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colour
inside

Semiconductor devices – Mechanical and climatic test methods –
Part 18: Ionizing radiation (total dose)

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SEMICONDUCTOR DEVICES – MECHANICAL AND CLIMATIC TEST METHODS –

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FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60749-18 has been prepared by IEC technical committee 47: Semiconductor devices.

This second edition cancels and replaces the first edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) updates to subclauses to better align the test method with MIL-STD 883J, method 1019, including the use of enhanced low dose rate sensitivity (ELDRS) testing;

b) addition of a Bibliography, which includes ASTM standards relevant to this test method.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
47/2539/FDIS	47/2554/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60749 series, published under the general title *Semiconductor devices – Mechanical and climatic test methods*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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SEMICONDUCTOR DEVICES –
MECHANICAL AND CLIMATIC TEST METHODS –

Part 18: Ionizing radiation (total dose)

1 Scope

This part of IEC 60749 provides a test procedure for defining requirements for testing packaged semiconductor integrated circuits and discrete semiconductor devices for ionizing radiation (total dose) effects from a cobalt-60 (^{60}Co) gamma ray source. Other suitable radiation sources can be used.

~~This standard provides an accelerated annealing test for estimating low dose rate ionizing radiation effects on devices. This annealing test is important for low dose rate or certain other applications in which devices may exhibit significant time-dependent effects.~~

There are four tests presented in this procedure:

a) a standard room temperature irradiation test;

b) an irradiation at elevated temperature/cryogenic temperature test;

c) an accelerated annealing test;

d) an enhanced low dose rate sensitivity (ELDRS) test.

The accelerated annealing test estimates how dose rate ionizing radiation effects on devices is important for low dose rate or certain other applications in which devices can exhibit significant time-dependent effects. The ELDRS test determines if devices with bipolar linear components exhibit sensitivity to enhanced radiation-induced damage at low dose rates.

This document addresses only steady-state irradiations, and is not applicable to pulse type irradiations.

It is intended for military~~-~~ and aerospace-related applications.

This document ~~may~~ can produce severe degradation of the electrical properties of irradiated devices and thus ~~should be~~ is considered a destructive test.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ionizing radiation effects, pl
changes in the electrical parameters of a device or integrated circuit resulting from radiation-induced charge

Note 1 to entry: These are also referred to as total dose effects.

3.2
in-flux test
electrical measurements made on devices during irradiation exposure

3.3
internal dose pattern
logic condition of all elements within a logic circuit during radiation exposure

3.4
non in-flux test
electrical measurements made on devices at any time other than during irradiation

3.5
remote test
electrical measurements made on devices that are physically removed from the radiation location

3.6
time-dependent effect
TDE
significant degradation in electrical parameters caused by the growth or annealing, or both, of radiation-induced trapped charge after irradiation

Note 1 to entry: Similar effects also take place during irradiation.

Note 2 to entry: This note applies to the French language only.

3.7
accelerated annealing test
procedure utilizing elevated temperature to accelerate time-dependent effects

3.8
enhanced low dose rate sensitivity
ELDRS
part that shows enhanced radiation-induced damage at dose rates below 0,5 Gy(Si)/s

Note 1 to entry: This note applies to the French language only.

3.9
overtest
factor that is applied to the specification dose to determine the test dose level that the samples have to pass to be acceptable at the specification level

Note 1 to entry: An overtest factor of 1,5 means that the parts should be tested at 1,5 times the specification dose.

3.10
parameter delta design margin
PDDM
design margin that is applied to the radiation-induced change in an electrical parameter

Note 1 to entry: For a PDDM of 2 the change in a parameter at a specified dose from the pre-irradiation value is multiplied by two and added to the pre-irradiation value to see if the sample exceeds the post-irradiation parameter limit. For example, if the pre-irradiation value of base current I_b is 30 nA and the post-irradiation value at 200 Gy(Si) is 70 nA (change in I_b is 40 nA), then for a PDDM of 2 the post-irradiation value would be 110 nA (30 nA + 2 x 40 nA). If the allowable post-irradiation limit is 100 nA, the part would fail.

4 Test apparatus

4.1 Choice of apparatus

The apparatus shall consist of the radiation source, electrical test instrumentation, test circuit board(s), cabling, interconnect board or switching system, an appropriate dosimetry measurement system, and an environmental chamber (if required for time-dependent effects measurements). Adequate precautions shall be observed to obtain an electrical measurement system with sufficient insulation, ample shielding, satisfactory grounding, and suitable low noise characteristics.

4.2 Radiation source

The radiation source used in the test shall be the uniform field of a ^{60}Co gamma ray source. Uniformity of the radiation field in the volume where devices are irradiated shall be within ±10 % as measured by the dosimetry system, unless otherwise specified. The intensity of the gamma ray field of the ^{60}Co source shall be known with an uncertainty of no more than ±5 %. Field uniformity and intensity can be affected by changes in the location of the device with respect to the radiation source and the presence of radiation absorption and scattering materials.

4.3 Dosimetry system

An appropriate dosimetry system shall be provided that is capable of carrying out the measurements called for in 5.3 (see Bibliography).

4.4 Electrical test instruments

All instrumentation used for electrical measurements shall have the stability, accuracy, and resolution required for accurate measurement of the electrical parameters. Any instrumentation required to operate in a radiation environment shall be appropriately shielded.

4.5 Test circuit board(s)

Devices to be irradiated shall either be mounted on or connected to circuit boards together with any associated circuitry necessary for device biasing during irradiation or for in situ measurements. Unless otherwise specified, all device input terminals and any others which ~~may~~ can affect the radiation response shall be electrically connected during irradiation, i.e. not left floating.

The geometry and materials of the completed board shall allow uniform irradiation of the devices under test. Good design and construction practices shall be used to prevent oscillations, minimize leakage currents, prevent electrical damage and obtain accurate measurements. Only sockets that are radiation resistant and do not exhibit significant leakages (relative to the devices under test) shall be used to mount devices and associated circuitry to the test board(s).

All apparatus used repeatedly in radiation fields shall be checked periodically for physical or electrical degradation. Components which are placed on the test circuit board, other than devices under test, shall be insensitive to the accumulated radiation or they shall be shielded from the radiation. Test fixtures shall be made such that materials will not perturb the uniformity of the radiation field intensity on the devices under test.

Leakage current shall be measured outside the field of radiation. With no devices installed in the sockets, the test circuit board shall be connected to the test system such that all expected sources of noise and interference are operative. With the maximum specified bias for the test device applied, the leakage current between any two terminals shall not exceed 10 % of the lowest current limit value in the pre-irradiation device specification.

Test circuit boards used to bias devices during accelerated annealing ~~must~~ shall be capable of withstanding the temperature requirements of the accelerated annealing test and shall be checked before and after testing for physical and electrical degradation.

4.6 Cabling

Cables connecting the test circuit boards in the radiation field to the test instrumentation shall be as short as possible. If long cables are necessary, line drivers ~~may~~ can be required. The cables shall have low capacitance and low leakage to ground, and low leakage between wires.

4.7 Interconnect or switching system

This system shall be located ~~external to~~ outside the radiation environment location, and provides the interface between the test instrumentation and the devices under test. It is part of the entire test system and subject to the limitation specified in 4.5 for leakage between terminals.

4.8 Environmental chamber

The environmental chamber for time-dependent effects testing, if required, shall be capable of maintaining the selected accelerated annealing temperature within ±5 °C.

4.9 Irradiation temperature chamber

The irradiation temperature chamber, if required for elevated temperature irradiation should be capable of maintaining a circuit under test at 100 °C ± 5 °C while it is being irradiated. The chamber should be capable of raising the temperature of the circuit under test from room temperature to the irradiation temperature within a reasonable time prior to irradiation and cooling the circuit under test from the irradiation temperature to room temperature in less than 20 min following irradiation. The irradiation bias shall be maintained during the heating and cooling. The method for raising, maintaining and lowering the temperature of the circuit under test can be by conduction through a heat sink using heating and cooling fluids, by convection using forced hot and cool air, or other means that will achieve the proper results. For cryogenic temperature irradiations, the chamber should be capable of maintaining the test device/unit at the required cryogenic temperature within ±5 °C (e.g., liquid helium or liquid nitrogen) while it is being irradiated. The chamber should be capable of maintaining the cryogenic temperature of the test device/unit during post-irradiation electrical testing.

5 Procedure

5.1 Test plan

The test devices shall be irradiated and subjected to accelerated annealing testing (if required for time-dependent effects testing) as specified by a test plan. This plan shall specify the device description, irradiation conditions, device bias conditions, dosimetry system, operating conditions, measurement parameters and conditions and accelerated annealing test conditions (if required).

5.2 Sample selection and handling

Only devices that have passed the electrical specifications as defined in the test plan shall be submitted to radiation testing. Unless otherwise specified, the test samples shall be randomly selected from the parent population and identically packaged. Each part shall be individually identifiable to enable pre- and post-irradiation comparison. For device types that are electrostatic discharge (ESD)-sensitive, proper handling techniques shall be used to prevent damage to the devices.

5.3 Burn-in

For some devices, there are differences in the total dose radiation response before and after burn-in. Unless it has been shown by prior characterization or by design that burn-in has a negligible effect (parameters remain within post-irradiation specified electrical limits) on the total dose radiation response, then one of the following functions ~~must~~ shall take place:

a) the manufacturer shall subject the radiation samples to the specified burn-in conditions prior to conducting total dose radiation testing; or

b) the manufacturer shall develop a correction factor, (which is acceptable to the parties to the test) taking into account the changes in total dose response resulting from subjecting the product to burn-in. The correction factor shall then be used to accept the product for total dose response without subjecting the test samples to burn-in.

5.4 Dosimetry measurements

The radiation field intensity at the location of the device under test shall be determined prior to testing by dosimetry or by source decay correction calculations, as appropriate, to ensure conformance to the test level and uniformity requirements.

The dose applied to the device under test shall be determined in one of two ways:

a) by measurement during the irradiation with an appropriate dosimeter; or

b) by correcting a previous dosimetry value for the decay of the ^{60}Co source intensity in the intervening time. Appropriate correction shall be made to convert from the measured or calculated dose in the dosimeter material to the dose in the device under test.

5.5 Lead/aluminium (Pb/Al) container

Test specimens shall be enclosed in a Pb/Al container to minimize dose enhancement effects caused by low-energy scattered radiation. A minimum of 1,5 mm of lead (Pb), surrounding an inner shield of at least 0,7 mm aluminium (Al) is required. This Pb/Al container produces an approximate charged particle equilibrium for Si and for thermoluminescence dosimetries (TLDs) such as CaF2. The radiation field intensity shall be measured inside the Pb/Al container (1) initially, (2) when the source is changed, or (3) when the orientation or configuration of the source, container or test-fixture is changed. This measurement shall be performed by placing a dosimeter (e.g. a TLD) in the device-irradiation container at the approximate test-device position. If it can be demonstrated that low energy scattered radiation is small enough that it will not cause dosimetry errors due to dose enhancement, the Pb/Al container may be omitted.

5.6 Radiation level(s)

The test devices shall be irradiated to the dose level(s) specified in the test plan within ±10 %. If multiple irradiations are required for a set of test devices, then the post-irradiation electrical parameter measurements shall be performed after each irradiation.

5.7 Radiation dose rate

5.7.1 Radiation dose rate determination

~~CAUTION: For the application of some bipolar and biCMOS devices to space-level dose rates, testing at condition A dose rates may not provide worst case results. These are devices that fail due to reduced transistor gain.~~

~~NOTE For those bipolar and biCMOS devices, where the application involves space-level dose rates and the excess base current has been observed to increase at decreasing dose rates, testing may be accomplished at the lowest dose rate of interest in accordance with Condition C in order to obtain a conservative estimate of the device performance.~~

The radiation dose rate for bipolar and BiCMOS linear or mixed-signal parts used in applications where the maximum dose rate is below 0,5 Gy(Si)/s shall be determined as described in 5.14. Parts used in low dose rate applications, unless they have been demonstrated to not exhibit an ELDRS response shall use condition C, condition D, or condition E.

A flow diagram for ionizing test procedures for MOS and digital bipolar devices is shown in Figure 1. A flow diagram for ionizing radiation test procedure for bipolar (or BiCMOS) linear or mixed-signal devices is shown in Figure 2.

NOTE Devices that contain both MOS and bipolar devices can require qualification to multiple subconditions to ensure that both ELDRS and traditional MOS effects are evaluated.

5.7.2 Condition A

For condition A (standard condition), the dose rate shall be between 0,5 Gy(Si)/s and 3 Gy(Si)/s for integrated circuits and between 0,5 Gy(Si)/s and 20 Gy(Si)/s for discrete semi-conductor devices. The dose rates may be different for each radiation dose level in a series; however, the dose rate shall not vary by more than ±10 % during each irradiation.

5.7.3 Condition B

For condition B, for MOS devices only, if the maximum dose rate is ~~<~~ less than 0,5 Gy(Si)/s in the intended application, the parties to the test ~~may~~ can agree to perform the test at a dose rate greater than or equal to the maximum dose rate of the intended application. Unless the exclusions in 5.13.2 b) are met, the accelerated annealing test of 5.13.3 shall be performed.

5.7.4 Condition C

For condition C, (as an alternative) the test may be performed at the dose rate of the intended application if this is agreed to by the parties to the test. Where the final user is not known, the test conditions and results shall be made available in the test report with each purchase order.

