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Guide for Measurement of Ionizing Dose-Rate Survivability and Burnout of Semiconductor Devices[1]

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1. Scope

1.1 This guide defines the detailed requirements for testing semiconductor devices for short-pulse high dose-rate ionization-induced survivability and burnout failure. The test facility shall be capable of providing the necessary dose rates to perform the measurements. Typically, large flash X-ray (FXR) machines operated in the photon mode, or FXR e-beam facilities are utilized because of their high dose-rate capabilities. Electron Linear Accelerators (LINACs) may be used if the dose rate is sufficient. Two modes of test are described: (*1*) A survivability test, and (*2*) A burnout failure level test.

1.2 The values stated in International System of Units (SI) are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E668 Practice for Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices

E1894 Guide for Selecting Dosimetry Systems for Application in Pulsed X-Ray Sources

F526 Test Method for Using Calorimeters for Total Dose Measurements in Pulsed Linear Accelerator or Flash X-ray Machines

2.2 *ISO/ASTM Standard:*[2]

51275 Practice for Use of a Radiochromic Film Dosimetry System

3. Terminology

3.1 *Definitions:*

3.1.1 *burnout failure level test*—a test performed to determine the maximum dose-rate level the device survives and the minmum dose-rate level where the device experiences burnout.

3.1.1.1 *Discussion*—In such a test, semiconductor devices are exposed to a series of irradiations of increasing dose-rate levels. The maximum dose rate at which the device survives is determined for worst-case bias conditions. The burnout failure level test is always a destructive test.

3.1.2 *dose rate*—the amount of energy absorbed per unit mass of a material per unit time during exposure to the radiation field (typically, expressed in units of Gy(material)/s). For pulsed radiation sources, dose rate typically refers to the peak dose rate during the pulse.

3.1.3 *dose rate induced latchup*—regenerative device action in which a parasitic region (for example, a four (4) layer p-n-p-n or n-p-n-p path) is turned on by the photocurrent generated by a pulse of ionizing radiation, and remains on for an indefinite period of time after the photocurrent subsides. The device will remain latched as long as the power supply delivers voltage greater than the holding voltage and current greater than the holding current. Latchup disrupts normal circuit operation in some portion of the circuit, and may also cause catastrophic failure due to local heating of semiconductor regions, metallization or bond wires.

3.1.4 *failure condition*—a device is considered to have undergone burnout failure if the device experiences one of the following conditions.

(*1*) *functional failure*—a device failure where the device under test, (DUT) fails functional tests following exposure.

(*2*) *parametric failure*—a device failure where the device under test, (DUT) fails parametric measurements after exposure.

3.1.4.1 *Discussion*—Functional or parametric failures may be caused by total ionizing dose mechanisms. See interferences for additional discussion.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.1.5 *high dose-rate burnout*—permanent damage to a semiconductor device caused by abnormally large currents flowing in junctions and resulting in a discontinuity in the normal current flow in the device.

3.1.5.1 *Discussion*—This effect strongly depends on the mode of operation and bias conditions. Temperature may also be a factor in damage to the device should latchup occur prior to failure. Latchup is known to be temperature dependent.

3.1.6 *ionizing dose rate response*—the transient changes which occur in the operating parameters or in the output signal of an operating device when exposed to an ionizing radiation pulse. See Terminology E170 for a definition of ionization. Within this standard, the scope of the dose rate response is restricted to consideration of linear microcircuits.

3.1.7 *ionizing radiation effects*—the changes in the electrical parameters of a microelectronic device resulting from radiation-induced trapped charge. These are also sometimes referred to as "total dose effects."

3.1.8 *latchup window*—a latchup window is the phenomenon in which a device exhibits latchup in a specific range of dose rates. Above and below this range, the device does not latchup. A device may exhibit more than one latchup window. This phenomenon has been observed for some complementary metal-oxide semiconductor (CMOS) logic devices and large scale integration (LSI) memories and may occur in other devices.

3.1.9 *survivability test*—A "pass/fail" test performed to determine the status of the device after being exposed to a predetermined dose-rate level. The survivability test is usually considered a destructive test.

4. Summary of Guide

4.1 Semiconductor devices are tested for burnout during and after exposure to an ionizing high dose-rate radiation pulse. The measurement is deemed as a survivability test when the test criteria is a pass/fail measurement at a predetermined dose-rate level, or deemed as a burnout failure level test when the maximum passing dose-rate level and the minimum failing dose rate level for burnout is determined experimentally.

4.2 The following quantities are unspecified in this guide and must be agreed upon between the parties to the test:

4.2.1 The maximum ionizing dose (total dose to which the devices will be subjected during the test),

4.2.2 The maximum dose rate to which the devices will be subjected during the test, and

4.2.3 The bias conditions to which the devices will be subjected during the test.

5. Significance and Use

5.1 The use of FXR or LINAC radiation sources for the determination of high dose-rate burnout in semiconductor devices is addressed in this guide. The goal of this guide is to provide a systematic approach to testing semiconductor devices for burnout or survivability.

5.2 The different types of failure modes that are possible are defined and discussed in this guide. Specifically, failure can be defined by a change in device parameters, or by a catastrophic failure of the device.

5.3 This guide can be used to determine if a device survives (that is, continues to operate and function within the specified performance parameters) when irradiated to a predetermined dose-rate level; or, the guide can be used to determine the dose-rate burnout failure level (that is, the minimum dose rate at which burnout failure occurs). However, since this latter test is destructive, the minimum dose-rate burnout failure level must be determined statistically.

6. Interferences

6.1 There are several interferences that need to be considered when this test procedure is applied.

6.2 *Ionizing Dose Damage*—Devices may be permanently damaged by the accumulation of ionizing dose. This limits the number of radiation pulses that can be applied during burnout testing. The ionizing dose sensitivity depends on fabrication techniques and device technology. The maximum ionizing total dose exposure of the devices under test must not exceed fifty percent (50 %) of their typical ionizing dose failure level for that specific part type to ensure that device failure is caused by the transient dose rate, and not by the total accumulated ionizing total dose.

6.2.1 *Radiation Level Step Size*—The size of the steps between successive radiation pulses (that is, the dose-rate increment) limits the accuracy of the determination of the burnout failure level.

6.3 *Latchup*—Some types of integrated circuits are susceptible to latchup during transient radiation exposure. If latchup occurs, the device will not function correctly until power is temporarily removed and reapplied. Permanent damage (burnout) may also occur during latchup; it is primarily caused by a substantial increase in power supply current that leads to increased power dissipation, localized heating, or both. Latchup is temperature dependent and testing at elevated temperature is required to establish worst-case operating conditions for latchup. Latchup testing is addressed elsewhere.

6.4 *Charge Build-up Damage*—Damage to a device may occur due to direct electron irradiation of the DUT leads. When using direct electron irradiations (see Section 7), all device leads must be shielded from the electron beam to reduce charge pickup that could cause abnormally large voltages to be generated on internal circuitry and produce damage not related to ionizing dose-rate burnout.

6.5 *Bias and Load Conditions*—Bias and load conditions may affect the survivability and burnout response. Usually, the objective of the test is to determine the dose-rate survivability or burnout under worst-case operating conditions.

6.5.1 *Input Bias*—Unless otherwise specified, the input bias condition shall be chosen to provide the worst-case operating conditions. For example, for digital devices, input pins that are in the high state should be tied directly to the supply voltage. For analog devices, input voltages generally should be at the maximum levels expected to be used. For both digital and