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Standard Guide for
Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Silicon Semiconductor Devices (Metric)[1]

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1. Scope

1.1 This guide defines the requirements and procedures for testing silicon discrete semiconductor devices and integrated circuits for rapid-annealing effects from displacement damage resulting from neutron radiation. This test will produce degradation of the electrical properties of the irradiated devices and should be considered a destructive test. Rapid annealing of displacement damage is usually associated with bipolar technologies.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E666 Practice for Calculating Absorbed Dose From Gamma or X Radiation

E720 Guide for Selection and Use of Neutron Sensors for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics

E721 Guide for Determining Neutron Energy Spectra from Neutron Sensors for Radiation-Hardness Testing of Electronics

E722 Practice for Characterizing Neutron Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics

F1032 Guide for Measuring Time-Dependent Total-Dose Effects in Semiconductor Devices Exposed to Pulsed Ionizing Radiation (Discontinued 1994)[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *annealing factor*—the ratio of the displacement damage (as manifested in device parametric measurements) as a function of time following a pulse of neutrons and the displacement damage remaining at the time the initial damage achieves quasi equilibrium, approximately 1000 s.

3.1.1.1 *Discussion*—Annealing factors have typical values of 2 to 10 for these periods of time following irradiation; see Refs (**1**, **2**, **3**, **4**, **5**, **6**, **7**).[4]

3.1.2 *in situ tests*—electrical measurements made on devices before, after, or during irradiation while they remain in the immediate vicinity of the irradiation location. All rapid-annealing measurements are performed in situ because measurement must begin immediately following irradiation (usually <1 ms).

3.1.3 *remote tests*—electrical measurements made on devices that are physically removed from the irradiation location. For the purpose of this guide, remote tests are used only for the characterization of the parts before and after they are subjected to the neutron radiation (see 6.4).

4. Summary of Guide

4.1 A rapid-annealing radiation test requires continual time-sequential electrical-parameter measurements of key parameters of a device be made immediately following exposure to a pulse of neutron radiation capable of causing significant displacement damage.

4.2 Because many factors enter into the effects of the radiation on the part, parties to the test must establish many circumstances of the test before the validity of the test can be established or the results of one group of parts can be meaningfully compared with those of another group. Those factors that must be established are as follows:

4.2.1 *Radiation Source*—The type and characteristics of the neutron radiation source to be used (see 6.2).

4.2.2 *Dose Rate Range*—The range of ionizing dose rates within which the neutron exposures must take place. These

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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] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

dose rates and the subsequent device response should not influence the parametric measurements being made (see 6.6).

4.2.3 *Operating Conditions*—The test circuit, electrical biases to be applied, and operating sequence (if applicable) for the part during and following exposure (see 6.5).

4.2.4 *Electrical Parameter Measurements*— The pre-irradiation and postirradiation measurements to be made on the test unit and the measurements of changes in the annealing-sensitive parameters to be made beginning immediately after exposure.

4.2.5 *Time Sequence*—The exposure time, time after exposure when measurements of the selected parameter(s) are to begin, time when measurements are to end, and time intervals between measurements.

4.2.6 *Neutron Fluence Levels*—The fluence range required to sustain the desired damage to the device.

4.2.6.1 *Total Dose Levels*—If the part is sensitive to an accompanying type of radiation (such as gamma rays) the levels to which the part can be exposed before the rapid-annealing measurement is affected (see 6.4).

4.2.7 *Dosimetry*—The type and technique used to measure the radiation levels. This is dependent to some extent on the radiation source selection.

4.2.7.1 Since a pulsed radiation source is implied for a rapid-annealing measurement, a time profile of the radiation intensity and its time relationship to the subsequent measurements is extremely helpful (see 7.1).

4.2.8 *Temperature*—The temperature during exposure and the allowable temperature change during the time interval of the rapid-annealing measurement (see 6.7).

4.2.9 *Experimental Configuration*—The physical arrangement of the radiation source, test unit, radiation shielding, and any other mechanical or electrical elements of this test.

5. Significance and Use

5.1 Electronic circuits used in many space, military, and nuclear power systems may be exposed to various levels and time profiles of neutron radiation. It is essential for the design and fabrication of such circuits that test methods be available that can determine the vulnerability or hardness (measure of nonvulnerability) of components to be used in them. A determination of hardness is often necessary for the short term (≈100 µs) as well as long term (permanent damage) following exposure.

6. Interferences

6.1 There are many factors that can affect the results of rapid-annealing tests. Care must be taken to control these factors to obtain consistent and reproducible results.

6.2 *Pulsed Neutron-Radiation Source*— Because the objective of a rapid-annealing test is to observe short-term damage effects, it is implied that this damage is incurred in a short time period and is severe enough to be easily measured. These factors imply a pulsed neutron source. The most commonly used source for rapid-annealing tests is a pulsed reactor. There are two types commonly used; the bare-assembly fast-burst reactor and the water-moderated TRIGA type (see Ref (**8**)).

6.3 *Energy Spectrum*—The neutron energies should be known to ensure correlation with design requirements. It should also be known that adequate damage to the part can be inflicted. Neutron fluences (n/cm^2) are commonly specified in terms of 1 MeV silicon damage equivalence or in percentage of the total above a given energy (see 7.5.1 and Guides E720 and E721, and Practice E722).

6.4 *Effects of Other Radiation*—Some parts that will be evaluated for neutron-induced rapid-annealing effects may also be affected by other types of radiation that may accompany the particles (such as gamma radiation with neutrons). (See Guide F1032 and Practice E666.) For this reason, characterization of the part type to both types of radiation is necessary prior to the rapid-annealing tests.

6.5 *Bias*—Rapid annealing effects from displacement-damage are usually associated with bipolar devices. Most of these effects are related to the electron density in semiconductor device junctions, which is a function of the operating-current bias level. Operating conditions during exposure and the rapid-annealing periods must be chosen to give a large or small degree of annealing as desired. Lacking any preference on the most desirable bias, those conditions that approximate the actual device application may be used.

6.6 *Dose Rate*:

6.6.1 The excess charge carrier concentration depends on the dose rate. High densities of excess carriers can affect trapping site charge states as well as carrier mobilities and lifetimes, altering post-radiation trapped charge densities and distributions. If the neutron radiation is accompanied by an ionizing radiation, the rapid-annealing measurements may be affected. The charge carriers created by ionizing radiation act just like those carriers injected by biasing the device (see 6.5).

6.6.2 Because the device parameter measured during a rapid-annealing test may be significantly altered by a high dose rate, it is necessary to ensure (through some functionality check) that the dose rate during irradiation does not reach a level that will upset the parameter being measured.

6.6.3 Photocurrents produced by the excess carriers generated by an ionizing radiation can alter internal bias levels of a semiconductor device, thereby causing a variation in the rapid-annealing response. Care must be taken to ensure that dose-rate levels remain below a level that will cause debiasing of the device.

6.6.4 For all of these reasons, the dose-rate range allowed for the rapid-annealing measurements must be considered by the parties to the test.

6.7 *Temperature*:

6.7.1 Because annealing of neutron-induced displacement damage is also dependent upon thermally activated processes as well as current injection, the temperature during irradiation and testing can affect the rapid-annealing measurements. It is recommended that all radiation exposures and measurements be done at 23 ± 5°C unless unique requirements or unusual environmental conditions dictate otherwise.

6.7.2 Because rapid annealing is affected by temperature, it is important to monitor possible temperature rise resulting from the pulse of radiation or a temperature rise of the radiation source.