5.7.5 Condition D

For condition D, for bipolar or BiCMOS linear or mixed-signal devices only, the parts shall be irradiated at less than or equal to 0,1 mGy(Si)/s.

5.7.6 Condition E

For condition E, for bipolar or BiCMOS linear or mixed-signal devices only, the parts shall be irradiated with the accelerated test conditions determined by characterization testing as discussed in 5.14.3. The accelerated test may include irradiation at an elevated temperature.

5.8 Temperature requirements

5.8.1 Room temperature radiation

Since radiation effects are temperature dependent, devices under test shall be irradiated in an ambient temperature of 24 °C ± 6 °C as measured at a point in the test chamber in close proximity to the test fixture. The electrical measurements shall be performed in an ambient temperature of ~~25~~ 24 °C ± ~~5~~ 6 °C. If devices are transported to and from a remote electrical measurement site, the temperature of the test devices shall not be allowed to increase by more than 10 °C from the irradiation environment. If any other temperature range is required, it shall be specified.

Caution: Annealing at ambient temperatures above the irradiation temperature can be significant, especially for the extended times allowed for the time between irradiations at low dose rate (condition D). It is important to ensure that the temperature of the parts is maintained within the above stated requirements to minimize annealing.

5.8.2 Elevated temperature irradiation

For bipolar or BiCMOS linear or mixed-signal devices irradiated using the condition E elevated temperature irradiation test, devices under test shall be irradiated in an ambient temperature determined by characterization testing (see 5.14.3) as measured at a point in the test chamber in close proximity to the test fixture (see 4.8 for details on raising and lowering the irradiation temperature).

5.8.3 Cryogenic temperature irradiation

For test devices/units operated in cryogenic temperature applications, the devices/units shall be irradiated at cryogenic temperature (see 4.8) and maintained at cryogenic temperature for post exposure characterization testing (see 5.11). The test device/units shall remain at cryogenic temperature throughout all irradiations and characterization testing until the final total dose exposure and characterization have been completed.

5.9 Electrical performance measurements

The electrical parameters to be measured and functional tests to be performed shall be specified in the test plan. As a check on the validity of the measurement system and pre- and post-irradiation data, at least one control sample shall be measured using the operating conditions provided in the governing device specifications. For automatic test equipment, there is no restriction on the test sequence provided that the rise in the device junction temperature is minimized. For manual measurements, the sequence of parameter measurements shall be chosen to allow the shortest possible measurement period. When a series of measurements is made, the tests shall be arranged so that the lowest power dissipation in the device occurs in the earliest measurements and the power dissipation increases with subsequent measurements in the sequence.

The pre- and post-irradiation electrical measurements shall be carried out on the same measurement system and the same sequence of measurements shall be maintained for each series of electrical measurements of devices in a test sample. Pulse-type measurements of electrical parameters should be used as appropriate to minimize heating and subsequent annealing effects. Devices which will be subjected to the accelerated annealing testing (see 5.13) may be given a pre-irradiation burn-in to eliminate burn-in related failures.

5.10 Test conditions

5.10.1 Choice of test conditions

The use of in-flux or non in-flux testing shall be specified in the test plan. (This ~~may~~ can depend on the intended application for which the data are being obtained.) The use of in-flux testing ~~may~~ can help to avoid variations introduced by post-irradiation time-dependent effects. However, errors ~~may~~ can occur for the situation where a device is irradiated in-flux with static bias, but where the electrical testing conditions require the use of dynamic bias for a significant fraction of the total irradiation period. Non-in-flux testing generally allows for more comprehensive electrical testing, but can be misleading if significant post-irradiation time-dependent effects occur.

5.10.2 In-flux testing

Each test device shall be checked for operation within specifications prior to being irradiated. After the entire system is in place for the in-flux radiation test, it shall be checked for proper interconnections, leakage (see 4.5), and noise level. To ensure the proper operation and stability of the test set-up, a control device with known parameter values shall be measured at all operational conditions called for in the test plan. This measurement shall be carried out either before the insertion of test devices or upon completion of the irradiation after removal of the test devices or both.

5.10.3 Remote testing

Unless otherwise specified, the bias shall be removed and the device leads placed in conductive foam (or similarly shorted) during transfer from the irradiation source to a remote tester and back again for further irradiation. This minimizes post-irradiation time-dependent effects.

5.10.4 Bias and loading conditions

Bias conditions for test devices during irradiation or accelerated annealing shall be within ±10 % of those specified by the test plan. The bias applied to the test devices shall be selected to produce the greatest radiation-induced damage or the worst-case damage for the intended application, if known. The bias, loading and internal dose-pattern conditions shall remain constant throughout a step-wise total ionizing dose exposure and anneal. If any of the bias, loading or internal dose-pattern conditions are not at the worst-case condition, then a justification for the conditions used shall be provided in the test plan and test report. While maximum voltage is often worst case some bipolar linear device parameters (e.g. input bias current or maximum output load current) exhibit more degradation with 0 V bias. The specified bias shall be maintained on each device in accordance with the test plan. Bias shall be checked immediately before and after irradiation. Care shall be taken in selecting the loading such that the rise in the junction temperature is minimized.

5.11 Post-irradiation procedure

Unless otherwise specified, the following time intervals shall be observed:

a) The time from the end of an irradiation to the start of electrical measurements shall be a maximum of 1 h for condition A. For conditions B, C, D and E, the time from the end of an irradiation to the start of electrical measurements may be equal to 10 % of the incremental irradiation time up to (but not exceeding) 72 h if this time is greater than 1 h, otherwise it shall be a maximum of 1 h. As an option for remote electrical testing, for conditions A, B, C, D and E, parts may be packed in dry ice until the start of electrical testing, but only if packed within 15 min after the completion of irradiation. While in dry ice, the part leads shall be shorted, the parts shall be verifiably maintained at a maximum temperature of −60 °C, and the time from completion of irradiation until the start of electrical testing may not exceed 72 h. The electrical testing shall be conducted after the parts have been restored to room temperature but within 30 min after the parts are removed from the dry ice. Electrical testing shall be as specified in 5.8.1. The times at room temperature and the times and temperature for the dry ice procedure may be different if demonstrated by a characterization test as described in 5.11 c) below.

b) The time to perform the electrical measurements and to return the device for a subsequent irradiation, if any, shall be within 2 h of the end of the prior irradiation for condition A. For conditions B, C, D and E, the time to perform the electrical measurements and to return the device for a subsequent irradiation, if any, may be equal to 20 % of the incremental irradiation time up to (but not exceeding) 120 h if this time is greater than 2 h, otherwise it shall be a maximum of 2 h. As an option for continued additional irradiation when parts are electrically tested at a remote location, for conditions A, B, C, D and E parts may be packed in dry ice until the start of irradiation, but only if packed within 15 min after the completion of electrical testing. While in the dry ice, the part leads shall be shorted, the parts shall be verifiably maintained at a maximum temperature of −60 °C, and the time from completion of electrical testing until the start of irradiation may not exceed 72 h. The radiation exposure shall begin after the parts have been restored to room temperature but within 30 min after the parts are removed from the dry ice. The times at room temperature and the times and temperature for the dry ice procedure may be different if demonstrated by a characterization test as described in 5.11 c) below.

c) If the dry ice test method is used, the characterization test shall be performed on annealing at the particular technology node of study to demonstrate that the annealing will be less than 10 % for all critical parameters compared to room temperature data taken within 1 h after irradiation. Other times and temperatures than those listed in 5.11 a) and 5.11 b) may be considered as part of the characterization test. However, the time for electrical measurements following irradiation shall not exceed 72 h and the time between successive irradiations shall not exceed 120 h. For example, if the manufacturer's cold temperature specification limit is higher than −60 °C this higher temperature may be allowed. For another example, if the parts show very little annealing at room temperature following condition A irradiation, the 1-h and 2-h limits could be increased. For any exceptions to the times and temperatures in 5.11 a) and 5.11 b) it shall be demonstrated that the annealing under these different conditions is within 10 % for all critical parameters compared to room temperature data taken within 1 h after irradiation, or the appropriate time limit for the irradiation test condition, if greater than 1 h. The characterization test results shall be included with the test report as specified in 5.15.

To minimize time-dependent effects, these intervals shall be as short as possible. The sequence of parameter measurements shall be maintained constant throughout the tests series.

5.12 Extended room temperature annealing test

5.12.1 Choice of annealing test

The tests of 5.2 to 5.11 are known to be overly conservative for some devices in a very low dose rate environment (e.g. dose rates characteristic of space missions). The extended room temperature annealing test provides an estimate of the performance of a device in a very low dose rate environment even though the testing is performed at a relatively high dose rate (e.g. 0,5 Gy(Si)/s to 3 Gy(Si)/s). The procedure involves irradiating the device following the procedures indicated in 5.2 to 5.11 and post-irradiation subjecting the device under test to a room temperature anneal for an appropriate period of time (see 5.12.2 c)) to allow leakage-related parameters that may have exceeded their pre-irradiation specification to return to within specification. The procedure is known to lead to a higher rate of device acceptance in cases:

a) where device failure when subjected to the tests in 5.2 to 5.11 has been caused by the buildup of trapped positive charge in relatively soft oxides; and

b) where this trapped positive charge anneals at a relatively high rate.

5.12.2 Need to perform an extended room temperature annealing test

The following criteria shall be used to determine whether an extended room temperature annealing test is appropriate.

a) The procedure is appropriate for either MOS or bipolar technology devices.

b) The procedure is appropriate where only parametric failures (as opposed to functional failure) occur. The parties to the test shall take appropriate steps to determine that the device under test is subject to only parametric failure over the total ionizing dose testing range.

c) The procedure is appropriate where the natural annealing response of the device under test will serve to correct the out-of-specification of any parametric response. Further, the procedure is known to lead to a higher rate of device acceptance in cases where the expected application irradiation dose rate is sufficiently low that ambient temperature annealing of the radiation-induced trapped positive charge can lead to a significant improvement of the device's behaviour. Cases where the expected application dose rate is lower than the test dose rate and lower than 0,001 Gy(Si)/s should be considered candidates for the application of this procedure. The parties to the test shall take appropriate steps to determine that the technology under test can provide the required annealing response over the total ionizing dose testing range.

5.12.3 Extended room temperature annealing test procedure

If the device fails the irradiation and testing specified in 5.2 to 5.11, an additional room temperature annealing test may be performed as follows.

a) Following the irradiation and testing of 5.2 to 5.11, subject the device under test to a room temperature anneal under worst-case static bias conditions. For information on worst case bias see 5.10.4.

b) The test will be carried out in such a fashion that the case of the device under test will have a temperature within the range 24 °C ± 6 °C.

c) Where possible, the room temperature anneal should continue for a length of time great enough to allow device parameters that have exceeded their pre-irradiation specification to return to within specification or post-irradiation parametric limit (PIPL) as established by the manufacturer. However, the time of the room temperature anneal shall not exceed t_{max}:

$$t_{\text{max}} = \frac{D_{\text{spec}}}{R_{\text{max}}}$$

where

D_{spec} is the total ionizing dose specification for the part, and

R_{max} is the maximum dose rate for the intended use.

d) Test the device under test for electrical performance as specified in 5.8 and 5.9. If the device under test passes electrical performance tests following the extended room temperature anneal, this shall be considered acceptable performance for a very low dose rate environment in spite of having previously failed the post-irradiation and electrical tests of 5.2 to 5.11.

5.13 MOS accelerated annealing test

5.13.1 Choice of MOS accelerated annealing test

The accelerated annealing test provides an estimate of worst-case degradation of MOS microcircuits in low dose rate environments. The procedure involves heating the device following irradiation at specified temperature, time and bias conditions. An accelerated annealing test (see 5.13.3) shall be performed for cases where time-dependent effects (TDEs) can cause a device to degrade significantly or fail. Only standard testing shall be performed as specified in 5.2 to 5.11 for cases where TDEs are known not to cause significant device degradation or failure (see 5.13.2) or where they do not need to be considered, as specified in 5.13.2.

5.13.2 Need to perform accelerated annealing test

The parties to the test shall take appropriate steps to determine whether accelerated annealing testing is required. The following criteria shall be used.

a) The tests called out in 5.13.3 shall be performed for any device or circuit type that contains MOS circuit elements (e.g. transistors or capacitors).

b) TDE tests may be omitted if
   1) circuits are known not to contain MOS elements by design, or
   2) the ionizing dose in the application, if known, is below 50 Gy(Si), or
   3) the lifetime of the device from the onset of the irradiation in the intended application, if known, is short compared with TDE times, or
   4) the test is carried out at the dose rate of the intended application, or
   5) the device type or IC technology has been demonstrated via characterization testing not to exhibit TDE changes in device parameters greater than experimental error (or greater than an otherwise specified upper limit) and the variables that affect TDE response are demonstrated to be under control for the specific vendor processes.

   At a minimum, the characterization testing in item 5) shall include an assessment of TDE on propagation delay, output drive, and minimum operating voltage parameters. Continuing process control of variables affecting TDE ~~may~~ can be demonstrated through lot sample tests of the radiation hardness of MOS test structures.

c) This document provides no guidance on the need to perform accelerated annealing tests on technologies that do not include MOS circuit elements.

