

JEDEC PUBLICATION

Test Procedure for the Measurement of Terrestrial Cosmic Ray Induced Destructive Effects in Power Semiconductor Devices

JEP151A

(Revision of JEP151, December 2015)

JANUARY 2022

JEDEC SOLID STATE TECHNOLOGY ASSOCIATION



NOTICE

JEDEC standards and publications contain material that has been prepared, reviewed, and approved through the JEDEC Board of Directors level and subsequently reviewed and approved by the JEDEC legal counsel.

JEDEC standards and publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for use by those other than JEDEC members, whether the standard is to be used either domestically or internationally.

JEDEC standards and publications are adopted without regard to whether or not their adoption may involve patents or articles, materials, or processes. By such action JEDEC does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the JEDEC standards or publications.

The information included in JEDEC standards and publications represents a sound approach to product specification and application, principally from the solid state device manufacturer viewpoint. Within the JEDEC organization there are procedures whereby a JEDEC standard or publication may be further processed and ultimately become an ANSI standard.

No claims to be in conformance with this standard may be made unless all requirements stated in the standard are met.

Inquiries, comments, and suggestions relative to the content of this JEDEC standard or publication should be addressed to JEDEC at the address below, or refer to www.jedec.org under Standards and Documents for alternative contact information.

Published by
©JEDEC Solid State Technology Association 2022
3103 North 10th Street
Suite 240 South
Arlington, VA 22201-2107

This document may be downloaded free of charge; however JEDEC retains the copyright on this material. By downloading this file the individual agrees not to charge for or resell the resulting material.

PRICE: Contact JEDEC

Printed in the U.S.A.
All rights reserved

PLEASE!

DON'T VIOLATE
THE
LAW!

This document is copyrighted by JEDEC and may not be
reproduced without permission.

For information, contact:

JEDEC Solid State Technology Association
3103 North 10th Street
Suite 240 South
Arlington, VA 22201-2107

or refer to www.jedec.org under Standards-Documents/Copyright Information.

sobco

Test Procedure for the Measurement of Terrestrial Cosmic Ray Induced Destructive Effects in Power Semiconductor Devices

Contents

1	Scope.....	1
2	Terms and definitions	2
3	Beam requirements.....	4
3.1	Beam characteristics	5
3.2	Beam flux	5
3.3	Acceleration factor	5
4	Test Set Up.....	6
4.1	Exposing devices to the nucleon beam.....	6
4.2	Application of voltage and temperature to the DUTs.....	7
4.3	Detection of failures of the DUTs during nucleon irradiation	7
4.4	Measuring the fluence to fail	7
5	Test Procedure	8
5.1	Test plan generation	8
5.2	Sample selection	8
5.3	Choosing beam intensity and stressor (voltage, temperature)	8
5.4	Device preparation.....	8
5.5	Evaluation of Device Failure Rates corresponding to cosmic radiation at sea level	9
6	Reporting Requirements	10
	Annex A (informative) References	11
	Annex B (informative) Example of an experimental set up.....	12
	Annex B (informative) Example of an experimental set up.....	12
	Annex C (informative) Example test plan	14
	Annex D (informative) Differences between revision	16

sobco

Test Procedure for the Measurement of Terrestrial Cosmic Ray Induced Destructive Effects in Power Semiconductor Devices

(From JEDEC Board Ballot JCB-21-52, formulated under the cognizance of JC-14.1 Subcommittee on Silicon Devices Reliability Qualification and Monitoring.)

1 Scope

The main reason for accelerated testing is the requirement for power electronic devices for high reliability, according to the respective application, and, therefore, to attain very low failure rates. Without accelerated testing any experimental validation of such low failure rates would be impossible.

Power electronic devices that are vulnerable to terrestrial cosmic radiation include power MOSFETs and JFETs, power diodes and IGBTs (Insulated Gate Bipolar Transistors), which are usually employed for power switching and power conversion. They also include GTOs (Gate Turn-Off Thyristors) and Thyristors. Power devices may be with or without control logic and they may be components of integrated circuit. The maximum rated blocking voltage is higher than 300V (see note 2). Power devices may be based on Si, SiC and GaN technologies.

