# SiC MOSFET module application note Reliability

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# 1. SiC MOSFET Module

## 1.1. Scope

The scope of this application note covers the following products. (Table 1.1.1)

Table 1.1.1 Product covered in this application note

| Part No. | Drain-source voltage rating ($V_{DSS}$) | Drain current ($I_D$) | Gate-source voltage rating ($V_{GSS}$) | Recommended gate drive voltage ($+V_{GG}/-V_{GG}$) |
|---|---|---|---|---|
| MG600Q2YMS3 | 1200V | 600A | +25V/-10V | +20V/-6V |
| MG400Q2YMS3 | 1200V | 600A | +25V/-10V | +20V/-6V |
| MG400V2YMS3 | 1700V | 400A | +25V/-10V | +20V/-6V |
| MG250V2YMS3 | 1700V | 250A | +25V/-10V | +20V/-6V |
| MG250YD2YMS3 | 2200V | 250A | +25V/-10V | +20V/-6V |
| MG800FXF2YMS3 | 3300V | 800A | +25V/-10V | +20V/-6V |
| MG800FXF1JMS3 | 3300V | 800A | +25V/-10V | +20V/-6V |
| MG800FXF1ZMS3 | 3300V | 800A | +25V/-10V | +20V/-6V |

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## 2. SiC MOSFET Module Reliability

The purpose of semiconductor product reliability testing is to ensure longevity, equipment functionality, and performance and maintained for end users.

However, there are challenges in terms of “time and cost”, especially for semiconductor products which require a long average lifespan and low failure rate. Conducting tests under real operating conditions would result in a substantial amount of testing time and a large number of tests.

As a result, reliability testing generally involves shortening testing time by accelerating factors like voltage, temperature, and humidity. Additionally, it includes using statistical methods to extract examples or consideration of similarities between processes and designs to optimize the number of test samples.

Regarding SiC MOSFET modules, they also undergo life tests and various environmental tests within the DAT (Design Approval Test) to confirm whether they meet required specifications, quality standards and reliability goals. (Table 2.1)