5.13.3 Accelerated annealing test procedure

If the device passes the tests of 5.2 to 5.11 or if it passes 5.12 (if that procedure is used) to the total ionising dose level specified in the test plan or device specification or drawing and the exclusions of 5.13.2 do not apply, the accelerated annealing test shall be conducted as follows:

a) Overtest
   1) Irradiate each test device to an additional 0,5 times the specified dose using the standard test conditions (5.2 to 5.11). Note that no electrical testing is required at this time.
   2) The additional 0,5 times irradiation in 5.13.3, item a) 1) may be omitted if it has been demonstrated via characterization testing that
      - none of the circuit propagation delay, output drive, and minimum operating voltage parameters recover toward their pre-irradiation value greater than experimental accelerated annealing test of 5.13.3 item b), and
      - the irradiation biases chosen for irradiation and accelerated annealing tests are worst-case for the response of these parameters during accelerated annealing.

   The characterization testing to establish worst-case irradiation and annealing biases shall be performed at the specified level. The testing shall at a minimum include separate exposures under static and dynamic irradiation bias, each followed by worst-case static bias during accelerated annealing according to 5.13.3, item b).

b) Accelerated annealing

   Heat each device under worst-case static bias conditions in an environmental chamber according to one of the following conditions:
   1) at 100 °C ± 5 °C for 168 h ± 12 h, or
   2) at an alternate temperature and time that has been demonstrated via characterization testing to cause equal or greater change in the parameter(s) of interest, for example propagation delay, output drive, and minimum operating voltage, in each test device as that caused by 5.13.3, item b) 1), or
   3) at an alternate temperature and time which will cause trapped hole annealing of~~>~~ more than 60 % and interface state annealing of~~<~~ less than 10 % as determined via characterization testing of NMOS test transistors from the same process. It shall be demonstrated that the radiation response of test transistors represents that of the device under test.

c) Electrical testing

   Following the accelerated annealing, the electrical test measurements shall be performed as specified in 5.9 and 5.10.

5.14 Test procedure for bipolar and BiCMOS linear or mixed signal devices with intended application dose rates less than 0,5 Gy(Si)/s

5.14.1 Need to perform ELDRS testing

Many bipolar linear parts exhibit ELDRS, which cannot be simulated with a room temperature of 0,5 Gy(Si)/s to 3 Gy(Si)/s irradiation plus elevated temperature anneal, such as that used for MOS parts (see ASTM F 1892 for more technical details). Parts that exhibit ELDRS shall be tested either at the intended application dose rate, at a specified low dose rate to an overtest radiation level, or with an accelerated test such as an elevated temperature irradiation test that includes a parameter delta design margin (see the characterization test for ELDRS parts, in 5.14.3). For part types that have not been characterized for ELDRS a characterization test shall be performed to determine if the part types are ELDRS susceptible. The ELDRS tests described in 5.14 may be omitted if:

a) devices are known not to contain bipolar transistors by design,

b) devices are known not to contain any linear circuit functions by design, or

c) the device type and IC technology have been demonstrated via characterization testing not to exhibit ELDRS (5.14.2) in device parameters greater than experimental error and the variables that affect ELDRS response are demonstrated to be under control for the specific vendor processes.

5.14.2 Determination of whether a part exhibits ELDRS

5.14.2.1 Characterization testing for ELDRS

If a part cannot be eliminated by the criteria in 5.14.1 and has not been characterized for ELDRS then the part shall be subjected to a characterization test to determine whether it exhibits ELDRS. This test shall be performed at two dose rates. If the part meets the criteria for ELDRS then an additional characterization test may be performed to establish the irradiation conditions for production or lot acceptance tests.

5.14.2.2 Characterization test to determine whether a part exhibits ELDRS

Select a minimum random sample out of twenty devices from a population representative of recent production runs. Smaller sample sizes may be used if agreed upon between the parties to the test. All of the selected devices shall have undergone appropriate elevated temperature reliability screens, for example burn-in and high temperature storage life. Divide the samples into four groups of five each and use the remaining part for a control. Perform pre-irradiation electrical characterization on all parts ensuring that they meet the Group A electrical tests. Irradiate five samples under a 0-V bias and another five under the irradiation bias given in the acquisition specification at 0,5 Gy(Si)/s to 3 Gy(Si)/s and room temperature. Irradiate five samples under a 0-V bias and another five under the irradiation bias given in the acquisition specification at < 0,1mGy (Si)/s and room temperature. Irradiate all samples to the same dose levels, including 0,5 times and 1,0 times the anticipated specification dose, and repeat the electrical characterization on each part at each dose level. Post-irradiation electrical measurements shall be performed in accordance with 5.11 where the low dose rate test is considered condition D. Calculate the radiation-induced change in each electrical parameter (Δ_{para}) for each sample at each radiation level. Calculate the ratio of the median Δ_{para} at low dose rate to the median Δ_{para} at high dose rate for each irradiation bias group at each total dose level. If this ratio exceeds 1,5 for any of the most sensitive parameters then the part is considered to be ELDRS susceptible. This test does not apply to parameters which exhibit changes that are within experimental error or whose values are below the pre-irradiation electrical specification limits at low dose rate at the specification dose.

5.14.3 Characterization of ELDRS parts to determine the irradiation conditions for production or lot acceptance testing

If the part type is known to exhibit ELDRS or has been shown to exhibit ELDRS by the characterization tests in 5.14.2.2 then the production or lot acceptance testing may be performed using the default low dose rate test at < 0,1mGy (Si)/s (condition D) or an accelerated test (condition E). For the accelerated test a detailed characterization shall be performed to establish the test parameters for the test. The accelerated test approach may include one of the following methods:

a) a room temperature low dose rate irradiation at a dose rate greater than 0,1mGy (Si)/s;

b) an elevated temperature irradiation;

c) combinations of high dose rate tests and elevated temperature anneals;

d) switched dose rates;

e) some other form of accelerated testing (for guidance on characterization of ELDRS parts see ASTM F 1892:2018, Appendix X2).

The characterization testing of the ELDRS parts shall demonstrate that the irradiation test procedure for production or lot acceptance testing will bound the low dose rate response for all critical electrical parameters at a dose rate of less than 0,1mGy (Si)/s using a combination of overtest and/or parameter delta design margins. Hence the characterization testing shall include irradiation at less than 0,1mGy (Si)/s, to the specification dose, as a baseline for comparison.

5.14.4 Low dose rate or elevated temperature irradiation test for bipolar or BiCMOS linear or mixed-signal devices

All devices that do not meet the exception of 5.14.1 shall be tested using one of the following test conditions:

a) Test at the dose rate agreed to. Irradiate each test device at the dose rate described in 5.7.4 (condition C) using the standard test conditions (5.2 to 5.11).

b) Test at a specified low dose rate. Irradiate each test device at the dose rate described in 5.7.5 (condition D) using the standard test conditions (5.2 to 5.11) with the following additional requirements: an overtest factor of 1,5 shall be applied to the radiation level, i.e. the part shall pass at a radiation level of 1,5 times the specification dose to be acceptable.

c) Test using an accelerated test method. Irradiate each test device with the accelerated test condition described in 5.7.6 (condition E) using the standard test conditions (5.2 to 5.11) with the following additional requirements: a parameter delta design margin and/or overtest factor shall be applied as established through the characterization testing described in 5.14.3.

5.15 Test report

As a minimum, the report shall include the device type number, serial number, the name of the manufacturer, package type, controlling specification, date code, and any other identifying numbers given by the manufacturer.

The bias circuit, parameter measurement circuits, the layout of the test apparatus with details of distances and materials used, and electrical noise and current leakage of the electrical measurement system for in-flux testing shall be reported using drawings or diagrams as appropriate.

Each data sheet shall include the test date, the radiation source used, the bias conditions during irradiation, the ambient temperature around the devices during irradiation and electrical testing, the duration of each irradiation, the time between irradiation and the start of the electrical measurements, the duration of the electrical measurements and the time to the next irradiation when step irradiations are used, the irradiation dose rate, electrical test conditions, dosimetry system and procedures, and the radiation test levels.

The pre- and post-irradiation data shall be recorded for each part and retained with the parent population data. Any anomalous incidents during the test shall be fully documented and reported. The accelerated annealing procedure, if used, shall be described. Any other radiation test procedures or test data required for the delivery shall be specified in the device specification, drawing or purchase order.

6 Summary

The following details shall be specified in the relevant specification:

a) device-type number(s), quantity, and governing specifications (see 5.2);

b) radiation dosimetry requirements (see 5.4);

c) radiation test levels including dose and dose rate (see 5.6 and 5.7);

d) irradiation, electrical test and transport temperatures if other than as specified in 5.8;

e) test methodology used if not maintaining cryogenic temperature as specified in 5.8;

f) electrical parameters to be measured and device operating conditions during measurement (see 5.9);

g) test conditions, for example in-flux or non in-flux type tests (see 5.10);

h) bias, loading and internal dose-pattern conditions for devices during irradiation (see 5.10.4);

i) time intervals of the post-irradiation measurements (see 5.11);

j) requirements for extended room temperature annealing test, if required (see 5.12);

k) requirements for accelerated annealing test, if required (see 5.13);

l) requirements for test for ELDRS, if required (see 5.14);

m) requirements for ELDRS testing, if required (see 5.14.4);

n) documentation required to be delivered with devices (see 5.15).

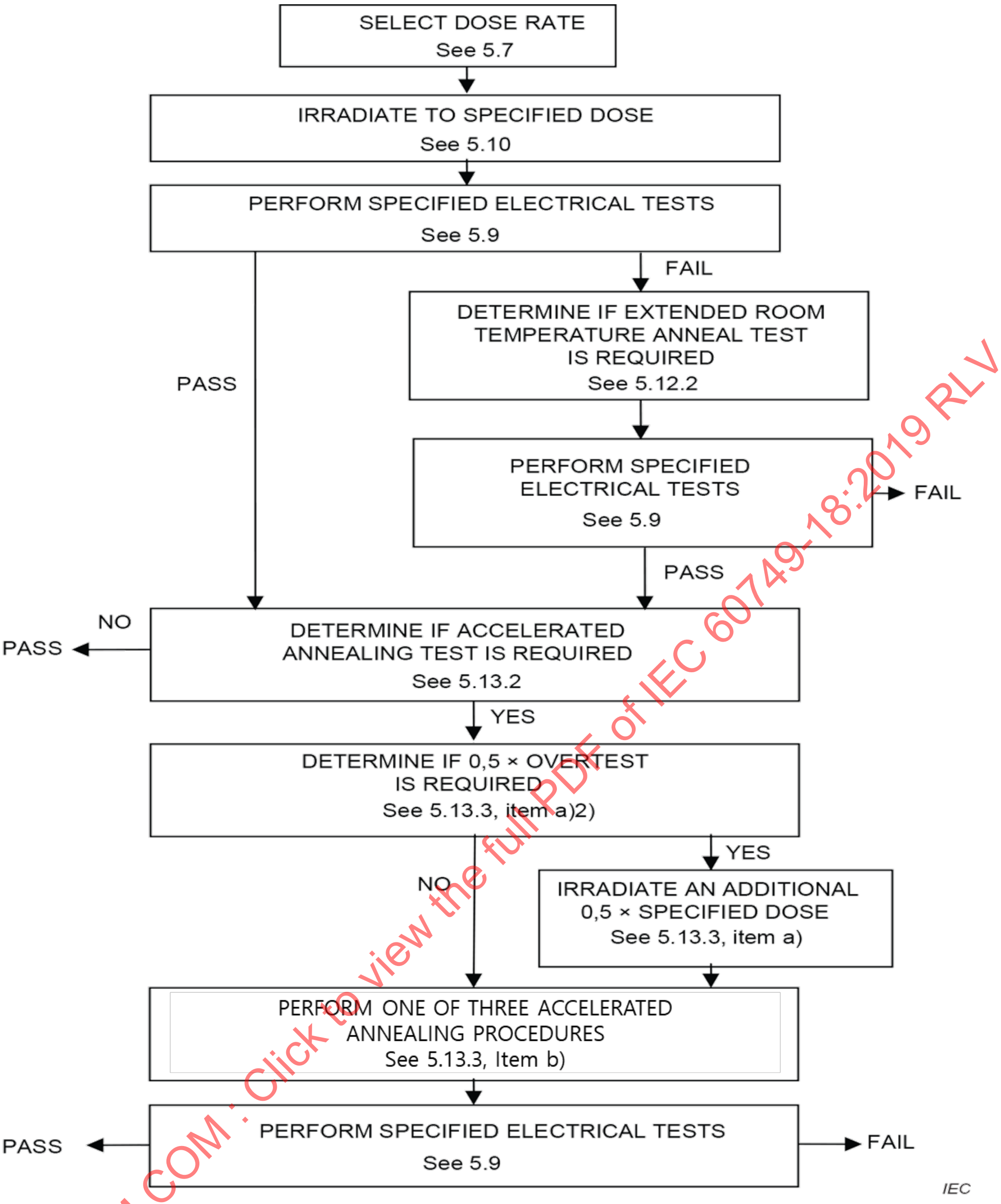

Figure 1 – Flow diagram for ionizing radiation test procedure for MOS and digital bipolar devices

