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Concentrator photovoltaic (CPV) solar cells and cell on carrier (CoC) assemblies – qualification

Cellules solaires photovoltaïques à concentration (PVC) et ensembles de cellules sur support (CoC) – Qualification

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CONCENTRATOR PHOTOVOLTAIC (CPV) SOLAR CELLS AND CELL ON CARRIER (CoC) ASSEMBLIES – QUALIFICATION

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

FDIS	Report on voting
82/1818/FDIS	82/1834/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.

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CONCENTRATOR PHOTOVOLTAIC (CPV) SOLAR CELLS AND CELL ON CARRIER (CoC) ASSEMBLIES – QUALIFICATION

1 Scope

This document specifies the minimum requirements for the qualification of concentrator photovoltaic (CPV) cells and Cell on Carrier (CoC) assemblies for incorporation into CPV receivers, modules and systems.

The object of this qualification standard is to determine the optoelectronic, mechanical, thermal, and processing characteristics of CPV cells and CoCs to show that they are capable of withstanding assembly processes and CPV application environments. The qualification tests of this document are designed to demonstrate that cells or CoCs are suitable for typical assembly processes, and when properly assembled, are capable of passing IEC 62108.

This document defines qualification testing for two levels of concentrator photovoltaic device assembly:

a) cell, or bare cell; and

b) cell on carrier (CoC).

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NOTE Note that a variety of alternate names are used within the industry, such as solar cell assembly, receiver, etc.

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2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60721-2-1:2013, *Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 60749-3:2017, *Semiconductor devices – Mechanical and climatic test methods – Part 3: External visual examination*

IEC 60749-6:2017, *Semiconductor devices – Mechanical and climatic test methods – Part 6: Storage at high temperature*

IEC 60749-14:2003, *Semiconductor devices – Mechanical and climatic test methods – Part 14: Robustness of terminations (lead integrity)*

IEC 60749-21:2011, *Semiconductor devices – Mechanical and climatic test methods – Part 21: Solderability*

IEC 60749-22:2002, *Semiconductor devices – Mechanical and climatic test methods – Part 22: Bond strength*

IEC 60904-1-1:2017, *Photovoltaic devices – Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices*

IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61193-2:2007, *Quality assessment systems – Part 2 selection and use of sampling plans for inspection of electronic components and packages*

IEC TS 61836:2016, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62108:2016, *Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval*

IEC 62137-1-2:2007, *Surface mounting technology – Environmental and endurance test methods for surface mount solder joint – Part 1-2: Shear strength test*

IEC 62670-1:2013, *Photovoltaic concentrators (CPV) – Performance testing – Part 1: Standard conditions*

IEC TS 62789:2014, *Photovoltaic concentrator cell documentation*

IEC 63202-2, *Photovoltaic cells – Part 2: Electroluminescence image for crystalline silicon solar cells*

ECSS-E-ST-20-08C Rev 1, 18 July 2012, *Space engineering – Photovoltaic assemblies and components – Part 7.5.8: Coating adherence (CA)*

MIL.ST-883-K, *Test Method Standard – Microcircuits Method 2019.9 Die shear strength*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and IEC 62108 apply, as well as the following.

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
bare cell
refers to a semiconductor die level. The physical form during a commercial transaction may be a separated solar cell, a diced wafer on tape, or even a processed wafer. The one common denominator is that the qualified configuration is completely unprotected and not ready for interconnection with the rest of a CPV module

