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Standard Guide for Neutron Irradiation of Unbiased Electronic Components¹

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1. Scope

1.1 This guide strictly applies only to the exposure of unbiased silicon (SI) or gallium arsenide (GaAs) semiconductor components (integrated circuits, transistors, and diodes) to neutron radiation from a nuclear reactor source to determine the permanent damage in the components. Validated 1-MeV damage functions codified in National Standards are not currently available for other semiconductor materials.

1.2 Elements of this guide with the deviations noted may also be applicable to the exposure of semiconductors comprised of other materials except that validated 1-MeV damage functions codified in National standards are not currently available.

1.3 Only the conditions of exposure are addressed in this guide. The effects of radiation on the test sample should be determined using appropriate electrical test methods.

1.4 This guide addresses those issues and concerns pertaining to irradiations with reactor spectrum neutrons.

1.5 System and subsystem exposures and test methods are not included in this guide.

1.6 This guide is applicable to irradiations conducted with the reactor operating in either the pulsed or steady-state mode. The range of interest for neutron fluence in displacement damage semiconductor testing range from approximately 10^9 to 10^{16} n/cm².

1.7 This guide does not address neutron-induced single or multiple neutron event effects or transient annealing.

1.8 This guide provides an alternative to Test Method 1017.3, Neutron Displacement Testing, a component of MIL-STD-883 and MIL-STD-750. The Department of Defense has restricted use of these MIL-STDs to programs existing in 1995 and earlier.

1.9 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

¹ This practice is under the jurisdiction of ASTM Committee F-1 on Electronics and is the direct responsibility of Subcommittee F01.11 on Quality and Hardness Assurance.

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2. Referenced Documents

2.1 ASTM Standards:

E 170 Terminology Relating to Radiation Measurements and Dosimetry²

E 264 Test Method for Determining Fast-Neutron Reaction Rates by Radioactivation of Nickel²

E 265 Test Method for Measuring Reaction Rates and Fast-Neutron Fluences by Radioactivation of Sulfur-32²

E 668 Practice for Application of Thermoluminescence Dosimetry (TLD) Systems for Determining Absorbed Dose in Radiation-Hardness Testing of Electronic Devices²

E 720 Guide for Selection and Use of Neutron-Activation Foils for Determining Neutron Spectra Employed in Radiation-Hardness Testing of Electronics²

E 721 Method for Determining Neutron Energy Spectra with Neutron-Activation Foils for Radiation-Hardness Testing of Electronics²

E 722 Practice for Characterizing Neutron Energy Fluence Spectra in Terms of an Equivalent Monoenergetic Neutron Fluence for Radiation-Hardness Testing of Electronics²

E 1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources²

E 1250 Test Method for Application of Ionization Chambers to Assess the Low Energy Gamma Component of Cobalt-60 Irradiators Used in Radiation-Hardness Testing of Silicon Electronic Devices²

E 1854 Practice for Ensuring Test Consistency in Neutron-Induced Displacement Damage of Electronic Parts²

F 980 Guide for the Measurement of Rapid Annealing of Neutron-Induced Displacement Damage in Semiconductor Devices.³

F 1892 Guide for Ionizing Radiation (Total Dose) Effects Testing of Semiconductor Devices³

2.2 Other Documents:

2.2.1 The Department of Defense publishes every few years a compendium of nuclear reactor facilities that may be suitable for neutron irradiation of electronic components:

² Annual Book of ASTM Standards, Vol 12.02.

³ Annual Book of ASTM Standards, Vol 10.04.

DASIAC SR-94-009, April 1996, Guide to Nuclear Weapons Effects Simulation Facilities and Techniques⁴

2.3 The Office of the Federal Register, National Archives and Records Administration publishes several documents that delineate the regulatory requirements for handling and transporting radioactive semiconductor components:

Code of Federal Regulations: Title 10 (Energy), Part 20, Standards for Protection Against Radiation⁵

Code of Federal Regulations: Title 10 (Energy), Part 30, Rules of General Applicability to Domestic Licensing of Byproduct Material⁵

Code of Federal Regulations: Title 49 (Transportation), Parts 100 to 177⁵

3. Terminology

3.1 *1 MeV equivalent fluence*—this expression is used by the radiation-hardness testing community to refer to the characterization of an incident neutron energy fluence spectrum, $\Phi(E)$, in terms of the fluence of monoenergetic neutrons at 1 MeV energy required to produce the same displacement damage in a specified irradiated material as $\Phi(E)$ (see Practice E 722 for details).