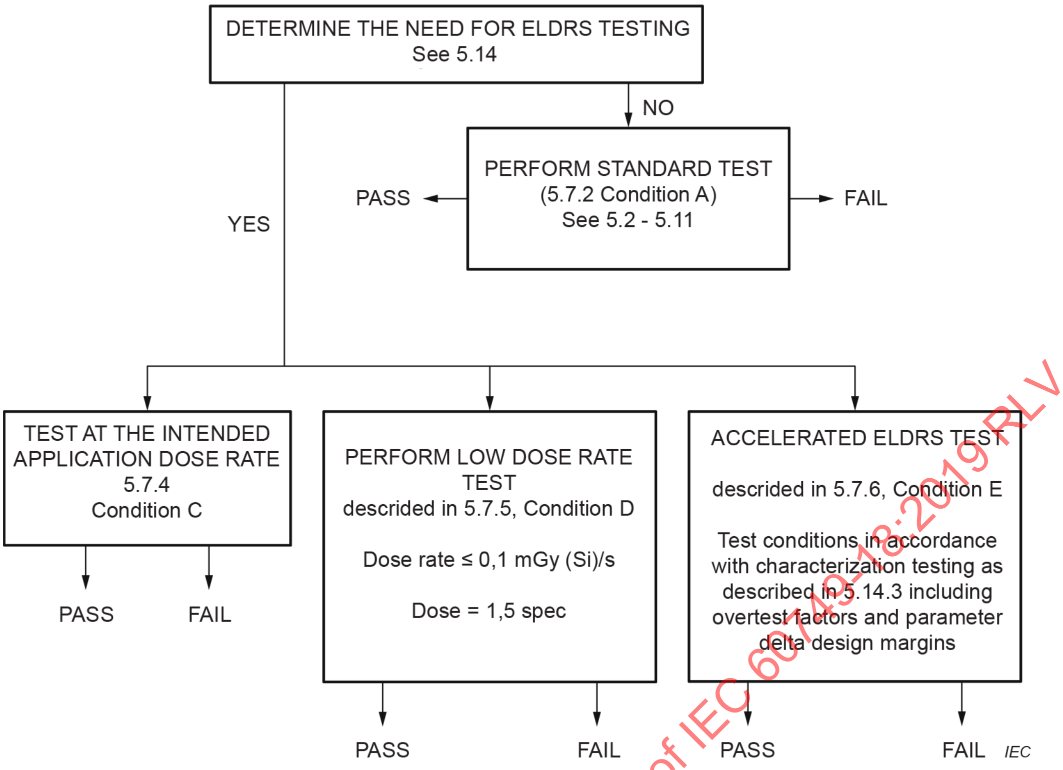

Figure 2 – Flow diagram for ionizing radiation test procedure for bipolar (or BiCMOS) linear or mixed-signal devices

Bibliography

ASTM E 666, *Standard practice for calculating absorbed dose from gamma or X radiation*

ASTM E 668, *Standard practice for application of thermoluminescence-dosimetry (TLD) systems for determining absorbed dose in radiation-hardness testing of electronic devices*

ASTM E 1249, *Standard practice for minimizing dosimetry errors in radiation hardness testing of silicon electronic devices using Co-60 sources*

ASTM E 1250, *Standard 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 devices*

ASTM F 1892:2018, *Standard guide for ionizing radiation (total dose) effects testing of semiconductor devices*

ISO/ASTM 51275, *Practice for use of a radiochromic film dosimetry system*

MIL-STD-883J, Method 1019.9, *Ionizing radiation (total dose) test procedure*

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INTERNATIONAL STANDARD

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Semiconductor devices – Mechanical and climatic test methods – Part 18: Ionizing radiation (total dose)

Dispositifs à semiconducteurs – Méthodes d’essais mécaniques et climatiques – Partie 18: Rayonnements ionisants (dose totale)

IEC 60749-18:2019-04(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SEMICONDUCTOR DEVICES – MECHANICAL AND CLIMATIC TEST METHODS –

Part 18: Ionizing radiation (total dose)

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60749-18 has been prepared by IEC technical committee 47: Semiconductor devices.

This second edition cancels and replaces the first edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) updates to subclauses to better align the test method with MIL-STD 883J, method 1019, including the use of enhanced low dose rate sensitivity (ELDRS) testing;
b) addition of a Bibliography, which includes ASTM standards relevant to this test method.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
47/2539/FDIS	47/2554/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60749 series, published under the general title *Semiconductor devices – Mechanical and climatic test methods*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

SEMICONDUCTOR DEVICES – MECHANICAL AND CLIMATIC TEST METHODS –

Part 18: Ionizing radiation (total dose)

1 Scope

This part of IEC 60749 provides a test procedure for defining requirements for testing packaged semiconductor integrated circuits and discrete semiconductor devices for ionizing radiation (total dose) effects from a cobalt-60 (^{60}Co) gamma ray source. Other suitable radiation sources can be used.

There are four tests presented in this procedure:

a) a standard room temperature irradiation test;
b) an irradiation at elevated temperature/cryogenic temperature test;
c) an accelerated annealing test;
d) an enhanced low dose rate sensitivity (ELDRS) test.

The accelerated annealing test estimates how dose rate ionizing radiation effects on devices is important for low dose rate or certain other applications in which devices can exhibit significant time-dependent effects. The ELDRS test determines if devices with bipolar linear components exhibit sensitivity to enhanced radiation-induced damage at low dose rates.

This document addresses only steady-state irradiations, and is not applicable to pulse type irradiations.

It is intended for military- and aerospace-related applications.

This document can produce severe degradation of the electrical properties of irradiated devices and thus is considered a destructive test.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ionizing radiation effects, pl
changes in the electrical parameters of a device or integrated circuit resulting from radiation-induced charge

Note 1 to entry: These are also referred to as total dose effects.

3.2
in-flux test
electrical measurements made on devices during irradiation exposure

3.3
internal dose pattern
logic condition of all elements within a logic circuit during radiation exposure

3.4
non in-flux test
electrical measurements made on devices at any time other than during irradiation

3.5
remote test
electrical measurements made on devices that are physically removed from the radiation location

3.6
time-dependent effect
TDE
significant degradation in electrical parameters caused by the growth or annealing, or both, of radiation-induced trapped charge after irradiation

Note 1 to entry: Similar effects also take place during irradiation.

Note 2 to entry: This note applies to the French language only.

3.7
accelerated annealing test
procedure utilizing elevated temperature to accelerate time-dependent effects

3.8
enhanced low dose rate sensitivity
ELDRS
part that shows enhanced radiation-induced damage at dose rates below 0,5 Gy(Si)/s

Note 1 to entry: This note applies to the French language only.

3.9
overtest
factor that is applied to the specification dose to determine the test dose level that the samples have to pass to be acceptable at the specification level

Note 1 to entry: An overtest factor of 1,5 means that the parts should be tested at 1,5 times the specification dose.

3.10
parameter delta design margin
PDDM
design margin that is applied to the radiation-induced change in an electrical parameter

Note 1 to entry: For a PDDM of 2 the change in a parameter at a specified dose from the pre-irradiation value is multiplied by two and added to the pre-irradiation value to see if the sample exceeds the post-irradiation parameter limit. For example, if the pre-irradiation value of base current I_b is 30 nA and the post-irradiation value at 200 Gy(Si) is 70 nA (change in I_b is 40 nA), then for a PDDM of 2 the post-irradiation value would be 110 nA (30 nA + 2 x 40 nA). If the allowable post-irradiation limit is 100 nA, the part would fail.

4 Test apparatus

4.1 Choice of apparatus

The apparatus shall consist of the radiation source, electrical test instrumentation, test circuit board(s), cabling, interconnect board or switching system, an appropriate dosimetry measurement system, and an environmental chamber (if required for time-dependent effects measurements). Adequate precautions shall be observed to obtain an electrical measurement system with sufficient insulation, ample shielding, satisfactory grounding, and suitable low noise characteristics.

4.2 Radiation source

The radiation source used in the test shall be the uniform field of a ^{60}Co gamma ray source. Uniformity of the radiation field in the volume where devices are irradiated shall be within ±10 % as measured by the dosimetry system, unless otherwise specified. The intensity of the gamma ray field of the ^{60}Co source shall be known with an uncertainty of no more than ±5 %. Field uniformity and intensity can be affected by changes in the location of the device with respect to the radiation source and the presence of radiation absorption and scattering materials.

4.3 Dosimetry system

An appropriate dosimetry system shall be provided that is capable of carrying out the measurements called for in 5.3 (see Bibliography).

4.4 Electrical test instruments

All instrumentation used for electrical measurements shall have the stability, accuracy, and resolution required for accurate measurement of the electrical parameters. Any instrumentation required to operate in a radiation environment shall be appropriately shielded.

4.5 Test circuit board(s)

Devices to be irradiated shall either be mounted on or connected to circuit boards together with any associated circuitry necessary for device biasing during irradiation or for in situ measurements. Unless otherwise specified, all device input terminals and any others which can affect the radiation response shall be electrically connected during irradiation, i.e. not left floating.

The geometry and materials of the completed board shall allow uniform irradiation of the devices under test. Good design and construction practices shall be used to prevent oscillations, minimize leakage currents, prevent electrical damage and obtain accurate measurements. Only sockets that are radiation resistant and do not exhibit significant leakages (relative to the devices under test) shall be used to mount devices and associated circuitry to the test board(s).

All apparatus used repeatedly in radiation fields shall be checked periodically for physical or electrical degradation. Components which are placed on the test circuit board, other than devices under test, shall be insensitive to the accumulated radiation or they shall be shielded from the radiation. Test fixtures shall be made such that materials will not perturb the uniformity of the radiation field intensity on the devices under test.

Leakage current shall be measured outside the field of radiation. With no devices installed in the sockets, the test circuit board shall be connected to the test system such that all expected sources of noise and interference are operative. With the maximum specified bias for the test device applied, the leakage current between any two terminals shall not exceed 10 % of the lowest current limit value in the pre-irradiation device specification.

Test circuit boards used to bias devices during accelerated annealing shall be capable of withstanding the temperature requirements of the accelerated annealing test and shall be checked before and after testing for physical and electrical degradation.

4.6 Cabling

Cables connecting the test circuit boards in the radiation field to the test instrumentation shall be as short as possible. If long cables are necessary, line drivers can be required. The cables shall have low capacitance and low leakage to ground, and low leakage between wires.

4.7 Interconnect or switching system

This system shall be located outside the radiation environment location, and provides the interface between the test instrumentation and the devices under test. It is part of the entire test system and subject to the limitation specified in 4.5 for leakage between terminals.

4.8 Environmental chamber

The environmental chamber for time-dependent effects testing, if required, shall be capable of maintaining the selected accelerated annealing temperature within ±5 °C.

4.9 Irradiation temperature chamber

The irradiation temperature chamber, if required for elevated temperature irradiation should be capable of maintaining a circuit under test at 100 °C ± 5 °C while it is being irradiated. The chamber should be capable of raising the temperature of the circuit under test from room temperature to the irradiation temperature within a reasonable time prior to irradiation and cooling the circuit under test from the irradiation temperature to room temperature in less than 20 min following irradiation. The irradiation bias shall be maintained during the heating and cooling. The method for raising, maintaining and lowering the temperature of the circuit under test can be by conduction through a heat sink using heating and cooling fluids, by convection using forced hot and cool air, or other means that will achieve the proper results. For cryogenic temperature irradiations, the chamber should be capable of maintaining the test device/unit at the required cryogenic temperature within ±5 °C (e.g., liquid helium or liquid nitrogen) while it is being irradiated. The chamber should be capable of maintaining the cryogenic temperature of the test device/unit during post-irradiation electrical testing.

5 Procedure

5.1 Test plan

The test devices shall be irradiated and subjected to accelerated annealing testing (if required for time-dependent effects testing) as specified by a test plan. This plan shall specify the device description, irradiation conditions, device bias conditions, dosimetry system, operating conditions, measurement parameters and conditions and accelerated annealing test conditions (if required).

5.2 Sample selection and handling

Only devices that have passed the electrical specifications as defined in the test plan shall be submitted to radiation testing. Unless otherwise specified, the test samples shall be randomly selected from the parent population and identically packaged. Each part shall be individually identifiable to enable pre- and post-irradiation comparison. For device types that are electrostatic discharge (ESD)-sensitive, proper handling techniques shall be used to prevent damage to the devices.

5.3 Burn-in

For some devices, there are differences in the total dose radiation response before and after burn-in. Unless it has been shown by prior characterization or by design that burn-in has a negligible effect (parameters remain within post-irradiation specified electrical limits) on the total dose radiation response, then one of the following functions shall take place:

a) the manufacturer shall subject the radiation samples to the specified burn-in conditions prior to conducting total dose radiation testing; or

b) the manufacturer shall develop a correction factor, (which is acceptable to the parties to the test) taking into account the changes in total dose response resulting from subjecting the product to burn-in. The correction factor shall then be used to accept the product for total dose response without subjecting the test samples to burn-in.

5.4 Dosimetry measurements

The radiation field intensity at the location of the device under test shall be determined prior to testing by dosimetry or by source decay correction calculations, as appropriate, to ensure conformance to the test level and uniformity requirements.

The dose applied to the device under test shall be determined in one of two ways:

a) by measurement during the irradiation with an appropriate dosimeter; or

b) by correcting a previous dosimetry value for the decay of the ^{60}Co source intensity in the intervening time. Appropriate correction shall be made to convert from the measured or calculated dose in the dosimeter material to the dose in the device under test.

5.5 Lead/aluminium (Pb/Al) container

Test specimens shall be enclosed in a Pb/Al container to minimize dose enhancement effects caused by low-energy scattered radiation. A minimum of 1,5 mm of lead (Pb), surrounding an inner shield of at least 0,7 mm aluminium (Al) is required. This Pb/Al container produces an approximate charged particle equilibrium for Si and for thermoluminescence dosimetries (TLDs) such as CaF2. The radiation field intensity shall be measured inside the Pb/Al container (1) initially, (2) when the source is changed, or (3) when the orientation or configuration of the source, container or test-fixture is changed. This measurement shall be performed by placing a dosimeter (e.g. a TLD) in the device-irradiation container at the approximate test-device position. If it can be demonstrated that low energy scattered radiation is small enough that it will not cause dosimetry errors due to dose enhancement, the Pb/Al container may be omitted.