Table 2.1 Example of MG600Q2YMS3 Reliability Tests

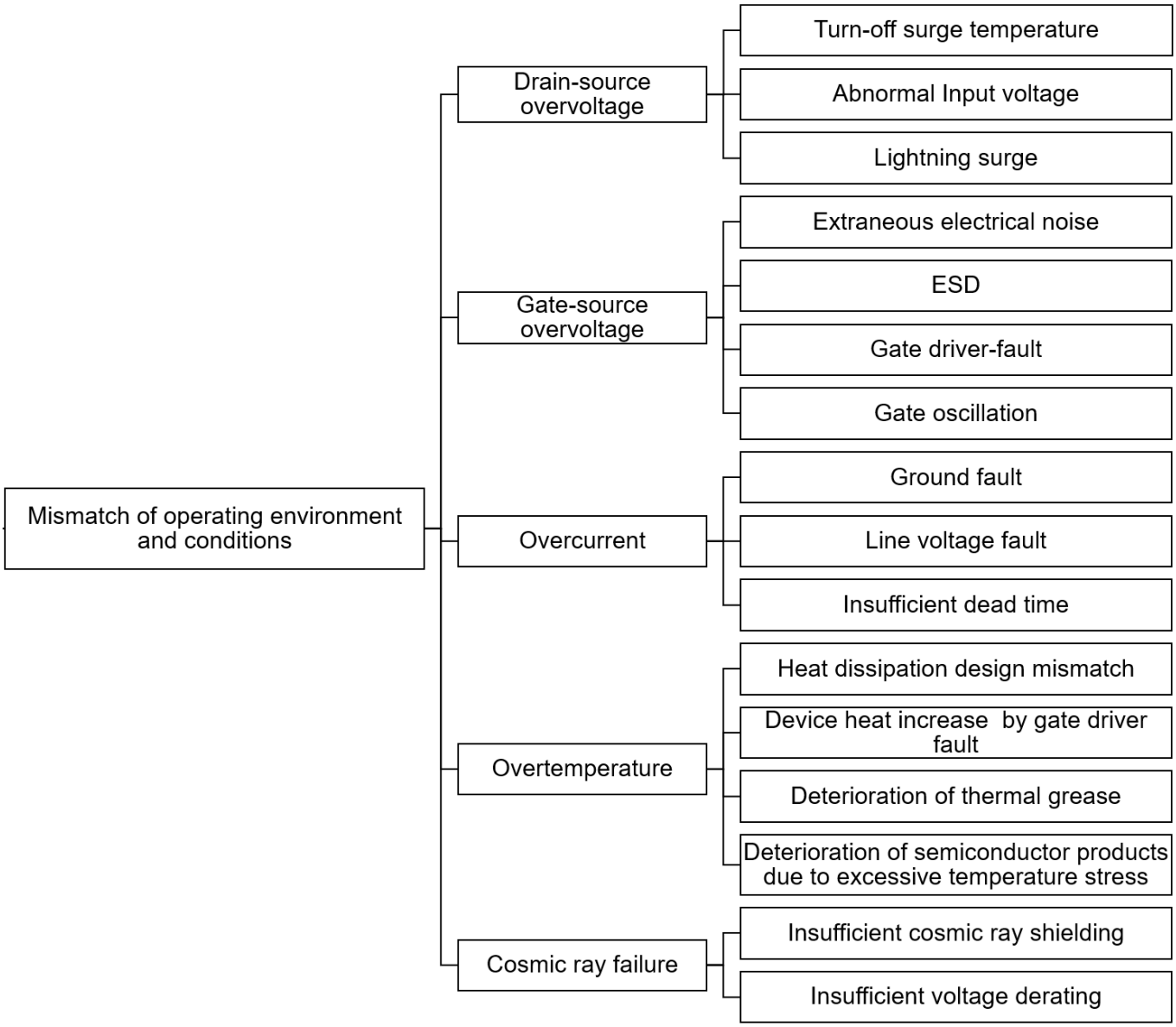
| Item | Compliant Standards | Test conditions |
|---|---|---|
| Temperature cycling | EIAJ ED-4701 | -40°C(60min) - 150°C(60min), cyclic |
| Vibration | EIAJ ED-4701 | 100 to 2000Hz, 200m/S2 X,Y, and Z direction |
| Shock | EIAJ ED-4701 | 5000m/s$^2$, pulse width：1ms X,Y, and Z direction, 5 times |
| Terminal strength | EIAJ ED-4701 | Main terminal: 4.5 N･m |
| High Temperature Reverse Bias | EIAJ ED-4701 | $V_{DS}$=1200V, $T_{ch}$=175°C |
| High temperature storage | EIAJ ED-4701 | Ta=150°C |
| Low temperature storage | EIAJ ED-4701 | Ta=-40°C |
| High temperature and high humidity storage | EIAJ ED-4701 | Ta=85°C, RH=85% |

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## 3. Failure mode of SiC MOSFET module

Failure modes of the SiC MOSFET module is shown in Table 3.1

Table 3.1 SiC MOSFET Module Failure Modes




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# 4. SiC MOSFET chip reliability

This chapter describes usage precautions with comparison of the reliability of SiC MOSFETs with the reliability of Si MOSFETs and Si IGBTs.

## 4.1. SiC MOSFET gate reliability

The gate oxide film of the SiC MOSFET and Si IGBTis the same (SiO2), and its electrical properties of the gate oxide film of SiC MOSFET (breakdown voltage, etc.) are the same as that of Si IGBT. The withstand of SiC MOSFETs to gate field strength is equivalent to that of Si IGBTs gate oxide films.

Furthermore, to ensure reliability in actual use, tests are conducted under the conditions determined for each product (absolute maximum gate-source voltage and maximum junction temperature) to confirm that there are no failures. (Table 4.1.1)

Table 4.1.1 MG800FXF2YMS3 Gate Reliability Test Conditions

| Item | Test Conditions | Number of samples | Number of failures |
|---|---|---|---|
| Gate-source voltage | $V_{GS}$=+25V, -10V<br>$V_{DS}$=0V<br>$T_{ch}$=175°C<br>1000 hours | 5 | 0 |

## 4.2. SiC MOSFET $V_{th}$ stability

When the gate of a MOS device is subjected to thermal and electrical stress, electrical characteristics fluctuations occur due to carrier capture at the surface of $SiO_2$. Particularly, SiC MOSFETs as power semiconductors react sensitively to this phenomenon and appears as a change in $V_{th}$. As $V_{th}$ changes, the on-voltage and switching speed change during the use of the SiC MOSFET module, so the change in $V_{th}$ must be significantly small.

