Designation: F980 – 16 (Reapproved 2024)

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

This standard is issued under the fixed designation F980; 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 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.

1.1.1 Heavy ion beams can also be used to characterize displacement damage annealing (**1**),[2] but ion beams have significant complications in the interpretation of the resulting device behavior due to the associated ionizing dose. The use of pulsed ion beams as a source of displacement damage is not within the scope of this standard.

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

1.3 *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.*

1.4 *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 *ASTM Standards:*[3]

E264 Test Method for Measuring Fast-Neutron Reaction Rates by Radioactivation of Nickel

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

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

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

E1855 Test Method for Use of 2N2222A Silicon Bipolar Transistors as Neutron Spectrum Sensors and Displacement Damage Monitors

E1894 Guide for Selecting Dosimetry Systems for Application in Pulsed X-Ray Sources

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *B*—gain also known as the common emitter gain. The ratio of the collector current over the base current at a constant V_{CE}.

3.1.2 *annealing function*—the ratio of the change in the displacement damage metric (as manifested in device parametric measurements) as a function of time following a pulse of neutrons to the change in the residual late-time displacement

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

[3] 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.

damage metric remaining at the time the imparted damage achieves quasi-equilibrium.

3.1.2.1 *Discussion*—This late-time quasi-equilibrium time is sometimes set to a fixed time on the order of approximately 1000 s, or it is, as in Test Method E1855, set to a displacement damage measurement made after temperature/time stabilizing thermal anneal procedure of 80 °C for 2 h. Fig. 1 shows an example of the annealing function for a 2N2907 pnp bipolar transistor with an operational current of 2 mA during and after the irradiation. The displacement damage metric of interest is often the reciprocal gain change in a bipolar device. This damage metric is widely used since the Messenger-Spratt equation (**2, 3**) states that this quantity, at late time, is proportional to the 1 MeV(Si) equivalent fluence; see Practice E722. In this case the

$$\left(\frac{1}{G_\infty}-\frac{1}{G_0}\right)=k\Phi \quad (1)$$

Φ is the 1 MeV(Si) equivalent fluence, k is a device-specific displacement damage constant referred to as the Messenger constant, G_0 is the initial gain of the device, and G_∞ is the late-time quasi-equilibrium gain of the device. For this damage metric, the anneal function, $AF(t)$, is given by:

$$AF(t)=\frac{\dfrac{1}{G(t)}-\dfrac{1}{G_0}}{\dfrac{1}{G_\infty}-\dfrac{1}{G_0}} \quad (2)$$

where $G(t)$ is the gain of the device at a time t.

3.1.2.2 *Discussion*—The annealing function has typical values of 2 to 10 for time periods extending out to several thousands of seconds following irradiation; see Refs (**4-10**). The annealing function decreases to unity at late time; "late time" is taken to be the time point where the G_∞ late-time quasi-equilibrium device gain was determined.

3.1.3 *displacement damage effects*—effects induced by the non-ionizing portion of the deposited energy during an irradiation. The dominant effect of displacement damage in bipolar silicon devices is a reduction in the minority carrier lifetime and a reduction in the common emitter current gain.

3.1.4 *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).

3.1.4.1 *Discussion*—For reactor neutron irradiations, there will be a gamma environment as well as a neutron pulse. In addition to the neutron displacement damage, the transient photocurrent from the gamma environment may affect the electrical measurements. During a fast-burst reactor pulse the peak gamma dose rate can exceed 1.E8 rad(Si)/s. The induced photocurrents may interfere with the determination of the early-time (<100 ms) device gain. Fig. 2 shows a representative time profile for the prompt gamma, prompt neutron, and delayed gamma radiation components for a maximum pulse in a fast-burst reactor. After a reactor pulse the delayed fission gamma environment will produce a photocurrent environment that extends out to the time when the device is removed from the reactor. The time-dependent importance of the device photocurrent response will vary with the operational currents within the device itself. At low operational currents the photocurrent interference current will exceed the operational currents for a longer period of time.

3.1.5 *LET*—linear energy transfer, also called the linear electronic stopping power, is the energy loss of an ionizing particle due to electronic collisions per unit distance into a material.

3.1.6 *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 that continual or periodic time-sequential electrical parameter measurements

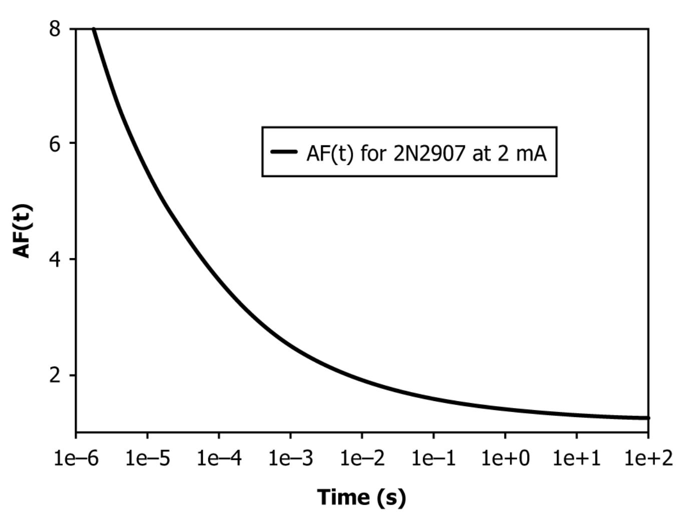

FIG. 1 Example Gain Annealing Function for a 2N2907 Bipolar Transistor