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

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1. Scope

~~1.1This 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: (~~

1.1 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.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

~~E666Practice for Calculating Absorbed Dose From Gamma or X Radiation~~

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~~ 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 Measuring Dose for Use in Linear Accelerator Pulsed Radiation Effects Tests

2.2 *ISO/ASTM Standard:*[2]

51275 Practice for Use of a Radiochromic Film Dosimetry System

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~~*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*~~—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.~~ —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.

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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.

3.1.3 *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 ~~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~~3.1.4.1 *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.~~ —Functional or parametric failures may be caused by total ionizing dose mechanisms. See interferences for additional discussion.

3.1.5 ~~*burnout level test*—a test performed to determine the actual dose-rate level where the device experiences burnout.~~ 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*~~—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.~~ —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, oxide sidewall logic 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

~~4.1Semiconductor 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.~~

4.1 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:

~~4.2.1The maximum ionizing (total dose to which the devices will be exposed, and~~

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

4.2.1 The maximum ionizing (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 ~~the survivability of~~ if a device~~,~~ survives (that is, ~~that~~ continues to operate and function within the ~~device survives~~ specified performance parameters) when irradiated to a predetermined dose-rate level; or, the guide can be used to determine the ~~survival~~ dose-rate ~~capability of~~ burnout failure level (that is, the ~~device.~~ minimum dose rate at which burnout failure occurs). However, since this latter test is destructive, the minimum dose-rate ~~level for~~ 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. Metal-oxide, semiconductor (MOS) devices are especially sensitive to ionizing dose ~~damage,~~damage; however, bipolar devices with oxide-isolated sidewalls or bipolar linear circuits may also be affected by low levels of ionizing dose. The maximum ionizing total dose exposure of the ~~test~~ devices under test must not exceed fifty percent (50 %) of their typical ionizing dose failure level ~~of the~~for that specific part type to ensure that ~~a~~ device failure is caused by ~~burnout,~~ the transient dose rate, and not by ~~an~~the total accumulated ionizing total dose.

6.2.1 *Radiation Level Step Size*—The size of the steps between successive radiation ~~levels~~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,~~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 ~~irradiation of the DUT leads. When using direct electron irradiations,~~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.~~ —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 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 metallization~~,~~ or semiconductor melting that is not readily detected by electrical ~~testing, or~~tests, and both, but may adversely affect device reliability. Devices that exceed the manufacturer's absolute limits for current or power during burnout ~~testing~~tests should not be used in high-reliability applications.

6.7 *Test Temperatures*~~—Testing~~—Tests shall be performed at ambient temperature, or at a temperature agreed upon between the parties to the test. If ~~testing is~~tests are performed in a vacuum, overheating may become an issue, ~~and temperature~~ requiring control ~~is required.~~ of the device's temperature.

7. Apparatus

7.1 *General*—The apparatus used for ~~testing~~tests 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~~tests 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; however, some LINACs are capable of meeting these requirements. 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 electron 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.~~), the ionizing dose accumulation per pulse. Finally, the FXR electron end-point energy must be greater than 1 MeV to ensure that the resulting bremsstrahlung photons have sufficient energy to penetrate the DUT.

7.1.3 *Flash X-ray (E-beam Mode)*~~—An~~—A FXR or LINAC 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. For FXRs, E-beam testing is generally performed with the DUT mounted in a vacuum to reduce air ionization effects. Special dosimetry techniques are required to ensure proper measurement of the dose. See Guide E1894 for information on the selection of dosimetry systems. Finally, the FXR or LINAC-electron endpoint energy must be greater than 2 MeV to ensure device penetration. ~~some~~Some necessary precautions are:

7.1.3.1 The electron beam must be constrained to the region that is to be irradiated. Support circuits and components must be shielded. Beam uniformity shall be determined by the test requirements.

7.1.3.2 The electron beam must be stopped within the test chamber and returned to the FXR to prevent unwanted currents in cables and secondary radiation in the exposure room.

7.1.3.3 All cables and wires must be protected from exposure to prevent extraneous currents. These currents may be caused by direct deposition of the beam in cables, or by magnetic coupling of the beams into the cable.

7.1.3.4 All cables and cable entries must be shielded from electromagnetic radiation caused by the firing of the FXR machine.