5.6 Radiation level(s)

The test devices shall be irradiated to the dose level(s) specified in the test plan within ±10 %. If multiple irradiations are required for a set of test devices, then the post-irradiation electrical parameter measurements shall be performed after each irradiation.

5.7 Radiation dose rate

5.7.1 Radiation dose rate determination

The radiation dose rate for bipolar and BiCMOS linear or mixed-signal parts used in applications where the maximum dose rate is below 0,5 Gy(Si)/s shall be determined as described in 5.14. Parts used in low dose rate applications, unless they have been demonstrated to not exhibit an ELDRS response shall use condition C, condition D, or condition E.

A flow diagram for ionizing test procedures for MOS and digital bipolar devices is shown in Figure 1. A flow diagram for ionizing radiation test procedure for bipolar (or BiCMOS) linear or mixed-signal devices is shown in Figure 2.

NOTE Devices that contain both MOS and bipolar devices can require qualification to multiple subconditions to ensure that both ELDRS and traditional MOS effects are evaluated.

5.7.2 Condition A

For condition A (standard condition), the dose rate shall be between 0,5 Gy(Si)/s and 3 Gy(Si)/s for integrated circuits and between 0,5 Gy(Si)/s and 20 Gy(Si)/s for discrete semi-conductor devices. The dose rates may be different for each radiation dose level in a series; however, the dose rate shall not vary by more than ±10 % during each irradiation.

5.7.3 Condition B

For condition B, for MOS devices only, if the maximum dose rate is less than 0,5 Gy(Si)/s in the intended application, the parties to the test can agree to perform the test at a dose rate greater than or equal to the maximum dose rate of the intended application. Unless the exclusions in 5.13.2 b) are met, the accelerated annealing test of 5.13.3 shall be performed.

5.7.4 Condition C

For condition C, (as an alternative) the test may be performed at the dose rate of the intended application if this is agreed to by the parties to the test. Where the final user is not known, the test conditions and results shall be made available in the test report with each purchase order.

5.7.5 Condition D

For condition D, for bipolar or BiCMOS linear or mixed-signal devices only, the parts shall be irradiated at less than or equal to 0,1 mGy(Si)/s.

5.7.6 Condition E

For condition E, for bipolar or BiCMOS linear or mixed-signal devices only, the parts shall be irradiated with the accelerated test conditions determined by characterization testing as discussed in 5.14.3. The accelerated test may include irradiation at an elevated temperature.

5.8 Temperature requirements

5.8.1 Room temperature radiation

Since radiation effects are temperature dependent, devices under test shall be irradiated in an ambient temperature of 24 °C ± 6 °C as measured at a point in the test chamber in close proximity to the test fixture. The electrical measurements shall be performed in an ambient temperature of 24 °C ± 6 °C. If devices are transported to and from a remote electrical measurement site, the temperature of the test devices shall not be allowed to increase by more than 10 °C from the irradiation environment. If any other temperature range is required, it shall be specified.

Caution: Annealing at ambient temperatures above the irradiation temperature can be significant, especially for the extended times allowed for the time between irradiations at low dose rate (condition D). It is important to ensure that the temperature of the parts is maintained within the above stated requirements to minimize annealing.

5.8.2 Elevated temperature irradiation

For bipolar or BiCMOS linear or mixed-signal devices irradiated using the condition E elevated temperature irradiation test, devices under test shall be irradiated in an ambient temperature determined by characterization testing (see 5.14.3) as measured at a point in the test chamber in close proximity to the test fixture (see 4.8 for details on raising and lowering the irradiation temperature).

5.8.3 Cryogenic temperature irradiation

For test devices/units operated in cryogenic temperature applications, the devices/units shall be irradiated at cryogenic temperature (see 4.8) and maintained at cryogenic temperature for post exposure characterization testing (see 5.11). The test device/units shall remain at cryogenic temperature throughout all irradiations and characterization testing until the final total dose exposure and characterization have been completed.

5.9 Electrical performance measurements

The electrical parameters to be measured and functional tests to be performed shall be specified in the test plan. As a check on the validity of the measurement system and pre- and post-irradiation data, at least one control sample shall be measured using the operating conditions provided in the governing device specifications. For automatic test equipment, there is no restriction on the test sequence provided that the rise in the device junction temperature is minimized. For manual measurements, the sequence of parameter measurements shall be chosen to allow the shortest possible measurement period. When a series of measurements is made, the tests shall be arranged so that the lowest power dissipation in the device occurs in the earliest measurements and the power dissipation increases with subsequent measurements in the sequence.

The pre- and post-irradiation electrical measurements shall be carried out on the same measurement system and the same sequence of measurements shall be maintained for each series of electrical measurements of devices in a test sample. Pulse-type measurements of electrical parameters should be used as appropriate to minimize heating and subsequent annealing effects. Devices which will be subjected to the accelerated annealing testing (see 5.13) may be given a pre-irradiation burn-in to eliminate burn-in related failures.

5.10 Test conditions

5.10.1 Choice of test conditions

The use of in-flux or non in-flux testing shall be specified in the test plan. (This can depend on the intended application for which the data are being obtained.) The use of in-flux testing can help to avoid variations introduced by post-irradiation time-dependent effects. However, errors can occur for the situation where a device is irradiated in-flux with static bias, but where the electrical testing conditions require the use of dynamic bias for a significant fraction of the total irradiation period. Non-in-flux testing generally allows for more comprehensive electrical testing, but can be misleading if significant post-irradiation time-dependent effects occur.

5.10.2 In-flux testing

Each test device shall be checked for operation within specifications prior to being irradiated. After the entire system is in place for the in-flux radiation test, it shall be checked for proper interconnections, leakage (see 4.5), and noise level. To ensure the proper operation and stability of the test set-up, a control device with known parameter values shall be measured at all operational conditions called for in the test plan. This measurement shall be carried out either before the insertion of test devices or upon completion of the irradiation after removal of the test devices or both.

5.10.3 Remote testing

Unless otherwise specified, the bias shall be removed and the device leads placed in conductive foam (or similarly shorted) during transfer from the irradiation source to a remote tester and back again for further irradiation. This minimizes post-irradiation time-dependent effects.

5.10.4 Bias and loading conditions

Bias conditions for test devices during irradiation or accelerated annealing shall be within ±10 % of those specified by the test plan. The bias applied to the test devices shall be selected to produce the greatest radiation-induced damage or the worst-case damage for the intended application, if known. The bias, loading and internal dose-pattern conditions shall remain constant throughout a step-wise total ionizing dose exposure and anneal. If any of the bias, loading or internal dose-pattern conditions are not at the worst-case condition, then a justification for the conditions used shall be provided in the test plan and test report. While maximum voltage is often worst case some bipolar linear device parameters (e.g. input bias current or maximum output load current) exhibit more degradation with 0 V bias. The specified bias shall be maintained on each device in accordance with the test plan. Bias shall be checked immediately before and after irradiation. Care shall be taken in selecting the loading such that the rise in the junction temperature is minimized.

5.11 Post-irradiation procedure

Unless otherwise specified, the following time intervals shall be observed:

a) The time from the end of an irradiation to the start of electrical measurements shall be a maximum of 1 h for condition A. For conditions B, C, D and E, the time from the end of an irradiation to the start of electrical measurements may be equal to 10 % of the incremental irradiation time up to (but not exceeding) 72 h if this time is greater than 1 h, otherwise it shall be a maximum of 1 h. As an option for remote electrical testing, for conditions A, B, C, D and E, parts may be packed in dry ice until the start of electrical testing, but only if packed within 15 min after the completion of irradiation. While in dry ice, the part leads shall be shorted, the parts shall be verifiably maintained at a maximum temperature of −60 °C, and the time from completion of irradiation until the start of electrical testing may not exceed 72 h. The electrical testing shall be conducted after the parts have been restored to room temperature but within 30 min after the parts are removed from the dry ice. Electrical testing shall be as specified in 5.8.1. The times at room temperature and the times and temperature for the dry ice procedure may be different if demonstrated by a characterization test as described in 5.11 c) below.

b) The time to perform the electrical measurements and to return the device for a subsequent irradiation, if any, shall be within 2 h of the end of the prior irradiation for condition A. For conditions B, C, D and E, the time to perform the electrical measurements and to return the device for a subsequent irradiation, if any, may be equal to 20 % of the incremental irradiation time up to (but not exceeding) 120 h if this time is greater than 2 h, otherwise it shall be a maximum of 2 h. As an option for continued additional irradiation when parts are electrically tested at a remote location, for conditions A, B, C, D and E parts may be packed in dry ice until the start of irradiation, but only if packed within 15 min after the completion of electrical testing. While in the dry ice, the part leads shall be shorted, the parts shall be verifiably maintained at a maximum temperature of −60 °C, and the time from completion of electrical testing until the start of irradiation may not exceed 72 h. The radiation exposure shall begin after the parts have been restored to room temperature but within 30 min after the parts are removed from the dry ice. The times at room temperature and the times and temperature for the dry ice procedure may be different if demonstrated by a characterization test as described in 5.11 c) below.

c) If the dry ice test method is used, the characterization test shall be performed on annealing at the particular technology node of study to demonstrate that the annealing will be less than 10 % for all critical parameters compared to room temperature data taken within 1 h after irradiation. Other times and temperatures than those listed in 5.11 a) and 5.11 b) may be considered as part of the characterization test. However, the time for electrical measurements following irradiation shall not exceed 72 h and the time between successive irradiations shall not exceed 120 h. For example, if the manufacturer's cold temperature specification limit is higher than −60 °C this higher temperature may be allowed. For another example, if the parts show very little annealing at room temperature following condition A irradiation, the 1-h and 2-h limits could be increased. For any exceptions to the times and temperatures in 5.11 a) and 5.11 b) it shall be demonstrated that the annealing under these different conditions is within 10 % for all critical parameters compared to room temperature data taken within 1 h after irradiation, or the appropriate time limit for the irradiation test condition, if greater than 1 h. The characterization test results shall be included with the test report as specified in 5.15.

To minimize time-dependent effects, these intervals shall be as short as possible. The sequence of parameter measurements shall be maintained constant throughout the tests series.

5.12 Extended room temperature annealing test

5.12.1 Choice of annealing test

The tests of 5.2 to 5.11 are known to be overly conservative for some devices in a very low dose rate environment (e.g. dose rates characteristic of space missions). The extended room temperature annealing test provides an estimate of the performance of a device in a very low dose rate environment even though the testing is performed at a relatively high dose rate (e.g. 0,5 Gy(Si)/s to 3 Gy(Si)/s). The procedure involves irradiating the device following the procedures indicated in 5.2 to 5.11 and post-irradiation subjecting the device under test to a room temperature anneal for an appropriate period of time (see 5.12.2 c)) to allow leakage-related parameters that may have exceeded their pre-irradiation specification to return to within specification. The procedure is known to lead to a higher rate of device acceptance in cases:

a) where device failure when subjected to the tests in 5.2 to 5.11 has been caused by the buildup of trapped positive charge in relatively soft oxides; and

b) where this trapped positive charge anneals at a relatively high rate.

5.12.2 Need to perform an extended room temperature annealing test

The following criteria shall be used to determine whether an extended room temperature annealing test is appropriate.

a) The procedure is appropriate for either MOS or bipolar technology devices.

b) The procedure is appropriate where only parametric failures (as opposed to functional failure) occur. The parties to the test shall take appropriate steps to determine that the device under test is subject to only parametric failure over the total ionizing dose testing range.

c) The procedure is appropriate where the natural annealing response of the device under test will serve to correct the out-of-specification of any parametric response. Further, the procedure is known to lead to a higher rate of device acceptance in cases where the expected application irradiation dose rate is sufficiently low that ambient temperature annealing of the radiation-induced trapped positive charge can lead to a significant improvement of the device's behaviour. Cases where the expected application dose rate is lower than the test dose rate and lower than 0,001 Gy(Si)/s should be considered candidates for the application of this procedure. The parties to the test shall take appropriate steps to determine that the technology under test can provide the required annealing response over the total ionizing dose testing range.

5.12.3 Extended room temperature annealing test procedure

If the device fails the irradiation and testing specified in 5.2 to 5.11, an additional room temperature annealing test may be performed as follows.

a) Following the irradiation and testing of 5.2 to 5.11, subject the device under test to a room temperature anneal under worst-case static bias conditions. For information on worst case bias see 5.10.4.

b) The test will be carried out in such a fashion that the case of the device under test will have a temperature within the range 24 °C ± 6 °C.

c) Where possible, the room temperature anneal should continue for a length of time great enough to allow device parameters that have exceeded their pre-irradiation specification to return to within specification or post-irradiation parametric limit (PIPL) as established by the manufacturer. However, the time of the room temperature anneal shall not exceed t_{max}:

$$t_{\text{max}} = \frac{D_{\text{spec}}}{R_{\text{max}}}$$

where

D_{spec} is the total ionizing dose specification for the part, and

R_{max} is the maximum dose rate for the intended use.

d) Test the device under test for electrical performance as specified in 5.8 and 5.9. If the device under test passes electrical performance tests following the extended room temperature anneal, this shall be considered acceptable performance for a very low dose rate environment in spite of having previously failed the post-irradiation and electrical tests of 5.2 to 5.11.