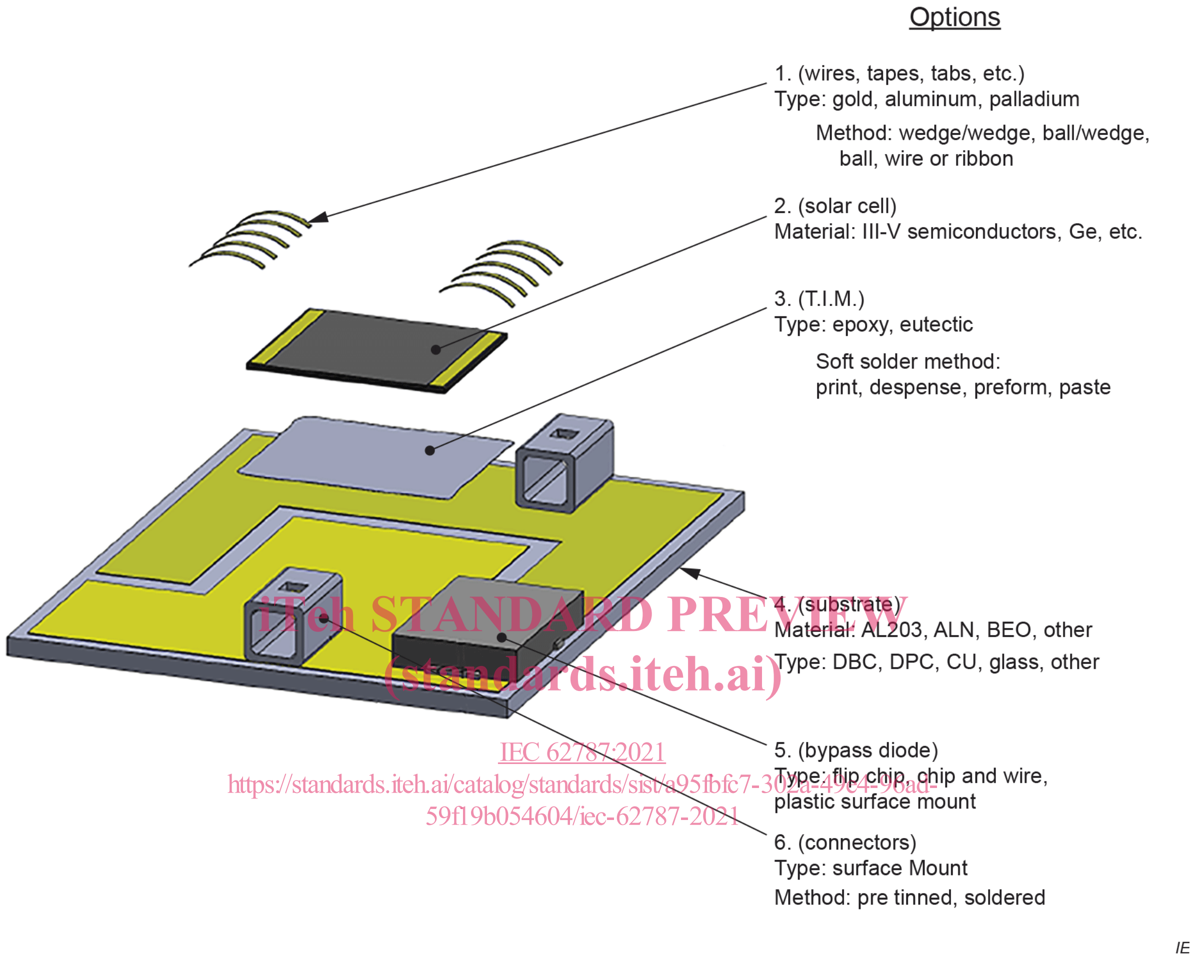
Note 1 to entry: For this qualified configuration, the customer is responsible for all integration and assembly.

Note 2 to entry: For some qualification tests, bare cells are mounted on a substrate, heatsink, or other type of carrier (see Figure 1c). This provides mechanical stability, robust electrical contacts, and appropriate thermal management, but it is not considered in the bare solar cell qualification.

3.2
Cell on Carrier
CoC
cell bonded and interconnected with a cell carrier, at a minimum (see Figure 1b). This is a relatively small, assembled unit in a relatively complete and rugged package

Note 1 to entry: A cell on carrier can optionally include a bypass diode, encapsulation of the cell and/or interconnects and a connector to simplify series or parallel connection. Alternatively, a CoC can also include multiple cells. A CoC does not include any optical element.

Note 2 to entry: Figure 1 shows an expanded schematic of common components in a CoC, along with two photos. Note that these photos illustrate relatively simple packages containing one primary photovoltaic device.



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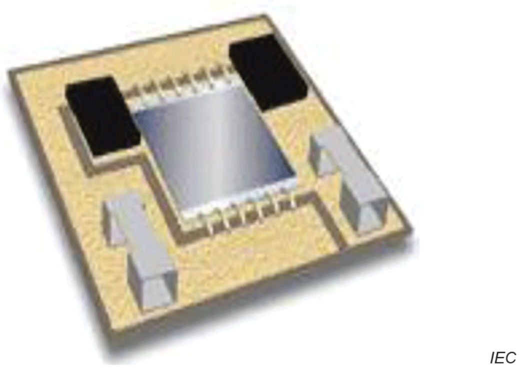
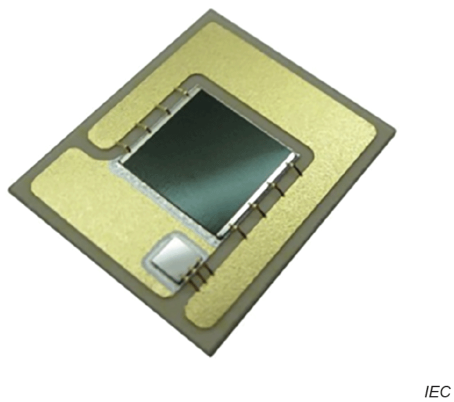
a) CoC exploded schematic



b) Cell on Carrier (CoC) with connectors and 2x packaged diodes. Intended for sale in this configuration.



c) Bare cell test assembly is intended to provide a test vehicle for bare cell qualification. Bypass diodes can be included or not. Not a CoC offered for sale.

Figure 1 – Schematics and photos of Cells on Carrier and bare cell test assembly

3.3
supplier
any entity that supplies CPV wafers (diced or undiced), CPV solar cells (separated on foils in sawing frames, single cells in trays or in reel) or CoCs to a customer

3.4
customer
any entity that buys some of these products from the supplier

4 Operating environment

CPV systems are typically designed to be operated in the "open-air climates" defined in IEC 60721-2-1 except the Polar one. Depending on the details of the system design, the bare solar cells and CoCs may or may not be protected from exposure to damp heat, freezing, condensation, and other elements of the CPV application environment. Figure 2 shows schematics of two CPV system designs.

