

JEDEC STANDARD

TEST STANDARD FOR THE MEASUREMENT OF PROTON RADIATION SINGLE EVENT EFFECTS IN ELECTRONIC DEVICES

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Introduction

This standard establishes requirements for conducting a proton single event effects (SEE) test in electronic devices. The standard can be referred to as a “Proton SEE Test Standard”. Historically used documents for guidance in proton SEE testing have been the JESD57 standard, the JESD89A standard and the ASTM 1192 guideline. The basic drawbacks to these documents with respect to proton SEE testing are that JESD57 and ASTM 1192 pertain to heavy ions and JESD89 pertains to neutrons. Proton induced upsets (and failure) have some similarities with these other particles; but as a general rule, the facilities used for proton testing do differ from those used for heavy ion and neutron, and as technologies have scaled (beyond 90nm) new complex modes of upset/failure have been observed during proton testing. This standard assures the user of (1) bounding an acceptable indirect ionization upset test as being done with energies between 40 – 500 MeV, (2) that consideration must be given to device overlayers and package lids, (3) a discussion on the clarity between a destructive and non-destructive events, (4) angular testing is different from that described in heavy ion testing and (5) to provide a listing of proton induced dominant SEEs.

TEST STANDARD FOR THE MEASUREMENT OF PROTON RADIATION SINGLE EVENT EFFECTS IN ELECTRONIC DEVICES

(From JEDEC Board Ballot JCB-13-41, formulated under the cognizance of the JC-13.4 Subcommittee on Radiation hardness: Assurance and Characterization.)

1 Scope

This test standard defines the requirements and procedures for 40 to 500 MeV proton irradiation of electronic devices for Single Event Effects (SEE), and reporting the results. Protons are capable of causing SEE by both direct and indirect ionization, however, in this energy range, indirect ionization will be the dominant cause of SEE [1-3]. Indirect ionization is produced from secondary particles of proton/material nuclear reactions, where the material is Si or any other element present in the semiconductor. Direct proton ionization is thought to be a minor source of SEE, at these energies. This energy range is also selected to coincide with the commonly used proton facilities, and result in the fewest energy dependent issues during test.

Proton energy is the primary variable in these irradiations: However the energies used in a test do not necessarily reflect the proton spectrum in space. The limits of the test energy range versus the actual environment must be taken into consideration during data analysis. The overall proton SEE rate can sometimes be well characterized by the SEE cross section in the 40-100 MeV range. However, for certain categories of devices an energy dependence in SEE cross-section has been noted. Devices that manifest this energy dependent response are typically those fabricated with heavy metal materials (e.g. tungsten, W, and copper, Cu) residing in close proximity to the sensitive volume and that also exhibit a threshold high enough that the heavy element scattering events are not swamped by more common silicon events. In all cases, the possible secondary reactions are dependent on the incident proton energy.

Proton testing is usually performed in open air with test samples that are not delidded. It is always the experimenter's responsibility to have knowledge of the location of the active die and any overlays of material (from all sources) which will degrade the raw beam energy, and to make the appropriate adjustments in reporting the results.

2 Normative references

The following standards contain provisions that, through reference in this text constitutes provisions for this test method. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

ASTM 1192, *Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiation of Semiconductor Devices*, 2000

ESA/SCC 25100, *Single Event Effects Test Method and Guidelines*

IEC/TS 62396-2, *Process Management for Avionics – Atmospheric radiation effects – Part 2: Guidelines for single event effects testing for avionics systems*, August 2008

JEP133C, *Guide for the Production and Acquisition of Radiation Hardness-Assured Multichip Modules and Hybrid Microcircuits*, January, 2010

JESD57, *Test Procedures for the Measurement of Single-Event Effects in Semiconductor Devices from Heavy Ion Irradiation*, December, 1996

JESD89A, *Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray-Induced Soft Errors in Semiconductor Devices*, October 1989

JESD89-3A, *Test Method for Beam Accelerated Soft Error Rate*, November, 2007

MIL-HDBK-814, *Ionizing Dose and Neutron Hardness Assurance Guidelines for Microcircuits and Semiconductor Devices*, 1994

MIL-STD-750, *Test Method 1080 Single Event Burnout and Single Event Gate Rupture*

3 Proton test considerations

3.1 Applicable test facilities

This test standard is only applicable when using a proton accelerator with proton energies in the range of 40-500 MeV. This test standard assumes that the selected accelerator test facility has the ability to mount and position the Device-Under-Test (DUT), provide proton dosimetry, calculate total ionizing dose (TID) and Non-Ionizing-Energy Loss (NIEL), and that the test organization exposing the parts has the capability for performing these tests