5.13 MOS accelerated annealing test

5.13.1 Choice of MOS accelerated annealing test

The accelerated annealing test provides an estimate of worst-case degradation of MOS microcircuits in low dose rate environments. The procedure involves heating the device following irradiation at specified temperature, time and bias conditions. An accelerated annealing test (see 5.13.3) shall be performed for cases where time-dependent effects (TDEs) can cause a device to degrade significantly or fail. Only standard testing shall be performed as specified in 5.2 to 5.11 for cases where TDEs are known not to cause significant device degradation or failure (see 5.13.2) or where they do not need to be considered, as specified in 5.13.2.

5.13.2 Need to perform accelerated annealing test

The parties to the test shall take appropriate steps to determine whether accelerated annealing testing is required. The following criteria shall be used.

a) The tests called out in 5.13.3 shall be performed for any device or circuit type that contains MOS circuit elements (e.g. transistors or capacitors).

b) TDE tests may be omitted if

  1) circuits are known not to contain MOS elements by design, or
  2) the ionizing dose in the application, if known, is below 50 Gy(Si), or
  3) the lifetime of the device from the onset of the irradiation in the intended application, if known, is short compared with TDE times, or
  4) the test is carried out at the dose rate of the intended application, or
  5) the device type or IC technology has been demonstrated via characterization testing not to exhibit TDE changes in device parameters greater than experimental error (or greater than an otherwise specified upper limit) and the variables that affect TDE response are demonstrated to be under control for the specific vendor processes.

     At a minimum, the characterization testing in item 5) shall include an assessment of TDE on propagation delay, output drive, and minimum operating voltage parameters. Continuing process control of variables affecting TDE can be demonstrated through lot sample tests of the radiation hardness of MOS test structures.

c) This document provides no guidance on the need to perform accelerated annealing tests on technologies that do not include MOS circuit elements.

5.13.3 Accelerated annealing test procedure

If the device passes the tests of 5.2 to 5.11 or if it passes 5.12 (if that procedure is used) to the total ionising dose level specified in the test plan or device specification or drawing and the exclusions of 5.13.2 do not apply, the accelerated annealing test shall be conducted as follows:

a) Overtest
   1) Irradiate each test device to an additional 0,5 times the specified dose using the standard test conditions (5.2 to 5.11). Note that no electrical testing is required at this time.
   2) The additional 0,5 times irradiation in 5.13.3, item a) 1) may be omitted if it has been demonstrated via characterization testing that
      – none of the circuit propagation delay, output drive, and minimum operating voltage parameters recover toward their pre-irradiation value greater than experimental accelerated annealing test of 5.13.3 item b), and
      – the irradiation biases chosen for irradiation and accelerated annealing tests are worst-case for the response of these parameters during accelerated annealing.

      The characterization testing to establish worst-case irradiation and annealing biases shall be performed at the specified level. The testing shall at a minimum include separate exposures under static and dynamic irradiation bias, each followed by worst-case static bias during accelerated annealing according to 5.13.3, item b).

b) Accelerated annealing

   Heat each device under worst-case static bias conditions in an environmental chamber according to one of the following conditions:
   1) at 100 °C ± 5 °C for 168 h ± 12 h, or
   2) at an alternate temperature and time that has been demonstrated via characterization testing to cause equal or greater change in the parameter(s) of interest, for example propagation delay, output drive, and minimum operating voltage, in each test device as that caused by 5.13.3, item b) 1), or
   3) at an alternate temperature and time which will cause trapped hole annealing of more than 60 % and interface state annealing of less than 10 % as determined via characterization testing of NMOS test transistors from the same process. It shall be demonstrated that the radiation response of test transistors represents that of the device under test.

c) Electrical testing

   Following the accelerated annealing, the electrical test measurements shall be performed as specified in 5.9 and 5.10.

5.14 Test procedure for bipolar and BiCMOS linear or mixed signal devices with intended application dose rates less than 0,5 Gy(Si)/s

5.14.1 Need to perform ELDRS testing

Many bipolar linear parts exhibit ELDRS, which cannot be simulated with a room temperature of 0,5 Gy(Si)/s to 3 Gy(Si)/s irradiation plus elevated temperature anneal, such as that used for MOS parts (see ASTM F 1892 for more technical details). Parts that exhibit ELDRS shall be tested either at the intended application dose rate, at a specified low dose rate to an overtest radiation level, or with an accelerated test such as an elevated temperature irradiation test that includes a parameter delta design margin (see the characterization test for ELDRS parts, in 5.14.3). For part types that have not been characterized for ELDRS a characterization test shall be performed to determine if the part types are ELDRS susceptible. The ELDRS tests described in 5.14 may be omitted if:

a) devices are known not to contain bipolar transistors by design,
b) devices are known not to contain any linear circuit functions by design, or

c) the device type and IC technology have been demonstrated via characterization testing not to exhibit ELDRS (5.14.2) in device parameters greater than experimental error and the variables that affect ELDRS response are demonstrated to be under control for the specific vendor processes.

5.14.2 Determination of whether a part exhibits ELDRS

5.14.2.1 Characterization testing for ELDRS

If a part cannot be eliminated by the criteria in 5.14.1 and has not been characterized for ELDRS then the part shall be subjected to a characterization test to determine whether it exhibits ELDRS. This test shall be performed at two dose rates. If the part meets the criteria for ELDRS then an additional characterization test may be performed to establish the irradiation conditions for production or lot acceptance tests.

5.14.2.2 Characterization test to determine whether a part exhibits ELDRS

Select a minimum random sample out of twenty devices from a population representative of recent production runs. Smaller sample sizes may be used if agreed upon between the parties to the test. All of the selected devices shall have undergone appropriate elevated temperature reliability screens, for example burn-in and high temperature storage life. Divide the samples into four groups of five each and use the remaining part for a control. Perform pre-irradiation electrical characterization on all parts ensuring that they meet the Group A electrical tests. Irradiate five samples under a 0-V bias and another five under the irradiation bias given in the acquisition specification at 0,5 Gy(Si)/s to 3 Gy(Si)/s and room temperature. Irradiate five samples under a 0-V bias and another five under the irradiation bias given in the acquisition specification at < 0,1mGy (Si)/s and room temperature. Irradiate all samples to the same dose levels, including 0,5 times and 1,0 times the anticipated specification dose, and repeat the electrical characterization on each part at each dose level. Post-irradiation electrical measurements shall be performed in accordance with 5.11 where the low dose rate test is considered condition D. Calculate the radiation-induced change in each electrical parameter (Δ_{para}) for each sample at each radiation level. Calculate the ratio of the median Δ_{para} at low dose rate to the median Δ_{para} at high dose rate for each irradiation bias group at each total dose level. If this ratio exceeds 1,5 for any of the most sensitive parameters then the part is considered to be ELDRS susceptible. This test does not apply to parameters which exhibit changes that are within experimental error or whose values are below the pre-irradiation electrical specification limits at low dose rate at the specification dose.

5.14.3 Characterization of ELDRS parts to determine the irradiation conditions for production or lot acceptance testing

If the part type is known to exhibit ELDRS or has been shown to exhibit ELDRS by the characterization tests in 5.14.2.2 then the production or lot acceptance testing may be performed using the default low dose rate test at < 0,1mGy (Si)/s (condition D) or an accelerated test (condition E). For the accelerated test a detailed characterization shall be performed to establish the test parameters for the test. The accelerated test approach may include one of the following methods:

a) a room temperature low dose rate irradiation at a dose rate greater than 0,1mGy (Si)/s;

b) an elevated temperature irradiation;

c) combinations of high dose rate tests and elevated temperature anneals;

d) switched dose rates;

e) some other form of accelerated testing (for guidance on characterization of ELDRS parts see ASTM F 1892:2018, Appendix X2).

The characterization testing of the ELDRS parts shall demonstrate that the irradiation test procedure for production or lot acceptance testing will bound the low dose rate response for all critical electrical parameters at a dose rate of less than 0,1mGy (Si)/s using a combination of overtest and/or parameter delta design margins. Hence the characterization testing shall include irradiation at less than 0,1mGy (Si)/s, to the specification dose, as a baseline for comparison.

5.14.4 Low dose rate or elevated temperature irradiation test for bipolar or BiCMOS linear or mixed-signal devices

All devices that do not meet the exception of 5.14.1 shall be tested using one of the following test conditions:

a) Test at the dose rate agreed to. Irradiate each test device at the dose rate described in 5.7.4 (condition C) using the standard test conditions (5.2 to 5.11).

b) Test at a specified low dose rate. Irradiate each test device at the dose rate described in 5.7.5 (condition D) using the standard test conditions (5.2 to 5.11) with the following additional requirements: an overtest factor of 1,5 shall be applied to the radiation level, i.e. the part shall pass at a radiation level of 1,5 times the specification dose to be acceptable.

c) Test using an accelerated test method. Irradiate each test device with the accelerated test condition described in 5.7.6 (condition E) using the standard test conditions (5.2 to 5.11) with the following additional requirements: a parameter delta design margin and/or overtest factor shall be applied as established through the characterization testing described in 5.14.3.

5.15 Test report

As a minimum, the report shall include the device type number, serial number, the name of the manufacturer, package type, controlling specification, date code, and any other identifying numbers given by the manufacturer.

The bias circuit, parameter measurement circuits, the layout of the test apparatus with details of distances and materials used, and electrical noise and current leakage of the electrical measurement system for in-flux testing shall be reported using drawings or diagrams as appropriate.

Each data sheet shall include the test date, the radiation source used, the bias conditions during irradiation, the ambient temperature around the devices during irradiation and electrical testing, the duration of each irradiation, the time between irradiation and the start of the electrical measurements, the duration of the electrical measurements and the time to the next irradiation when step irradiations are used, the irradiation dose rate, electrical test conditions, dosimetry system and procedures, and the radiation test levels.

The pre- and post-irradiation data shall be recorded for each part and retained with the parent population data. Any anomalous incidents during the test shall be fully documented and reported. The accelerated annealing procedure, if used, shall be described. Any other radiation test procedures or test data required for the delivery shall be specified in the device specification, drawing or purchase order.

6 Summary

The following details shall be specified in the relevant specification:

a) device-type number(s), quantity, and governing specifications (see 5.2);

b) radiation dosimetry requirements (see 5.4);

c) radiation test levels including dose and dose rate (see 5.6 and 5.7);

d) irradiation, electrical test and transport temperatures if other than as specified in 5.8;

e) test methodology used if not maintaining cryogenic temperature as specified in 5.8;

f) electrical parameters to be measured and device operating conditions during measurement (see 5.9);

g) test conditions, for example in-flux or non in-flux type tests (see 5.10);
h) bias, loading and internal dose-pattern conditions for devices during irradiation (see 5.10.4);
i) time intervals of the post-irradiation measurements (see 5.11);
j) requirements for extended room temperature annealing test, if required (see 5.12);
k) requirements for accelerated annealing test, if required (see 5.13);
l) requirements for test for ELDRS, if required (see 5.14);
m) requirements for ELDRS testing, if required (see 5.14.4);
n) documentation required to be delivered with devices (see 5.15).

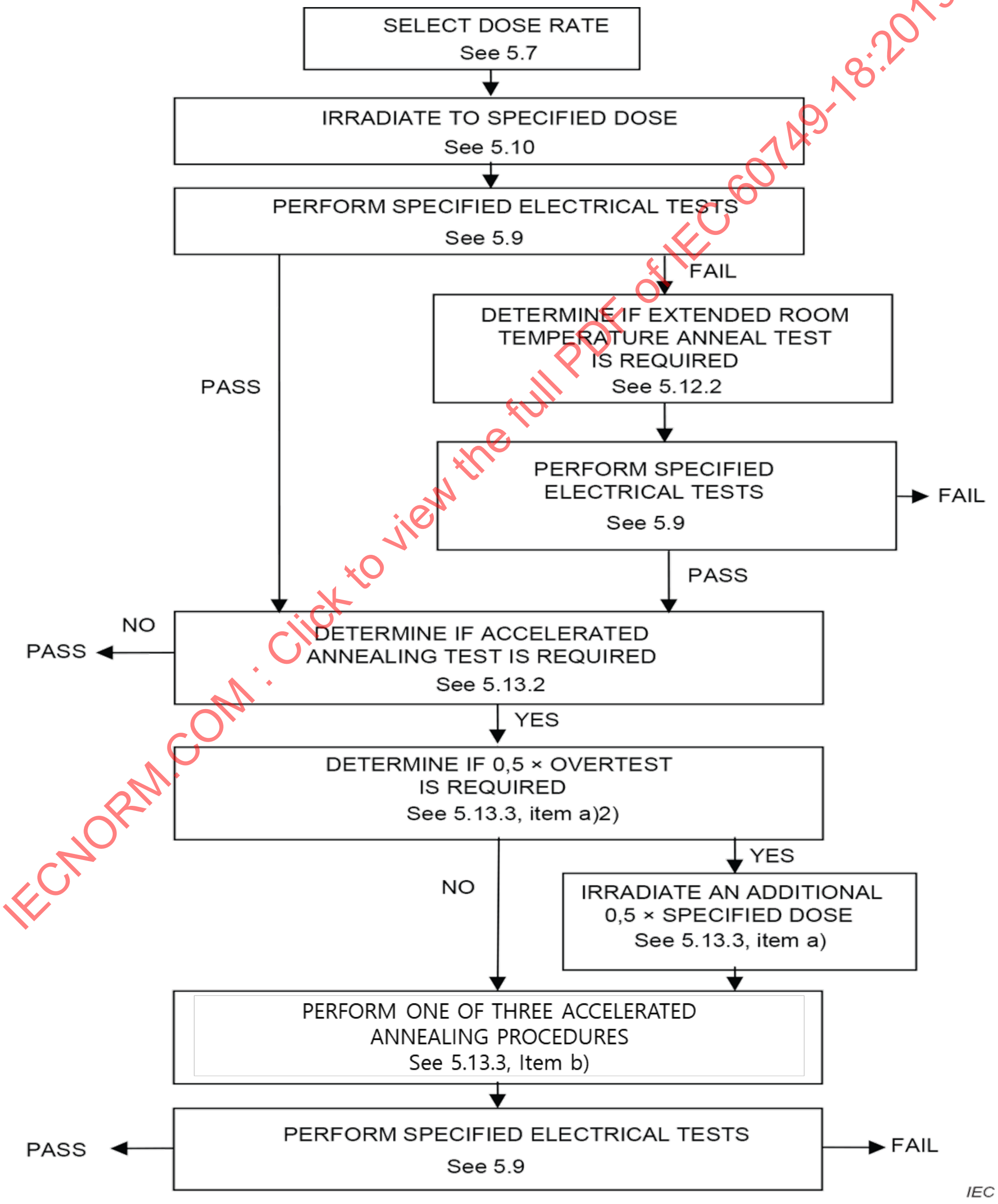

Figure 1 – Flow diagram for ionizing radiation test procedure for MOS and digital bipolar devices

