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

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1. Scope

1.1 This guide defines the detailed requirements for testing microcircuits for short pulse high dose-rate ionization-induced failure. Large flash x-ray (FXR) machines operated in the photon mode, or FXR e-beam facilities are required because of the high dose-rate levels that are necessary to cause burnout. Two modes of test are possible: (*1*) A survival test, and (*2*) A 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.

2. Referenced Documents

2.1 *ASTM Standards:*

E 666 Practice for Calculating Absorbed Dose from Gamma or X-Radiation[2]

E 668 Practice for the Application of Thermoluminescence-Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *dose rate*—energy absorbed per unit time per unit mass by a given material that is exposed to the radiation field (Gy/s, rd/s).

3.1.2 *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.

3.1.2.1 *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.

3.1.3 *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 the pre-irradiation functional tests following exposure.

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

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

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

3.1.5 *burnout level test*—a test performed to determine the actual dose-rate level where the device experiences burnout.

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

4. Summary of Guide

4.1 Semiconductor devices are tested for burnout after exposure to high ionizing dose-rate radiation. The measurement for high-dose-rate burnout may be a survival test consisting of a pass/fail measurement at a predetermined level; or it may be a failure level test where the actual 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 (total dose to which the devices will be exposed, and

4.2.2 The maximum high dose rate to which the devices will be exposed.

5. Significance and Use

5.1 The use of FXR 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 for burnout.

5.2 The different type 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 the survivability of a device, that is, that the device survives a predetermined level; or the guide can be used to determine the survival dose-rate

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[2] *Annual Book of ASTM Standards*, Vol. 12.02.

capability of the device. However, since this latter test is destructive, the minimum dose-rate level for failure 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. Metal oxide, semiconductor (MOS) devices are especially sensitive to ionizing dose damage, however, bipolar devices with oxide-isolated sidewalls may also be affected by low levels of ionizing dose. The maximum ionizing total dose exposure of the test devices must not exceed fifty percent (50 %) of the typical ionizing dose failure level of the specific part type to ensure that a device failure is caused by burnout, and not by an ionizing total dose.

6.2.1 *Radiation Level Step Size*—The size of the steps between successive radiation levels 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, 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 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*—The objective of the test is to determine the dose-rate survivability of the test devices when tested under worst case 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 analog devices, it is desirable to perform the burnout test using at least two different input conditions, such as minimum input levels and maximum input levels, or alternately with half the inputs tied high and the remaining tied low.

6.5.2 *Output Loading*—Unless otherwise specified, the DUT outputs shall be chosen to provide the worst-case conditions for device operation. For digital devices, worst case conditions should include maximum fan-out. For analog devices, worst-case conditions should include maximum output voltage or load current. For both digital and analog devices, it may be desirable to perform the burnout test using at least two different output conditions.

6.5.3 *Operating Voltage*—Unless otherwise specified, testing shall be performed using maximum operating voltages. The test setup shall be configured such that the transient power supply photocurrent shall not be limited by the external circuit resistance or lead inductance. Power supply stiffening capacitors shall be included to keep the power supply voltage from varying more than 10 % of the specified value during and after the radiation pulse.

6.6 *Over-Stress*—The high dose-rate burnout test should be considered destructive. Peak photocurrents in excess of 2 to 3 amperes can occur during these tests. These large currents can produce localized metalization, or semiconductor melting that is not readily detected by electrical testing, or both, but may adversely affect device reliability. Devices that exceed manufacturer's absolute limits for current or power during burnout testing should not be used in high-reliability applications.

6.7 *Test Temperatures*—Testing shall be performed at ambient temperature, or at a temperature agreed upon between the parties to the test. If testing is performed in a vacuum, overheating may be an issue, and temperature control is required.

7. Apparatus

7.1 *General*—The apparatus used for testing should include as a minimum, the radiation source, dosimetry equipment, a test circuit board, line drivers, cables and electrical instrumentation to measure the transient response, provide bias, and perform functional tests. Precautions shall be observed to obtain an electrical measurement system with ample shielding, satisfactory grounding, and low noise from electrical interference or from the radiation environment.

7.1.1 *Radiation Source*—The most appropriate radiation source for high dose-rate burnout testing is a FXR machine. The required dose rate for burnout cannot usually be achieved using an electron linear accelerator (LINAC) because LINACs typically cannot produce a sufficiently high dose rate over the critical active area of the device under test. Linear accelerators shall be used only with agreement of all parties to the test.

7.1.2 *Flash X-ray (Photon Mode)*—The choice of facilities depends on the available dose rate as well as other factors including photon spectrum, pulse width and end-point energy. The selection of the pulse width is affected by; (*a*), the dose rate required, and (*b*), the ionizing dose accumulation per pulse. Finally, the FXR end-point energy for the photon made must be greater than 1 MeV to ensure device penetration.

7.1.3 *Flash X-ray (E-beam Mode)*—An FXR operated in the e-beam mode generally provides a higher dose rate than similar machines operated in the photon mode. However, testing in the e-beam mode requires that appropriate precautions be taken and special test fixtures be used to ensure meaningful results. The beam produces a large magnetic field, which may interfere with the instrumentation, and can induce large circulating currents in device leads and metals. The beam also produces air ionization, induced charge on open leads, and unwanted cable currents and voltages. E-beam testing is generally performed with the DUT mounted in a vacuum to reduce air ionization effects. Special dosimetry techniques are