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)

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

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)

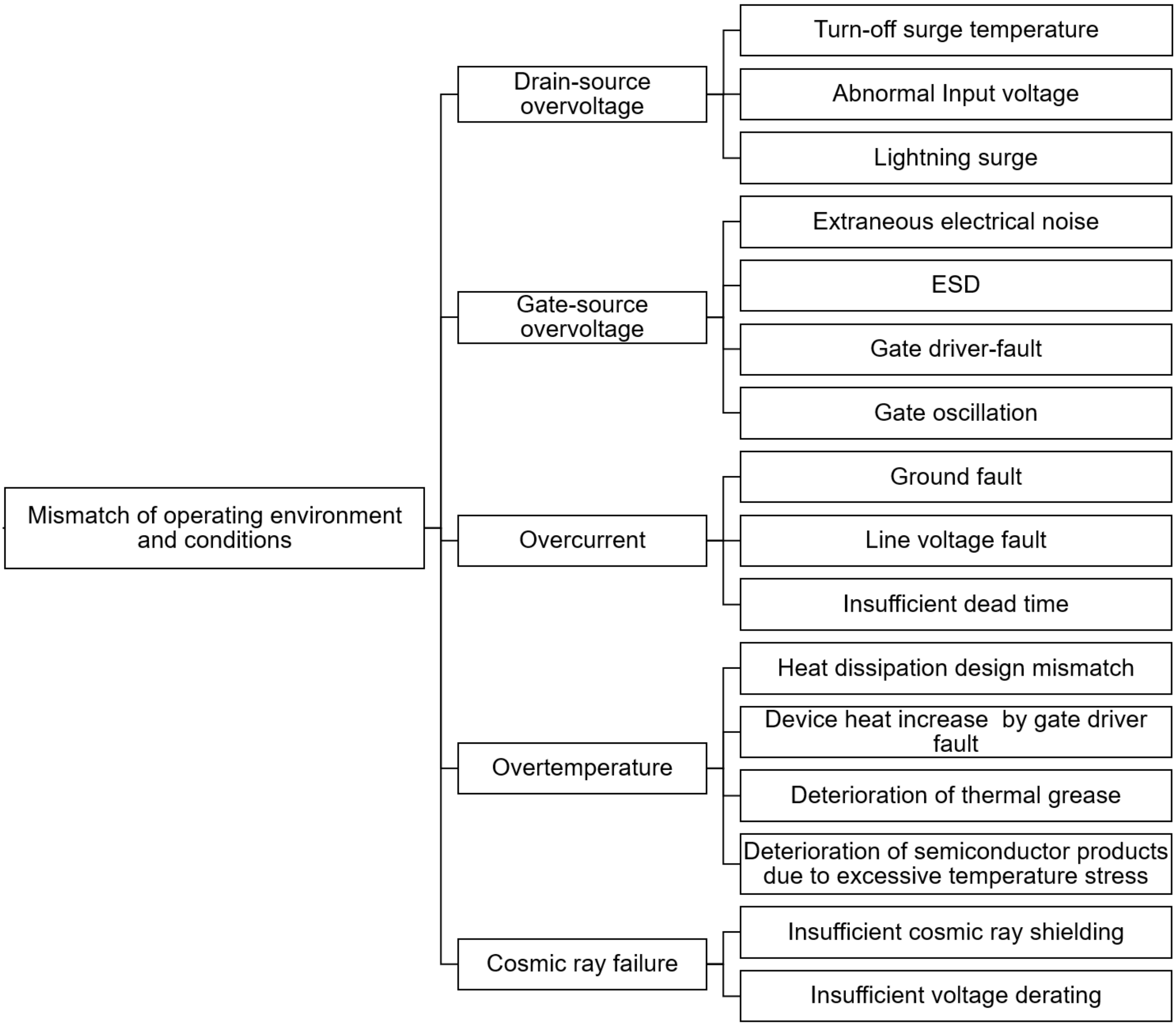
Table 2.1 Example of MG600Q2YMS3 Reliability Tests

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%

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)

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 V_{DS}=0V T_{ch}=175°C 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)