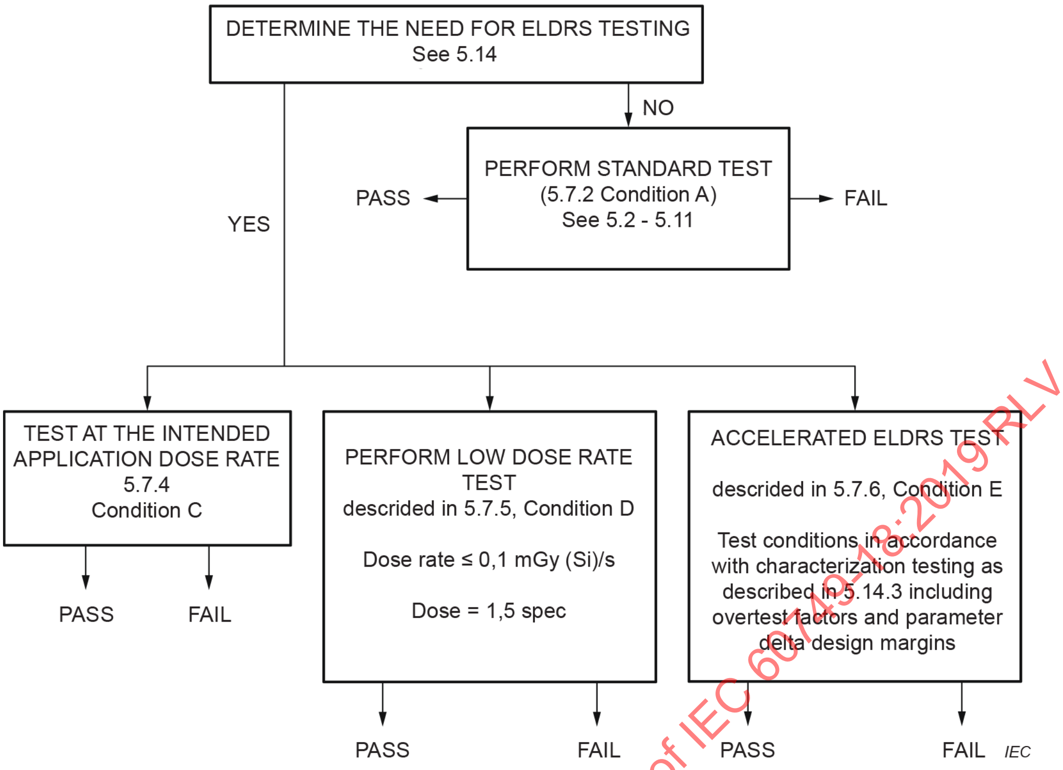

Figure 2 – Flow diagram for ionizing radiation test procedure for bipolar (or BiCMOS) linear or mixed-signal devices

Bibliography

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ASTM E 668, *Standard practice for application of thermoluminescence-dosimetry (TLD) systems for determining absorbed dose in radiation-hardness testing of electronic devices*

ASTM E 1249, *Standard practice for minimizing dosimetry errors in radiation hardness testing of silicon electronic devices using Co-60 sources*

ASTM E 1250, *Standard 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 devices*

ASTM F 1892:2018, *Standard guide for ionizing radiation (total dose) effects testing of semiconductor devices*

ISO/ASTM 51275, *Practice for use of a radiochromic film dosimetry system*

MIL-STD-883J, Method 1019.9, *Ionizing radiation (total dose) test procedure*

SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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DISPOSITIFS À SEMICONDUCTEURS – MÉTHODES D'ESSAIS MÉCANIQUES ET CLIMATIQUES –

Partie 18: Rayonnements ionisants (dose totale)

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La Norme internationale IEC 60749-18 a été établie par le comité technique 47 de l'IEC: Dispositifs à semiconducteurs.

Cette deuxième édition annule et remplace la première édition parue en 2002. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) mises à jour apportées aux paragraphes afin de mieux aligner la méthode d'essai avec la méthode 1 019 du document MIL-STD 883J, comprenant l'utilisation de l'essai de sensibilité accrue au faible débit de dose (ELDRS);

b) ajout d’une bibliographie, comprenant les normes ASTM correspondant à la présente méthode d’essai.

Le texte de cette Norme internationale est issu des documents suivants:

FDIS	Rapport de vote
47/2539/FDIS	47/2554/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60749, publiées sous le titre général *Dispositifs à semiconducteurs – Méthodes d’essais mécaniques et climatiques*, peut être consultée sur le site web de l’IEC.

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DISPOSITIFS À SEMICONDUCTEURS – MÉTHODES D'ESSAIS MÉCANIQUES ET CLIMATIQUES –

Partie 18: Rayonnements ionisants (dose totale)

1 Domaine d'application

La présente partie de l'IEC 60749 présente une procédure d'essai permettant de définir les exigences pour soumettre à essai des circuits intégrés à semiconducteurs sous boîtier et des dispositifs discrets à semiconducteurs, concernant les effets des rayonnements ionisants (dose totale) provenant d'une source de rayons gamma au cobalt-60 (^{60}Co). D'autres sources de rayonnements appropriées peuvent être utilisées.

Quatre essais sont présentés dans cette procédure:

a) un essai d'irradiation à température ambiante normale;
b) un essai d'irradiation à température élevée/à température cryogénique;
c) un essai de recuit accéléré;
d) un essai de sensibilité accrue au faible débit de dose (ELDRS).

L'essai de recuit accéléré évalue l'importance des effets du débit de dose des rayonnements ionisants sur les dispositifs pour les faibles débits de dose, ou certaines autres applications dans lesquelles les dispositifs peuvent présenter des effets liés au temps qui sont significatifs. L'essai ELDRS détermine si les dispositifs intégrant des dipôles linéaires présentent une sensibilité aux dommages accrus liés aux rayonnements, à de faibles débits de dose.

Le présent document ne concerne que les irradiations continues et ne s'applique pas aux irradiations pulsées.

Il est destiné aux applications des domaines militaire et aérospatial.

Le présent document peut être à l'origine d'une dégradation importante des propriétés électriques des dispositifs irradiés et est par conséquent considéré comme un essai destructif.

2 Références normatives

Le présent document ne contient aucune référence normative.

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
effets des rayonnements ionisants, pl
variations des paramètres électriques d'un dispositif ou d'un circuit intégré à la suite d'une charge induite par rayonnement

Note 1 à l'article: Ces effets sont également désignés par l'expression effets de dose totale.

3.2

essai en flux

mesures électriques réalisées sur les dispositifs au cours de leur exposition aux irradiations

3.3

distribution de dose interne

condition logique de tous les éléments au sein d'un circuit logique pendant l'exposition aux rayonnements

3.4

essai hors flux

mesures électriques réalisées sur des dispositifs à tout moment autre que celui de l'irradiation

3.5

essai à distance

mesures électriques réalisées sur les dispositifs qui sont physiquement retirés de l'emplacement de rayonnement

3.6

effet lié au temps

TDE

dégradation importante des paramètres électriques causée par la croissance ou le recuit, ou les deux, en raison de la charge absorbée induite par les rayonnements après irradiation

Note 1 à l'article: Des effets similaires se manifestent également au cours de l'irradiation.

Note 2 à l'article: L'abréviation "TDE" est dérivée du terme anglais développé correspondant "time-dependent effect".

3.7

essai de recuit accéléré

procédure utilisant une température élevée pour accélérer les effets liés au temps

3.8

sensibilité accrue au faible débit de dose

ELDRS

pièce présentant des dommages accrus dus aux rayonnements, à des débits de dose inférieurs à 0,5 Gy(Si)/s

Note 1 à l'article: L'abréviation "ELDRS" est dérivée du terme anglais développé correspondant "enhanced low dose rate sensitivity".

3.9

essai augmenté

facteur appliqué à la dose de la spécification afin de déterminer le niveau de dose d'essai auquel les échantillons doivent satisfaire pour être acceptés au niveau de la spécification

Note 1 à l'article: Un facteur d'essai augmenté de 1,5 signifie qu'il convient que les pièces soient soumises à essai à 1,5 fois la dose de la spécification.

3.10

marge de conception pour la variation des paramètres

PDDM

marge de conception appliquée à la variation d'un paramètre électrique, résultant des rayonnements

Note 1 à l'article: Pour une PDDM de 2, la variation d'un paramètre par rapport à la valeur avant irradiation, à une dose spécifiée, est multipliée par deux et ajoutée à la valeur avant irradiation, afin de déterminer si l'échantillon dépasse la limite du paramètre après irradiation. Par exemple, si la valeur avant irradiation du courant de base, I_b, est de 30 nA et que la valeur après irradiation à 200 Gy(Si) est de 70 nA (soit une variation de I_b de 40 nA), alors, pour une PDDM de 2, la valeur après irradiation est de 110 nA (30 nA + 2 x 40 nA). Si la limite autorisée après irradiation est de 100 nA, la pièce est considérée comme ayant échoué à l'essai.

Note 2 à l'article: L'abréviation «PDDM» est dérivée du terme anglais développé correspondant "Parameter Delta Design Margin".

4 Appareillage d'essai

4.1 Choix de l'appareillage

L'appareillage doit se composer d'une source de rayonnements, d'appareils de mesure pour les essais électriques, d'une ou de plusieurs cartes de circuit d'essai, de câblage, de carte d'interconnexion ou d'un système de commutation, d'un système de mesure de dosimétrie approprié et d'une enceinte climatique (si cela est exigé pour les mesures des effets liés au temps). Des précautions adéquates doivent être observées pour obtenir un système de mesure électrique présentant une isolation suffisante, un blindage étendu, une mise à la terre satisfaisante et des caractéristiques de faible bruit adaptées.

4.2 Source de rayonnements

La source de rayonnements utilisée dans l'essai doit être le champ uniforme d'une source de rayons gamma ^{60}Co. Sauf spécification contraire, l'uniformité du champ de rayonnement dans le volume où les dispositifs sont irradiés doit être dans les limites de ±10 % comme mesuré par le système dosimétrique. L'intensité du champ de rayons gamma de la source de ^{60}Co doit être connue avec une incertitude inférieure ou égale à ±5 %. L'uniformité et l'intensité du champ peuvent être affectées par des variations d'emplacement du dispositif par rapport à la source de rayonnements et la présence de matériaux d'absorption et de diffusion de rayonnement.

4.3 Système dosimétrique

Un système dosimétrique approprié doit être fourni, qui est capable de réaliser les mesures demandées en 5.3 (voir la Bibliographie).

4.4 Appareils de mesure pour essais électriques

Tous les appareils de mesure utilisés pour les mesures électriques doivent avoir la stabilité, la précision et la résolution exigées pour une mesure précise des paramètres électriques. Tout appareil de mesure dont il est exigé qu'il fonctionne dans un environnement soumis à des rayonnements doit être muni d'un blindage approprié.

4.5 Carte(s) de circuit d'essai

Les dispositifs à irradier doivent être soit montés sur, soit connectés à, des cartes de circuit avec toutes les connexions associées nécessaires à la polarisation des dispositifs au cours de l'irradiation ou à des mesures in situ. Sauf spécification contraire, toutes les broches d'entrée du dispositif et toute autre broche pouvant affecter la réponse aux rayonnements doivent être électriquement connectées pendant l'irradiation, c'est-à-dire, ne pas être laissées flottantes.

La disposition et les matériaux de la carte terminée doivent permettre une irradiation uniforme des dispositifs soumis à essai. De bonnes pratiques de conception et de construction doivent être utilisées pour empêcher les oscillations, réduire le plus possible les courants de fuite, empêcher les dommages électriques et obtenir des mesures précises. Seuls les supports qui résistent aux rayonnements et ne présentent pas de fuites importantes (par rapport aux dispositifs soumis à essai) doivent être utilisés pour le montage des dispositifs et des connexions associées sur la ou les cartes d'essai.