We have developed a technology to minimize the $V_{th}$ change of SiC MOSFETs and applied it to the chips of the SiC MOSFET module. (Figure 4.2.1, 4.2.2)

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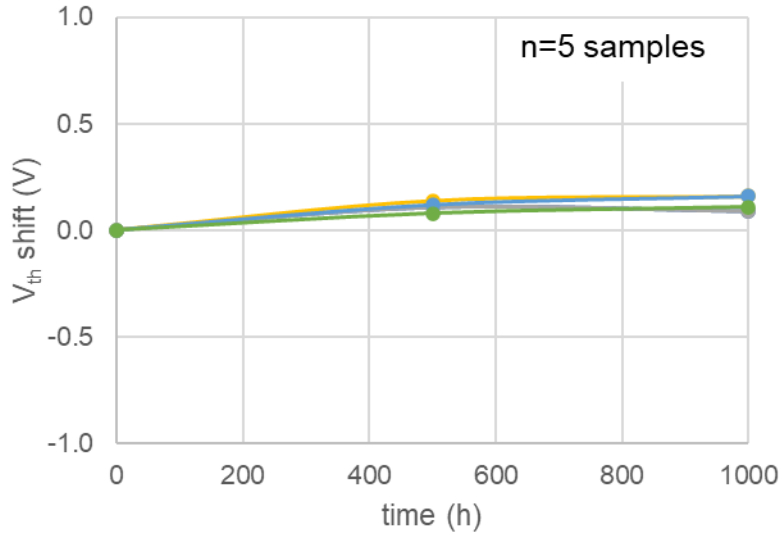



Fig. 4.2.1 $V_{th}$ shift with Continuous Positive Gate Bias Voltage Test
(MG800FXF2YMS3, $V_{GS}$=25V, $T_{ch}$=175°C)

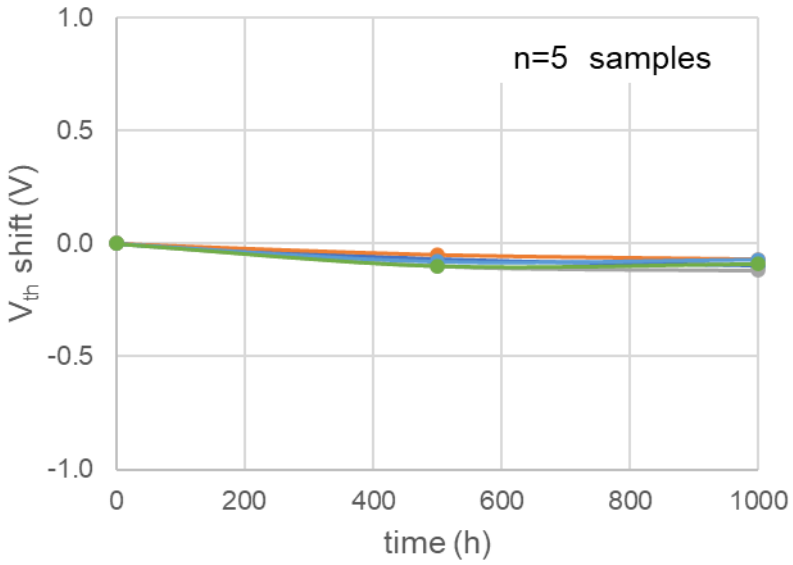



Fig. 4.2.2 $V_{th}$ shift with Continuous Negative Gate Bias Voltage Test
(MG800FXF2YMS3, $V_{GS}$=-10V, $T_{ch}$=175°C)

## 4.3. SBD embedded SiC MOSFET

Current technology has not been able to completely eliminate defects in SiC crystals used as semiconductor materials. In particular, SiC MOSFETs defects increase in size in the SiC crystal when the parasitic PN diode between the drain and source is in conduction. Expansion of crystal defects increase the on-resistance of the MOSFET and may result in failure.

Toshiba SiC MOSFETs solve this problem by adopting a structure in which Schottky barrier diodes (SBD) are integrated in parallel with the parasitic PN diodes on the MOSFET chip. (Figure 4.3.1)

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Reverse current flows the SBD in the MOSFET chip shunts the current of the parasitic PN diode. To avoid conducting the parasitic PN diode in this way, the growth of defects is eliminated.

