SiC MOSFET module application note Reliability

Table of contents

1. SiC MOSFET Module

1.1. Scope

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

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
MG400V2YMS3	1700V	400A	+25V/-10V	+20V/-6V
MG800FXF2YMS3	3300V	800A	+25V/-10V	+20V/-6V

Table 1.1.1 Product covered in this application note

2. SiC MOSFET Module Reliability

Semiconductor product reliability testing is intended to ensure that shipped semiconductor products, after assembly and adjustment by the customer, exhibit the desired lifetime, functionality, and performance in the hands of the end user. Nevertheless, there are constraints of time and money.

Because semiconductor products require a long lifetime and low failure rate, to test semiconductor products under actual usage conditions would require a great amount of test time and excessively large sample sizes.

The testing time is generally shortened therefore by accelerating voltage, temperature and humidity. In addition, statistical sampling is used, considering the similarities between process and design, so as to optimize the number of test samples.

SiC MOSFET modules are also subjected to life tests and various environmental tests in the DAT (Design Approval Test) to confirm that they meet the required specifications, quality, and reliability targets. (Table 2.1)

Item	Compliant Standards	Test conditions
Temperature cycling	EIAJ ED-4701	-40°C(60min) - 150°C(60min), cyclic
Vibration	EIAJ ED-4701	100~2000Hz, 200m/S2 X,Y,Z direction
Shock	EIAJ ED-4701	5000m/s^2, pulse width：1ms X,Y,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%