Tous les appareillages utilisés de manière répétée dans les champs de rayonnement doivent être vérifiés périodiquement pour identifier une dégradation physique ou électrique. Les composants qui sont placés sur la carte de circuit d'essai, autres que les dispositifs soumis à essai, ne doivent pas être sensibles aux rayonnements accumulés ou ils doivent être blindés contre ces rayonnements. Les fixations d'essai doivent être réalisées dans des matériaux qui ne perturbent pas l'uniformité de l'intensité du champ de rayonnement sur les dispositifs soumis à essai.

Le courant de fuite doit être mesuré à l'extérieur du champ de rayonnement. Aucun dispositif n'étant installé dans les supports, la carte de circuit d'essai doit être connectée au système d'essai de telle manière que toutes les sources de bruit et d'interférence attendues soient opérationnelles. La polarisation maximale spécifiée pour le dispositif soumis à essai étant appliquée, le courant de fuite entre deux broches quelconques ne doit pas dépasser 10 % de la valeur limite de courant la plus faible de la spécification du dispositif avant irradiation.

Les cartes de circuit d'essai utilisées pour la polarisation des dispositifs au cours du recuit accéléré doivent être capables de résister aux exigences de température de l'essai de recuit accéléré et leur dégradation physique et électrique doit être vérifiée avant et après les essais.

4.6 Câblage

Les câbles qui relient les cartes de circuit d'essai dans le champ de rayonnement aux appareils de mesure doivent être aussi courts que possible. Si des câbles de grande longueur sont nécessaires, des excitateurs de ligne peuvent être exigés. Les câbles doivent être de faible capacité et avoir une faible perte à la terre et une faible fuite entre fils.

4.7 Interconnexion ou système de commutation

Ce système doit être situé hors de l'emplacement de l'environnement de rayonnement et il constitue l'interface entre les appareils de mesure et les dispositifs soumis à essai. Il fait partie du système d'essai complet et il est soumis à la limitation spécifiée en 4.5 pour la fuite entre les broches.

4.8 Enceinte climatique

L'enceinte climatique pour les essais concernant les effets liés au temps doit, si cela est exigé, être capable de maintenir la température de recuit accéléré choisie dans les limites de ±5 °C.

4.9 Enceinte climatique d'irradiation

Il convient que l'enceinte climatique d'irradiation, si elle est exigée pour une irradiation à température élevée, soit capable de maintenir un circuit soumis à essai à une température de 100 °C ± 5 °C, pendant la durée de l'irradiation. Il convient que l'enceinte soit capable de faire passer la température du circuit soumis à essai de la température ambiante à la température d'irradiation dans un délai raisonnable, avant l'irradiation, puis de refroidir le circuit soumis à essai pour le faire passer de la température d'irradiation à la température ambiante en moins de 20 min à la suite de l'irradiation. La polarisation d'irradiation doit être maintenue pendant les phases de chauffage et de refroidissement. La méthode permettant d'élever, de maintenir et d'abaisser la température du circuit soumis à essai peut être une méthode par conduction, par le biais d'un dissipateur thermique utilisant des fluides de chauffage et de refroidissement, ou bien une méthode par convection, par le biais de flux d'air chaud et d'air froid pulsés, ou bien un autre moyen permettant d'obtenir les résultats appropriés. Pour les irradiations à température cryogénique, il convient que l'enceinte soit capable de maintenir l'unité/le dispositif soumis à essai à la température cryogénique exigée ±5 °C (par exemple la température de l'hélium liquide ou de l'azote liquide) au cours de l'irradiation. Il convient que l'enceinte soit capable de maintenir la température cryogénique de l'unité/du dispositif soumis à essai pendant les essais électriques post-irradiation.

5 Procédure

5.1 Plan d'essai

Les dispositifs d'essai doivent être irradiés et soumis à l'essai de recuit accéléré (si cela est exigé pour les essais des effets liés au temps) comme spécifié dans un plan d'essai. Ce plan doit spécifier la description du dispositif, les conditions d'irradiation, les conditions de polarisation du dispositif, le système dosimétrique, les conditions de fonctionnement, les paramètres et les conditions de mesure, et les conditions de l'essai de recuit accéléré (si cela est exigé).

5.2 Choix et manipulation de l'échantillon

Seuls les dispositifs qui ont passé avec succès les spécifications électriques telles que définies dans le plan d'essai doivent être soumis aux essais de rayonnements. Sauf spécification contraire, les échantillons d'essai doivent être choisis de manière aléatoire dans la population apparentée et être mis sous boîtier de manière identique. Chaque pièce doit être identifiable individuellement pour permettre une comparaison avant et après irradiation. Pour les types de dispositifs sensibles aux décharges électrostatiques (ESD, ElectroStatic Discharge), des techniques de manipulation adaptées doivent être utilisées pour éviter d'endommager les dispositifs.

5.3 Vieillissement artificiel à chaud

Pour certains dispositifs, il existe des différences dans la réponse aux rayonnements en dose totale avant et après le vieillissement artificiel à chaud. Sauf s'il a été démontré par une caractérisation préalable ou par la conception que le vieillissement artificiel à chaud a un effet négligeable (les paramètres restent dans les limites électriques spécifiées après irradiation) sur la réponse aux rayonnements en dose totale, l'une des opérations suivantes doit alors être entreprise:

a) le fabricant doit soumettre les échantillons destinés à être exposés aux rayonnements aux conditions spécifiées de vieillissement artificiel à chaud avant de réaliser les essais de rayonnements en dose totale; ou

b) le fabricant doit déterminer un facteur de correction (acceptable pour les parties prenantes à l'essai) prenant en compte les variations de la réponse en dose totale à la suite du vieillissement artificiel à chaud du produit. Le facteur de correction doit ensuite être utilisé pour accepter le produit pour une réponse en dose totale sans soumettre les échantillons d'essai au vieillissement artificiel à chaud.

5.4 Mesures dosimétriques

L'intensité du champ de rayonnement à l'emplacement du dispositif soumis à essai doit être déterminée avant les essais par dosimétrie ou par des calculs de correction de la baisse de la source, suivant le cas, pour assurer la conformité au niveau d'essai et aux exigences d'uniformité.

La dose appliquée au dispositif soumis à essai doit être déterminée de l'une des deux manières suivantes:

a) par mesure au cours de l'irradiation avec un dosimètre approprié; ou

b) en corrigeant une valeur dosimétrique antérieure pour la baisse de l'intensité de la source de ^{60}Co au cours du temps d'intervention. La correction appropriée doit être faite pour passer de la dose mesurée ou calculée dans le matériau du dosimètre à la dose dans le dispositif soumis à essai.

5.5 Conteneur en plomb/aluminium (Pb/Al)

Les éprouvettes doivent être placées à l'intérieur d'un conteneur en Pb/Al pour réduire le plus possible les effets accrus de la dose causés par les rayonnements diffusés à faible énergie. Du plomb (Pb) d'une épaisseur minimale de 1,5 mm, entourant un écran intérieur en aluminium (Al) d'une épaisseur minimale de 0,7 mm, est exigé. Ce conteneur Pb/Al produit un équilibre de particules chargées approximatif pour les Si et les dosimètres thermoluminescents (TLD, ThermoLuminescence Dosimeter), comme ceux au CaF2. L'intensité du champ de rayonnement doit être mesurée à l'intérieur du conteneur Pb/Al (1) initialement, (2) lorsque la source est modifiée ou (3) lorsque l'orientation ou la configuration de la source, du conteneur ou de la fixation d'essai est modifiée. Cette mesure doit être réalisée en plaçant un dosimètre (par exemple un TLD) dans le conteneur d'irradiation du dispositif à la position approximative du dispositif soumis à essai. S'il peut être démontré que des rayonnements diffusés à faible énergie sont assez faibles pour ne pas causer d'erreurs de dosimétrie dues à un accroissement de la dose, le conteneur Pb/Al peut être ignoré.

5.6 Niveau(x) de rayonnements

Les dispositifs d'essai doivent être irradiés au(x) niveau(x) de dose spécifié(s) dans le plan d'essai dans les limites de ±10 %. Si des irradiations multiples sont exigées pour un jeu de dispositifs d'essai, alors les mesures de paramètres électriques après irradiation doivent être réalisées pour chaque irradiation.

5.7 Débit de dose de rayonnements

5.7.1 Détermination du débit de dose de rayonnements

Le débit de dose de rayonnements pour les circuits linéaires bipolaires et les circuits linéaires à semiconducteur métal oxyde complémentaire bipolaire (BiCMOS, Bipolar Complementary Metal-Oxyde-Semiconductor) ou les circuits à signaux mixtes, utilisés dans les applications supposant un débit de dose maximal inférieur à 0,5 Gy(Si)/s, doit être déterminé comme indiqué en 5.14. Pour les pièces utilisées dans les applications à faible débit de dose, sauf s'il a été démontré qu'elles ne présentaient pas de réponse ELDRS, la condition à utiliser doit être la condition C, la condition D ou la condition E.

Le schéma de principe des procédures de l'essai aux rayonnements ionisants pour les dispositifs MOS et les dispositifs bipolaires numériques est représenté à la Figure 1. Le schéma de principe de la procédure de l'essai aux rayonnements ionisants pour les dispositifs linéaires bipolaires (ou BiCMOS) ou les dispositifs à signaux mixtes est représenté à la Figure 2.

NOTE Les dispositifs contenant à la fois des dispositifs MOS et des dispositifs bipolaires peuvent exiger une qualification selon plusieurs sous-conditions, afin d'assurer que les effets de l'ELDRS ainsi que les effets traditionnels liés aux dispositifs MOS sont évalués.

5.7.2 Condition A

Pour la condition A (condition normale), le débit de dose doit être compris entre 0,5 Gy(Si)/s et 3 Gy(Si)/s pour les circuits intégrés, et entre 0,5 Gy(Si)/s et 20 Gy(Si)/s pour les dispositifs discrets à semiconducteurs. Les débits de dose peuvent être différents pour chaque niveau de dose de rayonnements au sein d'une série; cependant, le débit de dose ne doit pas varier au-delà de ±10 % au cours de chaque irradiation.

5.7.3 Condition B

Pour la condition B, pour les dispositifs MOS uniquement, si le débit de dose maximal est inférieur à 0,5 Gy(Si)/s dans l'application prévue, les parties prenantes à l'essai peuvent s'accorder pour réaliser l'essai à un débit de dose supérieur ou égal au débit de dose maximal pour l'application prévue. Sauf cas des exclusions de 5.13.2 b), l'essai de recuit accéléré de 5.13.3 doit être réalisé.

5.7.4 Condition C

Pour la condition C, (en variante) l'essai peut être réalisé au débit de dose de l'application prévue sous réserve d'accord entre les parties prenantes à l'essai. Lorsque l'utilisateur final est inconnu, les conditions et les résultats d'essai doivent être mis à disposition via le rapport d'essai, fourni pour chaque ordre d'achat.

5.7.5 Condition D

Pour la condition D, uniquement pour les dispositifs linéaires bipolaires ou BiCMOS, ou les dispositifs à signaux mixtes, les pièces doivent être irradiées à un débit de dose inférieur ou égal à 0,1 mGy(Si)/s.

5.7.6 Condition E

Pour la condition E, uniquement pour les dispositifs linéaires bipolaires ou BiCMOS, ou les dispositifs à signaux mixtes, les pièces doivent être irradiées dans les conditions d'essai accéléré déterminées par les essais de caractérisation, comme décrit en 5.14.3. L'essai accéléré peut inclure une irradiation à température élevée.

5.8 Exigences de température

5.8.1 Rayonnements à température ambiante

Les effets des rayonnements étant liés à la température, les dispositifs soumis à essai doivent être irradiés à une température ambiante de 24 °C ± 6 °C mesurée en un point de l'enceinte à proximité de la fixation d'essai. Les mesures électriques doivent être réalisées à une température ambiante de 24 °C ± 6 °C. Si les dispositifs sont transportés vers ou à partir d'un site de mesure électrique éloigné, la température des dispositifs d'essai ne doit pas augmenter de plus de 10 °C par rapport à l'environnement d'irradiation. Si une quelconque autre plage de températures est exigée, elle doit être spécifiée.

Attention: A des températures ambiantes supérieures à la température d'irradiation, le recuit peut être important, notamment en cas de période prolongée entre les irradiations à faible débit de dose (condition D). Il est important de s'assurer que la température des pièces est maintenue dans la limite des exigences déclarées ci-dessus, afin de réduire le plus possible le recuit.

5.8.2 Irradiation à température élevée

Pour les dispositifs linéaires bipolaires ou BiCMOS, ou les dispositifs à signaux mixtes, irradiés selon l'essai d'irradiation à température élevée en appliquant la condition E, les dispositifs soumis à essai doivent être irradiés à une température ambiante déterminée par les essais de caractérisation (voir 5.14.3), comme mesuré en un point de l'enceinte à proximité de la fixation d'essai (voir 4.8 pour les détails sur l'élévation et la réduction de la température d'irradiation).

5.8.3 Irradiation à température cryogénique

Pour les unités/dispositifs d'essai exploités dans des applications à température cryogénique, les unités/dispositifs doivent être irradiés à température cryogénique (voir 4.8), puis maintenus à température cryogénique pour les essais de caractérisation post-exposition (voir 5.11). Les unités/dispositifs d'essai doivent rester à température cryogénique tout au long de l'ensemble des irradiations et des essais de caractérisation, jusqu'à ce que l'exposition aux rayonnements en dose totale et la caractérisation soient finalisées.