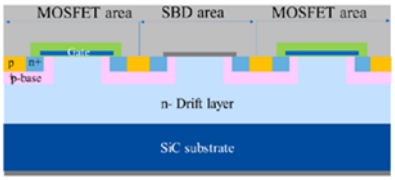



Figure 4.3.1 Structure of SBD embedded SiC MOSFET

## 4.4. Cosmic ray random failure of SiC MOSFET

Power devices including Si MOSFETs and Si IGBTs react with cosmic rays from outer space, causing failures which are called single event burnouts (SEBs). The probability of this phenomenon is high at higher altitudes and during the use of the SiC MOSFET module at higher drain voltage. (Figure 4.4.1)

The resistance to this failure is called Long Term DC Stability (LTDS). Sufficient derating should be provided when using SiC MOSFETs.

Contact us to estimate the cosmic ray random failure rate for use at high altitude areas or at high operating voltage conditions.

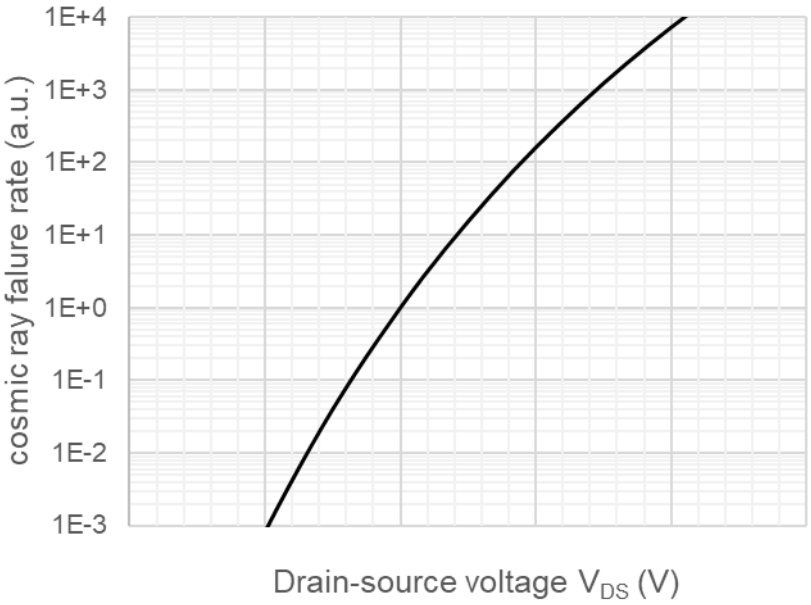



Figure 4.4.1 An Example of SiC MOSFET LTDS

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# 5. Reliability of package of SiC MOSFET module

The reliability of the package of SiC MOSFET module is mainly effected by thermal stress. The SiC MOSFET module experience temperature swings which depends on the operating conditions. Due to this temperature swing, the internal materials of the module deteriorate under the thermal stress. Since temperature swings vary depending on operating conditions, heat dissipation conditions, etc., it is necessary to estimate the life of the SiC MOSFET module.

## 5.1. Temperature stress and lifetime of SiC MOSFET module

A typical failure of the temperature cycling stress of power modules occurs between materials with different thermal expansion coefficients of the materials.

Thermal fatigue failures mainly occur at the contact point between the chip and bonding wires and at the solder between the insulating substrate and the baseplate. The former depends on the thermal cycling history of $T_{ch}$ and the latter on the case temperature $T_c$.

Our SiC MOSFET modules use the latest technology to dramatically improve the thermal cycling stress between the insulation substrate and the baseplate. As a result, the bonding wire lift off occurs before solder deterioration between the insulation plate and the baseplate, so thermal stress reliability needs to be considered only on the thermal history of the $T_{ch}$.

The heat stress before the failure is expressed by the number of cycles until failure, counting the rise and fall of temperature as one cycle. There are three important parameters to consider being Tvjmax, ΔTvj, and Ton. Tvjmax is the maximum temperature of the channel, ΔTvj is the difference between the minimum and maximum temperature of the channel for a temperature cycle, and Ton is the duration that the SiC MOSFET chip is conducting, which is equal to the duration at which the temperature of the chip rises.