7.1.3.5 An evacuated chamber for the test ~~is~~may be required to reduce the effects of air ionization.

7.2 *Dosimetry Equipment*—Dosimetry equipment shall include the following:

(a) ~~a system for measuring ionizing dose, such as a thermoluminescent dosimeter (TLD) or calorimeter,~~ a system for measuring ionizing dose, such as a thermoluminescent dosimeter (TLD) or calorimeter (see Practice E668 and Test Method F526),

(b) ~~a pulse shape monitor, and~~ a pulse shape monitor (see Guide E1894), and

(c) a dosimeter that allows the dose rate to be determined from electronic measurements, for example, a positive intrinsic negative (PIN) detector, Faraday cup, secondary emission monitor, photoconductive detector (PCD), or current transformer (see Guide E1894).

NOTE 1—PIN represents a semiconductor structure consisting of highly P and N regions on the two sides of an intrinsic or relatively pure region.

7.2.1 *Thermoluminescent Detector (TLD)*~~—Exposure of thermoluminescent detectors to ionizing radiation creates thermoluminescent centers that when subsequently heated, emit light. The radiant energy is proportional to the total absorbed dose in the detector. This type of detector can cover a dose range from approximately 0.1Mrd to 1Mrd (see Practice E668~~—Exposure of thermoluminescent detectors to ionizing radiation creates thermoluminescent centers that when subsequently heated, emit light. For photon and low energy electron irradiation, the radiant light energy is proportional to the total absorbed dose in the detector. The TLD may have sensitivities to the linear energy transfer (LET) of the delivered ionizing dose, which will result in different signal-to-dose proportionality for irradiation by densely ionized regions produced by irradiation with heavy ions or neutrons. This type of detector can cover a dose range from approximately 0.01 Gy(TLD) to 10^4Gy(TLD) (see Practice E668).

7.2.2 *Calorimeter*—A silicon calorimeter system can be constructed by attaching a thermocouple to a small (1 by 1 by 0.1 mm) block of silicon. The thermocouple-silicon block assembly is surrounded by closed-cell polyurethane foam and mounted in ~~an~~ aluminum housing. The aluminum provides electron isolation and equilibration in a medium-energy photon environment, and the polyurethane foam provides thermal isolation. A typical thermal decay time constant for such a system is about 3 to 4 s and typical sensitivities are about ~~1000~~10 to ~~1500 rd(Si)/µV.~~ 15 Gy(Si)µV.

7.2.3 *PIN Diodes*—A PIN diode is the solid state equivalent of an ionization chamber. The magnitude of photo-charge generated and collected in a back-biased diode is directly proportional to the absorbed dose. Since the generation rate for silicon is 4.3 × $10^{\cancel{9}11}$~~. . . rd(Si), 4.3 × 10^9~~ carrier ~~pairs/rd (Si),~~ pairs/Gy(Si), these devices can be calibrated knowing only the detector geometry. Calibration depends on the PIN bias and may change with accumulated exposure. Most PIN diodes have a linear response up to a dose rate of approximately 1 × $10^{\cancel{10}8}$ ~~rd(Si)/s.~~Gy(Si)/s. (**Warning** —Care must be taken when using PIN diodes to ensure that the indicated PIN dose rate is equivalent to that absorbed by the DUT. Factors that can affect dosimetry include the FXR photon spectrum, the method used to calibrate the PIN diode, and the location of the PIN diode relative to the DUT.)

7.2.4 *PCD*—a photoconductive detector. Diamond or GaAs are typical PCD active materials. This active dosimeter has a very rapid, picoseconds, response to the ionizing dose in the active material.

7.2.5 *Opti-chromic Dosimeters*—Opti-chromic dosimeters have many of the same advantages as TLDs – see ISO/ASTM Practice 51275. These devices are relatively small, passive, inexpensive, and retain accurate dose information for months between irradiation and measurement of dose. The useful dose range of these devices is ~~400rd(Si)~~ 14 Gy (H_2O) to ~~20Krd(Si).~~ 100 kGy (H_2O). The device response is nearly linear with dose. Opti-chromic dosimeters are calibrated in a ~~Co~~ ^{60}Co cell using NIST traceable exposures. The dose response is independent of dose rate up to $10^{\cancel{12}13}$~~rd(Si)/s.~~ Gy(H_2O)/s.

7.3 *Test Circuit*—The test circuit shall contain the ~~device under test,~~DUT, wiring, and auxiliary components as required. It shall allow the application of power and bias signals at the device inputs and outputs. Power supply stiffening capacitors shall be included to keep the power supply voltage from changing more than 10 % of its specified value during and after the radiation pulse (see 8.4). Capacitors placed across the supply voltage shall be located as close to the DUT as possible, but shall not be exposed