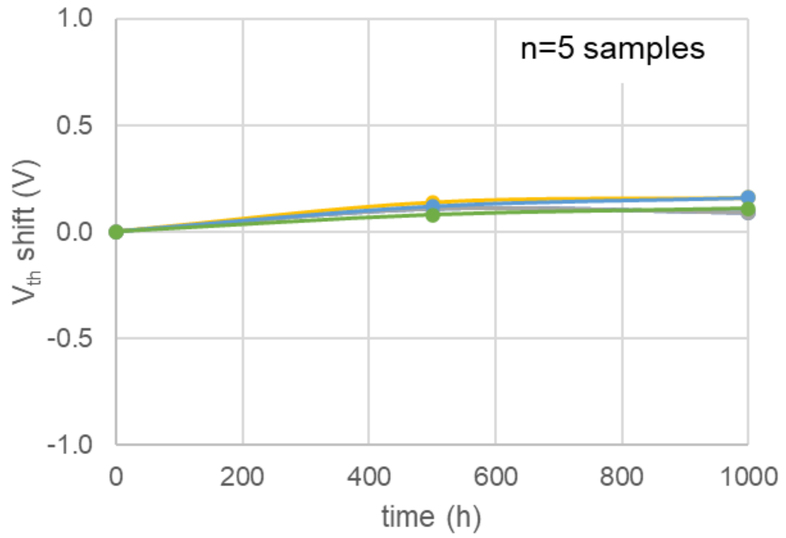


Fig. 4.2.1 V_{th} shift with Continuous Positive Gate Bias Voltage Test
(MG800FXF2YMS3, V_{GS}=25V, T_{ch}=175°C)

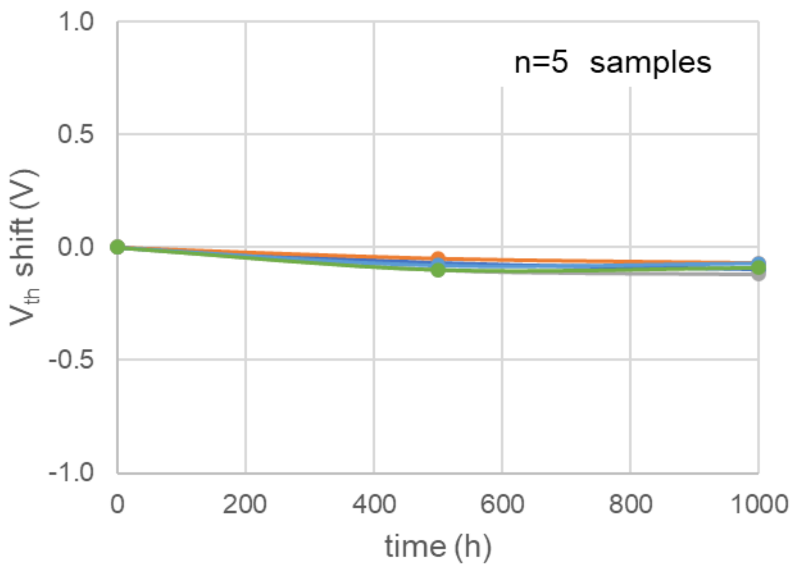


Fig. 4.2.2 V_{th} shift with Continuous Negative Gate Bias Voltage Test
(MG800FXF2YMS3, V_{GS}=-10V, T_{ch}=175°C)

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)

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.

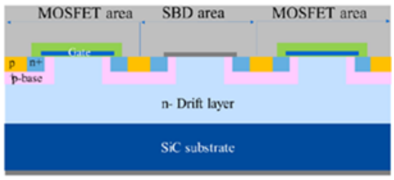


Figure 4.3.1 Structure of SBD embedded SiC MOSFET

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.

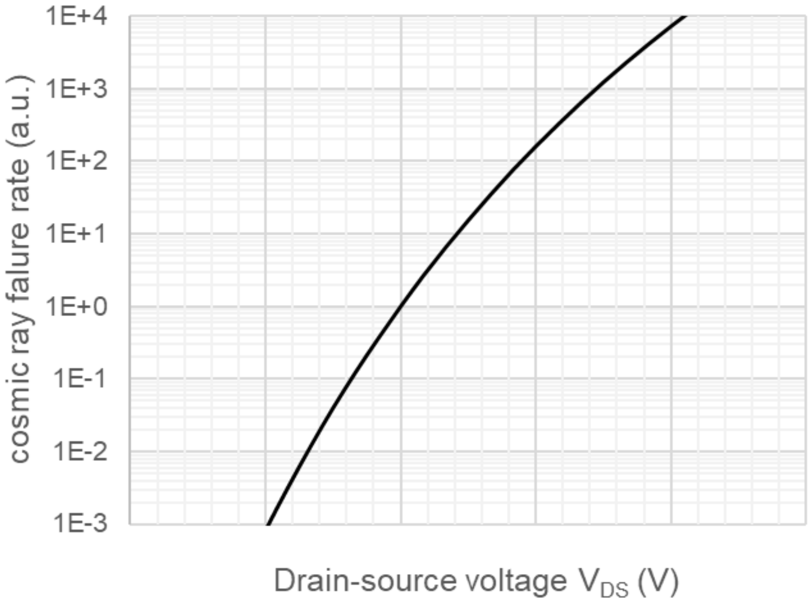


Figure 4.4.1 An Example of SiC MOSFET LTDS

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.