This test method defines the requirements and procedures for terrestrial destructive (see note 1) single-event effects (SEE) for example, single-event breakdown (SEB), single-event latch-up (SEL) and single-event gate rupture (SEGR) testing. It is valid when using an accelerator, generating a nucleon beam of either

- Mono-energetic protons or mono-energetic neutrons of at least 150 MeV energy, or
- Neutrons from a spallation spectrum with maximum energy of at least 150 MeV

This test method does not apply to testing that uses beams with particles heavier than protons.

This specific choice of nucleon beam energies is stipulated by the mechanism of power device failure due to terrestrial cosmic radiation. Terrestrial cosmic rays [4] result from extended air showers created by the collision of highly energetic particles of the primary (galactic) cosmic radiation and consist mostly of photons and electrons, muons, pions and nucleons, i.e., protons and neutrons. At sea level about 95% of the strongly interacting particles are neutrons.

For SEB to occur in a power device, e.g. a power diode, a nuclear collision between a neutron or proton and a silicon nucleus has to create highly-ionizing spallation fragments which in turn will generate a dense plasma of electron-hole pairs within the semiconductor material. If the local plasma density is high enough this will initiate massive carrier multiplication by impact ionization. Resembling discharge in gases, a “streamer” will sweep through the device which will be filled with carriers and short-circuited, as a consequence. Thermal destruction of the power device might ensue [5].

This mechanism is in contrast to the failure modes in microelectronic storage devices, SRAMs or DRAMs, where SEU are related to the radiation-induced charging or discharging of storage cells, and which are non-destructive.

1 Scope (cont'd)

Accordingly, nucleon beam properties for accelerated testing against Soft Errors [6], which is described in JEDEC Standard JESD89, are different from those that have to be employed for accelerated testing of SEB/SEGR in power devices. Specifically, highly ionizing spallation fragment from the silicon-nucleon collision are required to set off a streamer-like discharge. This process is strongly dependent on the applied voltage but also, the primary nucleon has to have an energy that is significantly higher than that for SEU testing. As borne out by experiment, the cross-section for SEB in power devices is significantly reduced below 150MeV for the range of typical application voltages. If mono-energetic beams are to be employed for the purpose of accelerated testing, therefore, a minimum energy of 150 MeV has to be ensured to assume worst-case conditions for the terrestrial radiation environment.

NOTE 1 This test method addresses a separate risk than does JESD89 tests for non-destructive SEE due to cosmic radiation effects on terrestrial applications.

NOTE 2 The basic failure mechanism [3] stipulates the electric field-enhanced carrier multiplication from an initial charge deposition by a nucleon-nucleus collision fragment. The initial charge for this process is, in general, much lower as compared to high-LET heavy-ion-induced charge. Massive charge multiplication as a root cause for device failure is therefore limited to power devices of high blocking voltage. Due to thick active substrates layers of these devices of many carrier mean free path lengths along with high internal electric field strengths carrier multiplication is significant also for relatively low induced carrier densities. As borne out by experience, a minimum nominal blocking voltage of 300 V is required for terrestrial cosmic radiation to cause device failure. For devices of lower voltage rating, massive charge generation by avalanche multiplication is less effective, even for high internal electric field strengths, due to limited substrate thickness.

2 Terms and definitions

The following are the terms included in the body of the text.

ALARA principle: Acronym for “As Low As Reasonably Achievable”.

NOTE This principle in radiation protection states that exposure to ionizing radiation should be kept as low as possible, even lower than prescribed by legal requirements, if this is achievable.

CR: cosmic ray

cross section: The number of failures per unit fluence for a given device.

NOTE If one can assume that the depth of the sensitive volume is small compared to its lateral dimensions, the SEE cross section (σ) can be calculated as follows:

$$\sigma = \frac{\text{number of failures}}{\text{fluence}}$$

The recommended cross-section units are $\text{cm}^2/\text{device}$.

DUT: Device under test.

FIT: failure-in-time, 1 FIT corresponding to 1 failure in 10^9 device-hours.