Table 2.1 An Example of MG600Q2YMS3 Reliability Test

3. Failure mode of SiC MOSFET module

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

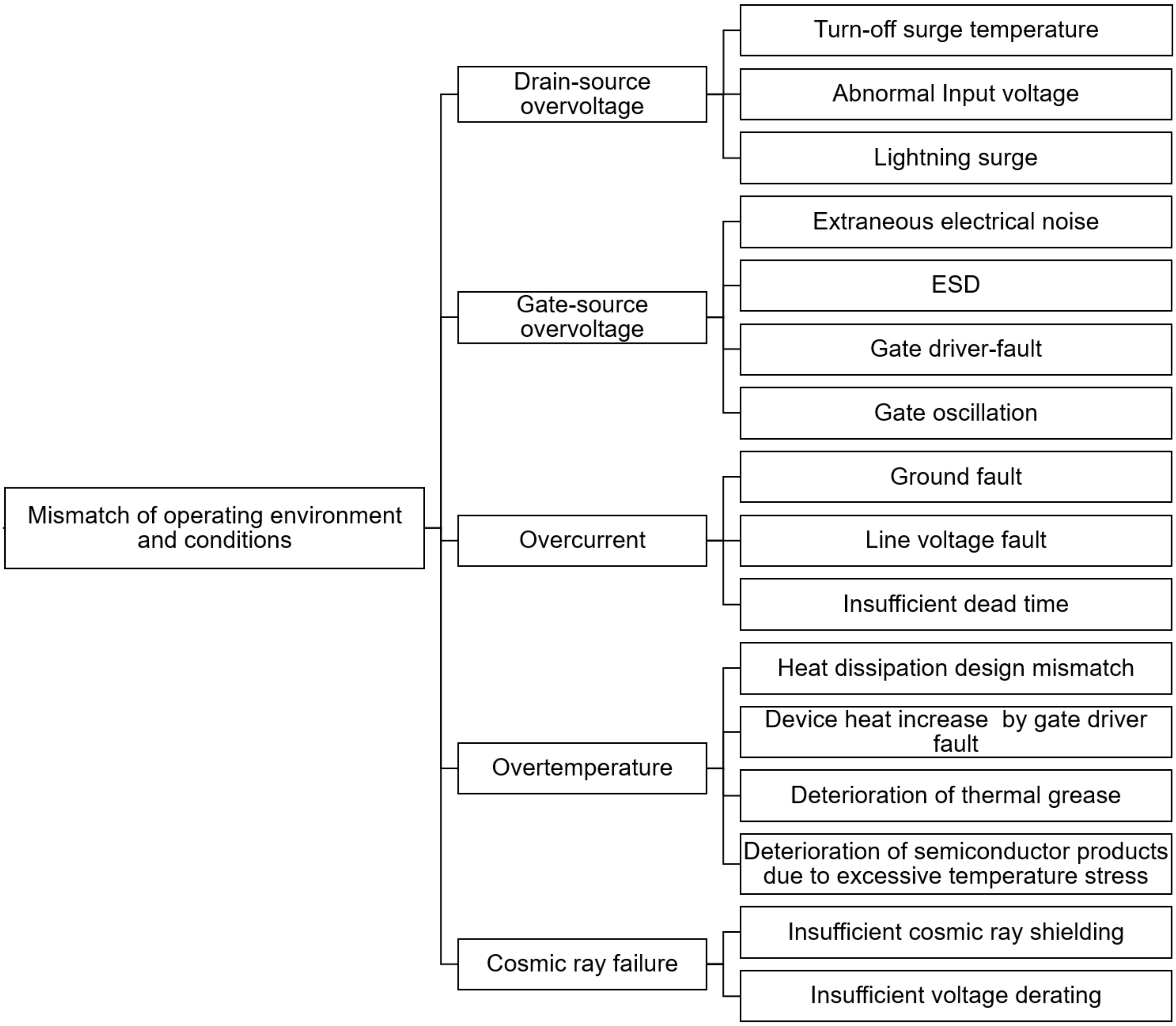

Table 3.1 SiC MOSFET Module Failure Modes

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)

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

Table 4.1.1 MG800FXF2YMS3 Gate Reliability Test Conditions

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 about the gate threshold voltage, which 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)

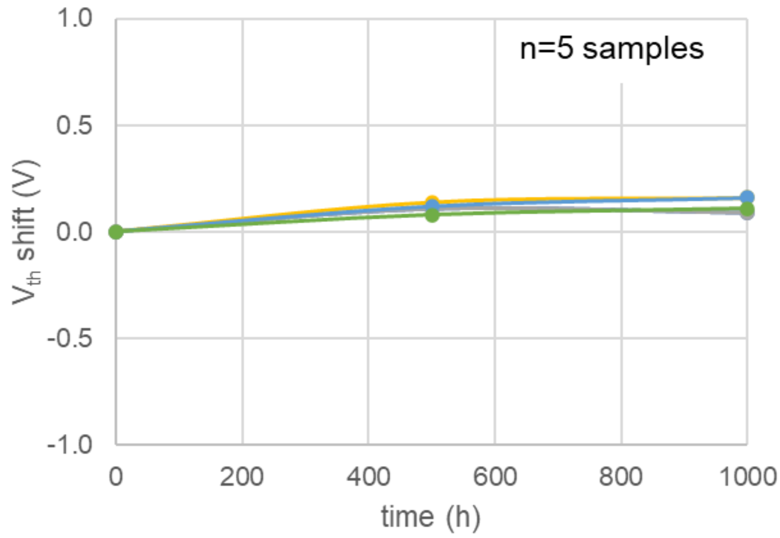

Fig. 4.2.1 V_{th} shift with Continuous Positive Gate Bias Voltage Test
(MG800FXF2YMS3, V_{GS}=25V, T_{ch}=175°C)

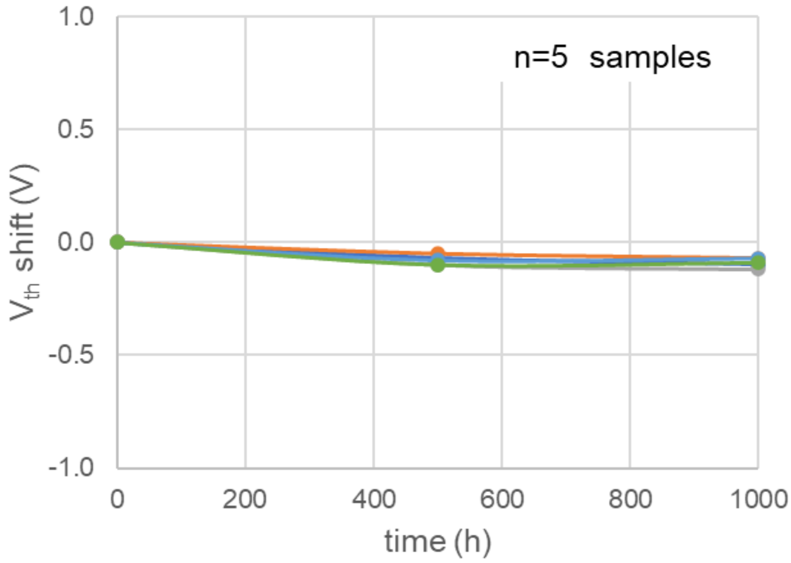

Fig. 4.2.2 V_{th} shift with Continuous Negative Gate Bias Voltage Test
(MG800FXF2YMS3, V_{GS}=-10V, T_{ch}=175°C)