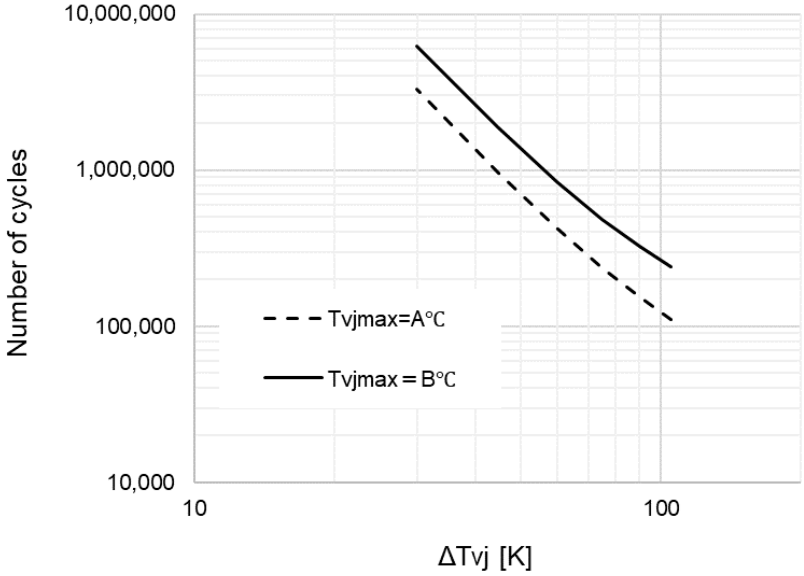


Figure 5.1.1 An Example of the relationship between ΔTvj and number of cycles

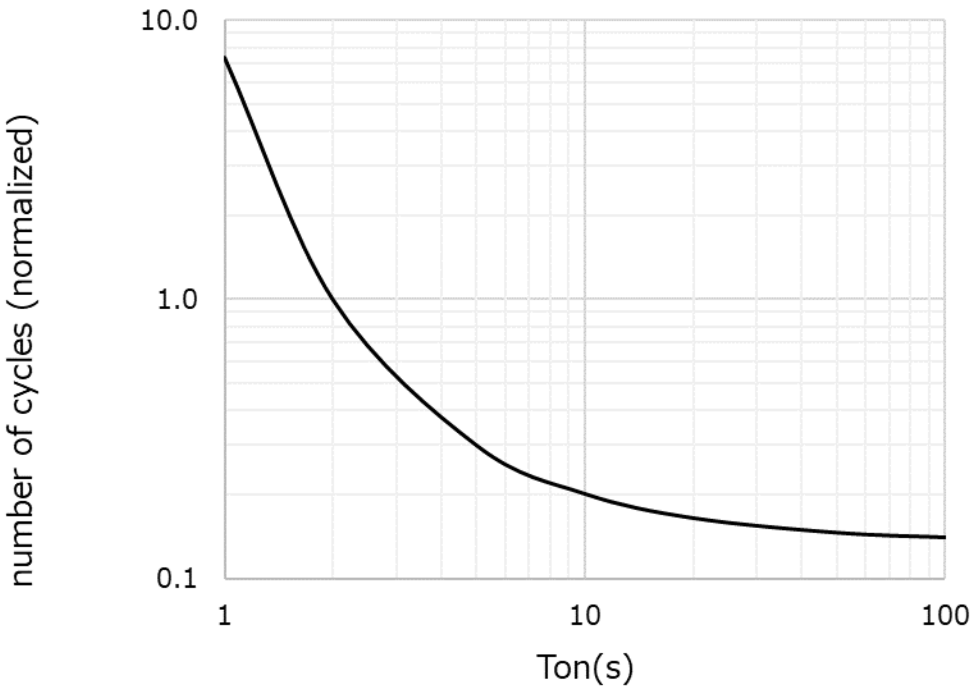


Figure 5.1.2 An Example of the relationship between Ton and number of cycles
(Normalized at Ton = 2 seconds as 1)

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as “TOSHIBA”.
Hardware, software and systems described in this document are collectively referred to as “Product”.

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**

Toshiba Electronic Devices & Storage Corporation
https://toshiba.semicon-storage.com/