3.1.1 *Discussion*—Historically, the material has been assumed to be silicon (Si). The emergence of gallium arsenide (GaAs) as a significant alternate semiconductor material, whose radiation damage effects mechanisms differ substantially from Si based devices, requires that future use of the 1 MeV equivalent fluence expression include the explicit specification of the irradiation semiconductor material.

3.2 *silicon damage equivalent (SDE)*—expression synonymous with “1 MeV equivalent fluence in silicon.”

3.3 *equivalent monoenergetic neutron fluence* ($\Phi_{\text{eq, Eref, mat}}$)—an equivalent monoenergetic neutron fluence that characterizes an incident energy-fluence spectrum, $\Phi(E)$, in terms of the fluence of monoenergetic neutrons at a specific energy, Eref, required to produce the same displacement damage in a specified irradiated material, mat (see Practice E 722 for details).

3.3.1 *Discussion*—The appropriate expressions for commonly used 1 MeV equivalent fluence are $\Phi_{\text{eq, 1 MeV, Si}}$ for silicon semiconductor devices and $\Phi_{\text{eq, 1 MeV, GaAs}}$ for gallium arsenide based devices. See Practice E 722 for a more thorough treatment of the meaning and significant limitations imposed on the use of these expressions.

4. Summary of Guide

4.1 Evaluation of neutron radiation-induced damage in semiconductor components and circuits requires that the following steps be taken:

4.1.1 Select a suitable reactor facility where the radiation environment and exposure geometry desired are both available and currently characterized (within the last 15 months). A reasonably complete list is contained in DASIAC SR-94-009.

⁴ Available from Defense Special Weapons Agency, Washington, DC 20305-1000.

⁵ Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

Practice E 1854 contains detailed guidance to assist the user in selecting a reactor facility that is certified to be adequately calibrated.

4.1.2 Prepare test plan and fixtures,

4.1.3 Conduct pre-irradiation electrical test of the test sample,

4.1.4 Expose test sample and dosimeters,

4.1.5 Retrieve irradiated test sample,

4.1.6 Read dosimeters,

4.1.7 Conduct post-irradiation electrical tests, and

4.1.8 Repeat 4.1.4 through 4.1.7 until the desired cumulative fluence is achieved or until degradation of the test device will not allow any further useful data to be taken.

4.2 Operations addressed in this guide are only those relating to reactor facility selection, irradiation procedure and fixture development, positioning and exposure of the test sample, and shipment of the irradiated samples to the parent facility. Dosimetry methods are covered in existing ASTM standards referenced in Section 2, and many pre- and post-exposure electrical measurement procedures are contained in the literature. Dosimetry is usually supplied by the reactor facility.

5. Significance and Use

5.1 Semiconductor devices are permanently damaged by reactor spectrum neutrons. The effect of such damage on the performance of an electronic component can be determined by measuring the component electrical characteristics before and after exposure to fast neutrons in the neutron fluence range of interest. The resulting data can be utilized in the design of electronic circuits that are tolerant of the degradation exhibited by that component.

5.2 This guide provides a method by which the exposure of silicon and gallium arsenide semiconductor devices to neutron irradiation may be performed in a manner that is repeatable and which will allow comparison to be made of data taken at different facilities.

5.3 For semiconductors other than silicon and gallium arsenide, this guide provides a method that can improve consistency in the measurements and assurance that data from various facilities can be compared on the same equivalence fluence scale when the applicable validated 1-MeV damage functions are codified in National standards. In the absence of a validated 1-MeV damage function, the non-ionizing energy loss (NIEL) as a function incident neutron energy, normalized to the NIEL at 1 MeV, may be used as an approximation. See Practice E 722 for a description of the method.

6. Interferences

6.1 Gamma Effects:

6.1.1 All nuclear reactors produce gamma radiation coincident with the production of neutrons. Gamma rays are produced in the fission process directly and are emitted by fission products and activated materials. Furthermore, these gamma rays produce secondary gamma rays and fluorescence photons in reactor fuel, moderator, and surrounding materials. Consequently, degradation in piecepart performance may be produced by gamma rays as well as neutrons, and because of the softer photon spectra dose enhancement may be a problem. If