4.3. SBD embedded SiC MOSFET

Current technology has not been able to completely eliminate defects in SiC crystals used as semiconductor materials. Particularly, SiC MOSFETs have a problem that defects in the SiC crystal expand 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 diode (SBD) is integrated in parallel with the parasitic PN diode on the MOSFET chip. (Figure 4.3.1)

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 suppressed.

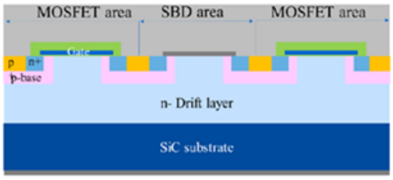

Figure 4.3.1 Structure of SBD embedded SiC MOSFET

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 is called single event burnout (SEB). The probability of this phenomenon is higher at high altitudes and using 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 of the cosmic ray random failure rate for use at high altitude areas or at high operating voltage conditions.

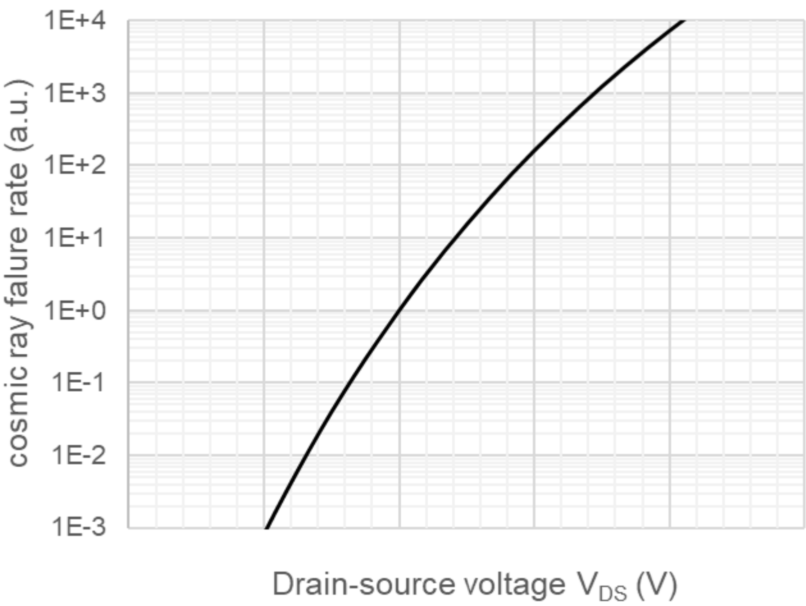

Figure 4.4.1 An Example of SiC MOSFET LTDS

5. Reliability of package of SiC MOSFET module

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

5.1. Temperature stress and lifetime of SiC MOSFET module

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

Thermal fatigue failures mainly occur at the contact of 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, 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 considering 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 time that the SiC MOSFET chip is conducting, which is equal to the time the temperature of the chip rises.

The contact of bonding wire and SiC MOSFET chip experience distortions by expansion and contraction due to temperature cycle. The larger the ΔTvj, the greater the strain of the package materials, therefore the larger the ΔTvj, the shorter the lifetime 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 Tvjmas, ΔTvj, Ton of the number of cycles dependency on each product.