The contact of the bonding wire and the SiC MOSFET chip experiences distortions by expansion and contraction due to the temperature cycle. The larger the ΔTvj, the greater the strain of the package materials, hence the larger the ΔTvj, the shorter the lifetime of the power module becomes. (Figure 5.1.1) When the ΔTvj is the same, the longer Ton causes greater effect of the strain. (Figure 5.1.2) Please contact us for the individual Tvjmas, ΔTvj, Ton, and the number of cycles dependencies of each product.

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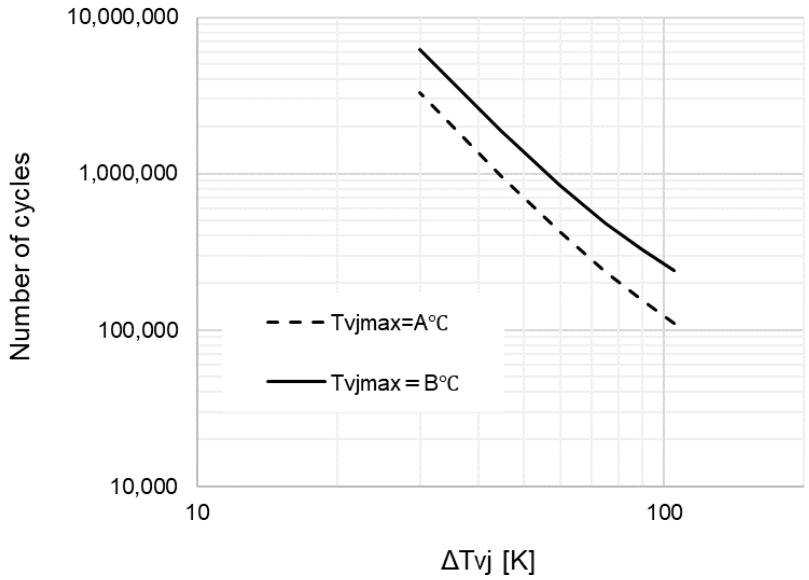



Figure 5.1.1 An Example of the relationship between ΔTvj and number of cycles

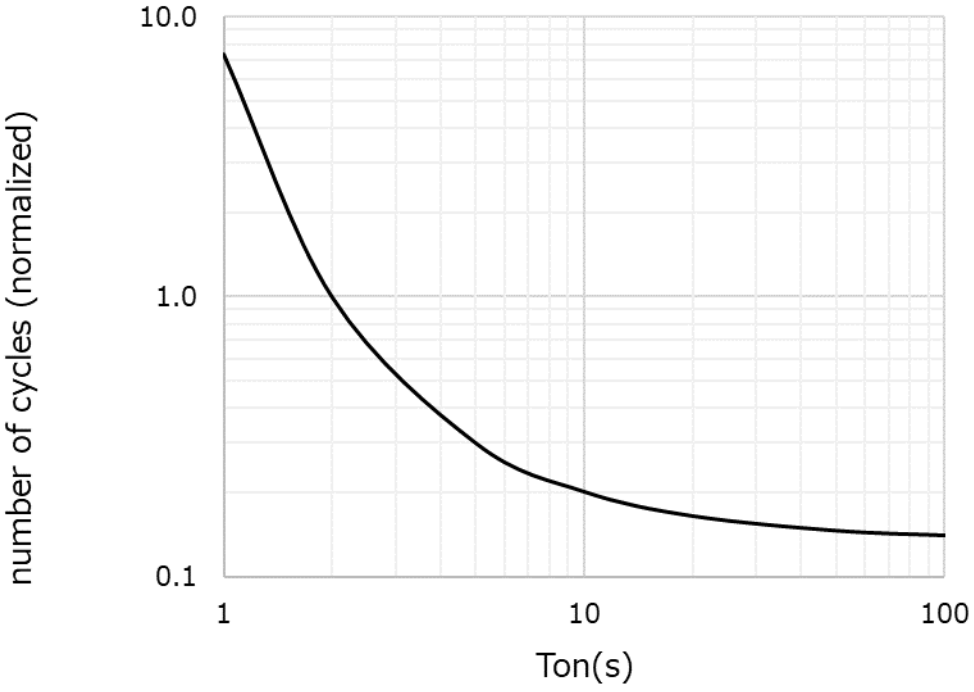



Figure 5.1.2 An Example of the relationship between Ton and number of cycles
(Normalized at Ton = 2 seconds as 1)

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