3.2 Basic effects addressed

This test specification is applicable to Single-Event Effects. These effects are manifested as soft errors (non-destructive) or hard errors (which may be directly destructive, or “hard” in that it requires power reset to resume proper operation) induced by either the proton or the byproducts of subsequent nuclear reactions with the target materials. The soft error effects include Single-Event Upset (SEU), Multiple-Bit Upset (MBU), and Single-Event Transient (SET). Hard errors effects include Single-Event Gate Rupture (SEGR), Single-Event Latchup (SEL), Single-Event Burnout (SEB) and Single-Event Functional Interrupt (SEFI). As technology changes, new effects are being observed regularly, and it is the responsibility of the tester to be ready for unanticipated results and report them promptly. The use of proton beams for displacement damage or total ionizing dose measurements is not covered by this test standard.

High current states caused by some of the hard errors described above may also lead to latent damage to metallization or junctions. These may result in reduced reliability of the device. While not a direct part of this test method, additional life test and analysis may be required to properly evaluate these effects.

3.3 Limits of the test standard

This test standard is strictly for SEE tests with moderate energy protons, and does not apply to SEE testing that uses heavy ions, neutrons, low energy protons and other lighter particles.

3.4 Test standard objective

The standard is written to observe the dominant proton SEEs in a test sample; these effects are usually produced by ionization caused by nuclear reaction byproducts of proton interactions with materials of the semiconductor device. Most experiments are not capable of determining the difference between a direct proton ionization SEE and one caused by the reaction particles, but at these energies direct proton ionization events are rare, unlike the direct ionization effects of heavy ions. Protons are the dominant source of radiation in many orbital regimes, so obtaining a correct rate prediction in the relevant environment is a primary reason proton tests are performed. The appropriate range of proton energies for a test is determined by system requirements. This is discussed further in 3.6.

3.4 Test standard objective (cont'd)

SEE effects from direct ionization have been observed in advanced technologies (below 100nm) primarily at proton energies below 5 MeV [4-10]. Test at these energies is specifically prohibited in this test method as all aspects of low energy test are significantly more complex than test in the 50-500 MeV range, and require expertise beyond the guidance herein. This is discussed further as a potential interference in 3.6.

For SEU, SET, SEFI and SEL, the end product of the test is a plot of the appropriate single event effect cross-section as a function of proton energy. The plot should include the measured cross-sections for all proton energies measured. A typical cross-section curve increases in cross-section rapidly above a threshold value, and then tends to saturate above some energy. The key to achieving an adequate data set for subsequent rate predictions is to capture the “knee” region where the part achieves saturation. Multiple-bit upsets (MBU) are an increasing concern. The test report should either separate MBU from SBU, or expressly state this separation was not performed.

When no SEL are observed in a sample set during irradiations at the highest energy tested (whose fluence should be determined by the expected environment, with margin), the part has traditionally been defined as SEL immune, to the tested energy. This is an accurate statement of the test result, but not a guarantee of SEL immunity. It has been demonstrated that some devices only display SEL at energies >400 MeV [11]. These high energy SEL are primarily caused by proton reactions with heavy metals in the device, such as tungsten (W), and copper (Cu). The corresponding cross-section may be very low, but demonstrates the part is not immune to SEL. This risk must be evaluated by the individual system, and incorporated into the test planning appropriately. If SEL are observed, which is often defined as a part failure, it is good practice to look for the SEL threshold at reduced energies (as available), when possible. SEL is highly dependent on temperature and device voltage. This drives the test conditions utilized in 3.5 and 5.8. Proton irradiations should not be utilized to infer heavy ion SEL performance. Proton test energies are discussed further in 3.6.

SEB and SEGR require additional variable voltage sources and iterative exposures to establish safe degraded operational limits of the device. The details on this electrical test procedure can be found in MIL-STD-750, test method 1080.

These data can be combined with the predicted proton environment of the intended space application in order to determine the SEE rate for the microelectronic devices due to protons. This test method is directed towards the irradiation of a single DUT (integrated circuit) which is actively biased in a test configuration applicable for the expected use. It is also applicable for isolated irradiation of DUTs within a complex assembly, but the extra steps necessary for preparation are not detailed herein. Some facilities have the ability to spread the beam while maintaining uniformity. This may allow for irradiation of circuit cards or assemblies, but additional adaptations are required and not covered herein.