}-V_{DS} Characteristics

5. If Si IGBT replaced with SiC MOSFET, what will change?

By replacing Si IGBT with SiC MOSFET, it is possible to reduce the size and weight of the euipments due to high-frequency operation, and to achieve highly efficient power conversion. The compared images of Si MOSFET/IGBT and SiC MOSFET characteristics are shown in Table 1.

*: Fast Recovery Diode ★: Higher numbers indicate superiority

Electrical Characteristics Symbol (Improvement)	Relation on application use	Si material		SiC material
		MOSFET	IGBT (Built in *FRD)	MOSFET (Built in SBD)
High voltage range (Large)	High voltage range of set	★★	★★★	★★★
Switching Loss (Small)	Efficiency (Smallness of the loss at the Turn-on/off time)	★★	★	★★★
Forward voltage of Built in Diode (Small)	Efficiency (Smallness of the loss at the energy for Diode)	★★	★★	★★★
Reverse recovery time of Built in Diode t_{rr} (Small)	Efficiency Smallness of the loss at the Turn-on)	★	★★	★★★

Table 1. Si、IGBT、SiC MOSFET Characteristics Comparison

Figures 7-1 and 7-2 show the swithing loss wave form when our SiC MOSFET and Si IGBT are switched at 25°C. Compared with IGBT, the turn-off loss and turn-on loss are reduced by 65%.
①The reduction of turn-off loss is influenced by the fact that SiC MOSFET has no minority carrier accumulation as in IGBT and no loss due to the tail current.
②The reduction in turn-on loss is due to the fact that SiC SBD built into SiC MOSFET has a smaller t_{rr}・I_{rr} of affecting the loss than Si FRD built into Si IGBT.

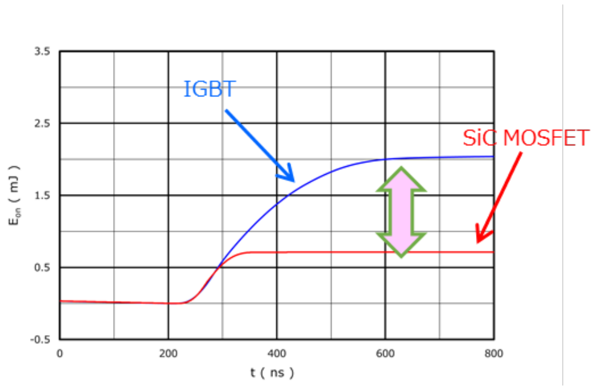

Figure 7-1. SiC MOSFET and Si IGBT Turn-on Switching Loss

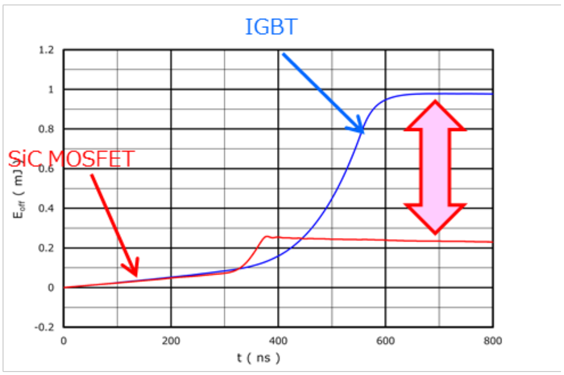

Figure 7-2. SiC MOSFET and Si IGBT Turn-off Switching Loss

6. Is there anything to note about the Gate drive voltage?

The explanation below illustrates our SiC MOSFET TW070J120B.

<Notes on Gate Control Voltage>

② Absolute max. rating-10V $\leq V_{GS} \leq$ 25V

②To set the gate-voltage at turn-on to 18V to 20V.

③Set the gate voltage at turn-off to 0 to -5 V.

④The gate-to-source capacitance shall be sufficiently charged with the gate charge.

<Details>

①Should be within the absolute maximum ratings

The absolute max. rated V_{GS}=+25,-10V including the surge voltage (overshoot and undershoot) should not be exceeded.

②To set the gate-voltage at turn-on to 18V to 20V.

$R_{DS(ON)}$ is shown in Fig. 8. The on-resistance rises sharply below 18V in Figure 8.

By setting V_{GS} between 18V and 20V, you can reduce the variation with low on-resistance.

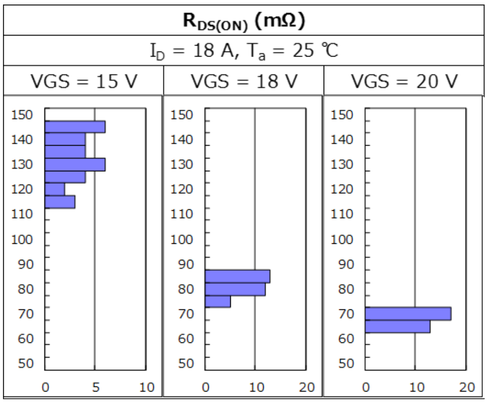

Figure 8. $R_{DS(ON)}$ Distribution map

③Set the gate voltage at turn-off to 0 to-5 V.

The curve of $V_{th} – T_a$ is shown in Fig. 9. The lower limit of the gate-threshold-voltage V_{th} is 4.2V at 25°C. In addition, as shown in the temperature characteristic curve, V_{th} has a negative temperature coefficient. It decreases around 1.5V at 25°C to 175°C. Please confirm the FET will not be turned on incorrectly because gate voltage during the off-period beyond V_{th} due to the effect of voltage fluctuation etc. during actual operation.

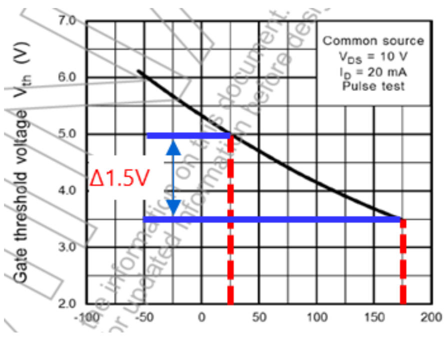

Figure 9. V_{th} Characteristic on temperature

④Drive current

The gate-to-source capacitance must be charged with gate charges in order for V_{GS} to be applied and turned on. As shown in Table2, V_{GS}=0 to 20V is typically 70nC. Provide a current that can sufficiently charge at the frequency to be used.

6.3. Gate Charge Characteristics (T_a = 25 °C unless otherwise specified)

Characteristics	Symbol	Test Condition	Min	Typ.	Max	Unit
Total gate charge (gate-source plus gate-drain)	Q_g	V_{DD} ≈ 800 V, V_{GS} = 20 V, I_D = 36 A	—	(70)	—	nC
Gate-source charge 1	Q_{gs1}		—	(20)	—	
Gate-drain charge	Q_{gd}		—	(25)	—	

Table 2. Electrical Characteristics(Q_g) in data sheet

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