Designation: E1855 – 20

Standard Test Method for Use of 2N2222A Silicon Bipolar Transistors as Neutron Spectrum Sensors and Displacement Damage Monitors[1]

This standard is issued under the fixed designation E1855; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the use of 2N2222A silicon bipolar transistors as dosimetry sensors in the determination of neutron energy spectra and as 1-MeV(Si) equivalent displacement damage fluence monitors.

1.2 The neutron displacement in silicon can serve as a neutron spectrum sensor in the range 0.1 to 2.0 MeV and can serve as a substitute when fission foils are not available. It has been applied in the fluence range between 2×10^{12} n/cm^2 to 1×10^{14} n/cm^2 and should be useful up to 1×10^{15} n/cm^2. This test method details the acquisition and use of 1-MeV(Si) equivalent fluence information for the partial determination of the neutron spectra by using 2N2222A transistors.

1.3 This sensor yields a direct measurement of the silicon 1-MeV equivalent fluence by the transfer technique.

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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 establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *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 The ASTM standards E170, E261, and E265 provide a background for understanding how sensors are used in radiation measurements and general dosimetry. The rest of the standards referenced in the list discuss relevant terminology, the choice of sensors, spectrum determinations with sensor data, and the prediction of neutron displacement damage in some semiconductor devices, particularly silicon.

2.2 *ASTM Standards:*[2]

E170 Terminology Relating to Radiation Measurements and Dosimetry

E261 Practice for Determining Neutron Fluence, Fluence Rate, and Spectra by Radioactivation Techniques

E265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32

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

E844 Guide for Sensor Set Design and Irradiation for Reactor Surveillance

E944 Guide for Application of Neutron Spectrum Adjustment Methods in Reactor Surveillance

E1854 Practice for Ensuring Test Consistency in Neutron-Induced Displacement Damage of Electronic Parts

E2005 Guide for Benchmark Testing of Reactor Dosimetry in Standard and Reference Neutron Fields

E2450 Practice for Application of CaF_2(Mn) Thermoluminescence Dosimeters in Mixed Neutron-Photon Environments

3. Terminology

3.1 *Symbols:*

Φ_1 = the silicon 1-MeV equivalent fluence (see Practice E722).

$h_{FE} = i_c/i_b$ where i_c is the collector current and i_b is the base current, in a common-emitter circuit.

[1] This test method is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.07 on Radiation Dosimetry for Radiation Effects on Materials and Devices.

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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.

4. Summary of Test Method

4.1 Gain degradation resulting from neutron displacement damage in 2N2222A silicon bipolar transistors that is produced by a test environment is compared with gain degradation produced by a reference neutron environment. The Φ_{1_r} in the reference environment is derived from the known reference spectrum and serves to calibrate the device response for future determination of a measured Φ_{1_t} in the test environment (**1, 2**)[3]. The subscripts *r* and *t* refer to the reference and test environments respectively.

4.2 The measured Φ_{1_t} may be used as a sensor response in a spectrum adjustment code. The results given by this sensor can be combined with reaction foil activities to determine the spectrum (**3, 4**).

4.3 Spectra compatible with the responses of many sensors may be used to calculate a more reliable measure of the displacement damage.

5. Significance and Use

5.1 The neutron test spectrum must be known in order to use a measured device response to predict the device performance in an operational environment (Practice E1854). Typically, neutron spectra are determined using a set of sensors with response functions sensitive over the neutron energy region to which the device under test (DUT) responds (Guide E721). For silicon bipolar devices exposed in reactor neutron spectra, this effective energy range is between 0.01 and 10 MeV. A typical set of activation reactions that lack fission reactions from nuclides such as ^{235}U, ^{237}Np, or ^{239}Pu, will have very poor sensitivity to the spectrum between 0.01 and 2 MeV. For a pool-type reactor spectrum, 70 % of the DUT electronic damage response may lie in this range making its determination of critical importance.

5.2 When dosimeters with a significant response in the 0.01 to 2 MeV energy region, such as fission foils, are unavailable, silicon transistors can provide a dosimeter with the needed response to define the spectrum in this critical energy range. When fission foils are part of the sensor set, the silicon sensor provides confirmation of the spectral shape in this energy region.

5.3 Silicon bipolar transistors, such as type 2N2222A, are inexpensive, smaller than fission foils contained in a boron ball, and sensitive to a part of the neutron spectrum important to the damage of modern silicon electronics. They also can be used directly in arrays to spatially map 1-MeV(Si) equivalent displacement damage fluence. The proper set of steps to take in reading the transistor-gain degradation is described in this test method.

5.4 The energy-dependence of the displacement damage function for silicon is found in Practice E722. The major portion of the response for the silicon transistors will generally be above 100 keV.

[3] The boldface numbers in parentheses refer to a list of references at the end of this test method.

6. Apparatus

6.1 The 2N2222A silicon bipolar transistor has a demonstrated response in agreement with calculated Φ_1 values in widely varied environments (**5**). It is recommended that a minimum of three transistors be calibrated together and used at each location to be characterized. In addition, at least three transistors should be used as control devices that will not be irradiated during the test exposure. The control transistors should be exposed one time to a calibration exposure of about 1.0×10^{13} n/cm^2 1-MeV(Si) equivalent fluence and then annealed (baked out) at 180°C for 24 h followed by ambient air cooling to room temperature before being used as controls. These control transistors are not exposed again to radiation during the testing steps, but are read with the exposed transistors to provide temperature correction.

6.2 A dry oven for annealing is needed to stabilize the gain after both the calibration-exposure and gain readout are completed for the reference environment. The oven shall be able to maintain the set temperature to within ±3.0°C at 80°C and at 180°C. It would be prudent to have a timer for automatic shutdown and an emergency power system (UPS). Shutdown with a timer will require a door-opening mechanism to initiate ambient air-cooling.

6.3 An electronic system is required to maintain appropriate transistor bias and currents and to read the currents for the gain measurements. A programmable tester or parameter analyzer can operate in pulsed mode to mitigate heating effects and provide gain values quickly. The parameter tester determines the common-emitter current gain by injecting a pulse of current into the base region, measuring the collector current, and determining the current ratio i_c/i_b at a fixed bias of 10 V on the collector terminal. The bias voltage is measured between the collector and the base (see Ref (**6**)).

6.4 A reference neutron source (Guide E2005) for calibration of the transistors is required. The neutron fluence and neutron fluence spectrum of the reference source must be known. National Institute for Standards and Technology (NIST) benchmark fields (**7**) are recommended for use as primary standards, and a well characterized fast burst reactor, such as the one at White Sands Missile Range, is recommended as a reference benchmark field.

6.5 A suitable fluence monitor, such as a nickel foil, shall be exposed along with the transistors during exposures. A photon-sensitive detector such as a CaF_2 thermolumenescence detector (TLD) shall be included in each test package to monitor the gamma ray dose. Care must be taken in the determination of the gamma environment to correct for any neutron response from the photon-sensitive detector that is used. Practice E2450 provides guidance on how to correct a CaF_2:Mn TLD for the neutron response.

NOTE 1—Ionizing dose is produced by photon irradiation in bulk silicon and SiO_2. The ionizing dose can induce trapped holes and interface states in the oxide of the silicon devices. This resulting trapped charge can induce electric fields and create interface traps that change the gain in a bipolar device.