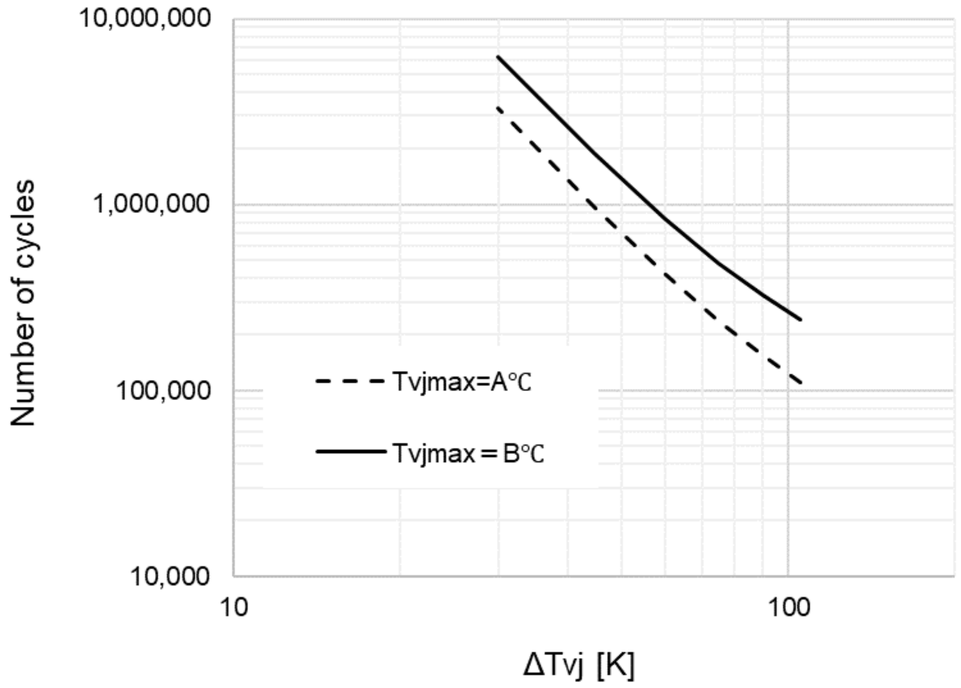

Figure 5.1.1 An Example of the relationship between ΔTvj and number of cycles

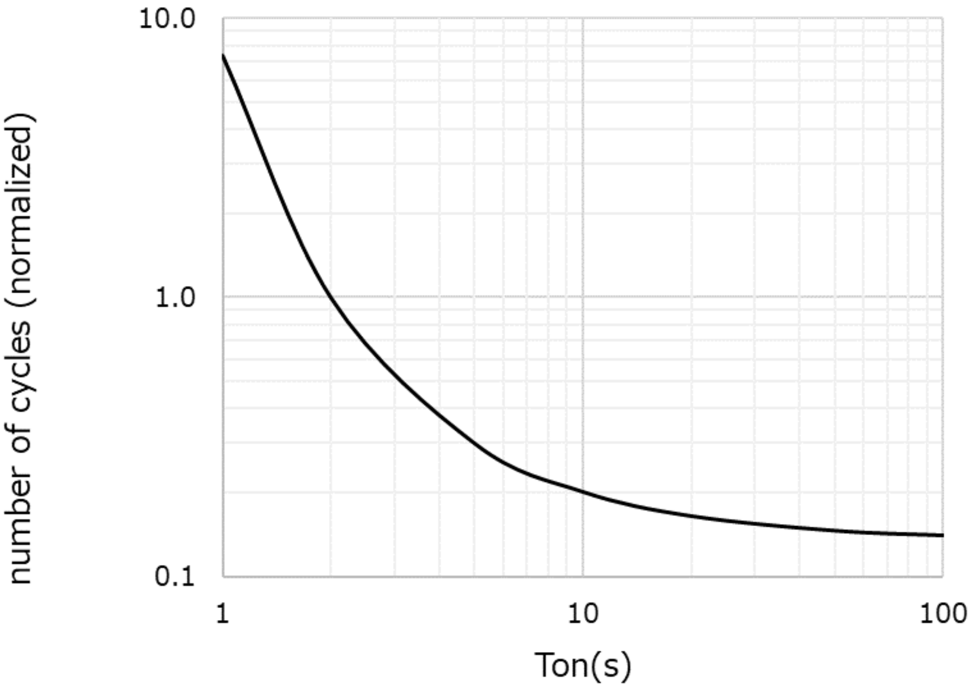

Figure 5.1.2 An Example of the relationship between Ton and number of cycles
(Normalized at Ton = 2 seconds as 1)

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