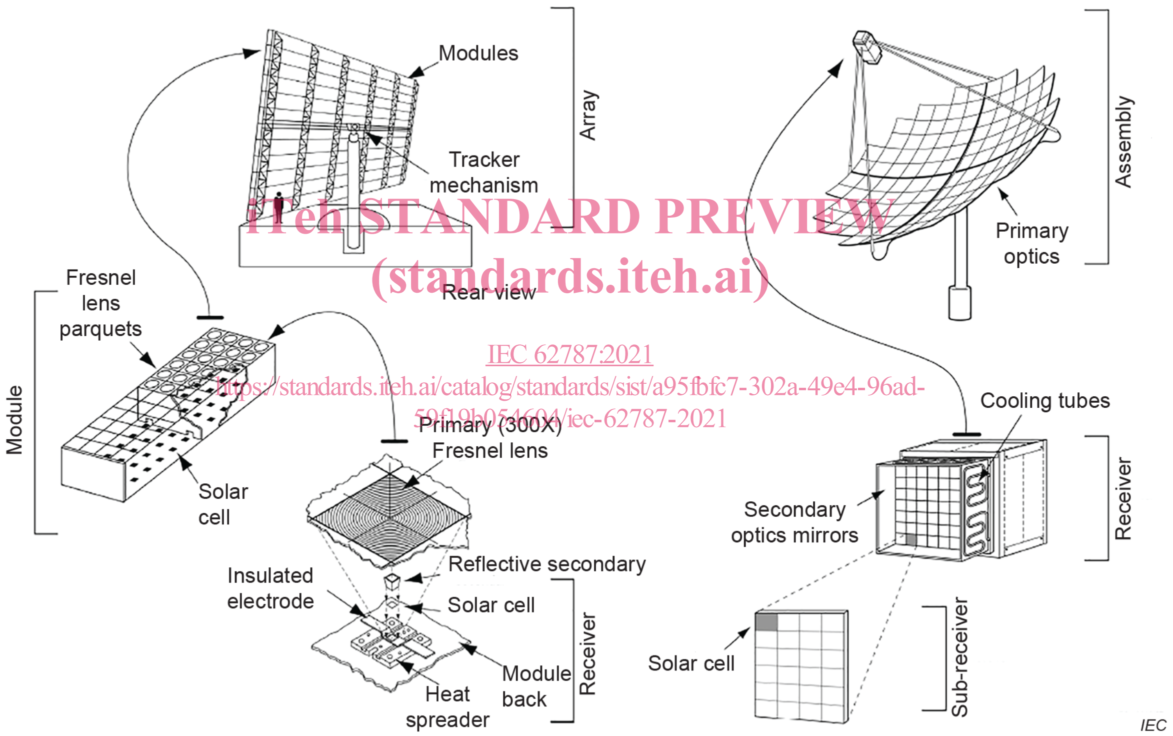


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Figure 2 – Representative samples of CPV systems, where cells and CoCs are deployed

Regardless of the specific design approach taken, the high incident irradiance impinging on the solar cells in CPV systems will cause them to operate at (local) temperatures that can be significantly higher than the maximum ambient temperature specified for the system as a whole.

5 Sampling

Device samples used in qualification testing shall be selected randomly in accordance with IEC 61193-2 from a minimum of two manufacturing batches and subjected to the defined Process Identification Document (PID) manufacturing and screening steps.

The number of devices to be tested in each qualification test shall not be less than the sample sizes specified in Clause 8. In order to provide statistical meaning to the number of devices, IEC 61193-2 has been used since it assigns a defect probability as a function of number of samples.

The samples for each test of Table 1 and Table 2 shall be chosen randomly from the qualification lot. The qualification lot shall be a production lot of at least 1 000 bare cells/CoCs. The production lot shall be formed from at least two epitaxial runs and three metal/ARC depositions carried out in different weeks.

6 Marking

Due to the very small bare solar cell dimensions any marking on cell is usually not possible. Therefore, an ID mapping needs to be applied. Regarding CoC under test, they shall be clearly marked or identified for later tracking of data records. The required information for both bare cells and CoCs are:

– name, monogram, or symbol of manufacturer;
– type or model number;
– serial number;
– polarity of terminals or leads;
– the date, place of manufacture, and cell materials should be marked, or be traceable from the serial number.

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7 Characterization methods for measuring the performance of bare cells and CoCs subjected to qualification tests

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7.1 General

The optoelectronic performance characterization based on illumination I-V curves tries to identify optoelectronic performance degradation of test samples caused by the required qualification tests. Therefore, illumination I-V curve has to be performed before and after qualification tests. The goal of the illumination I-V curve is on the relative power degradation, not on the absolute power output. Scanning Acoustic Microscopy (SAM) is also required but only for CoCs.

In addition, electroluminescence mapping and dark I-V curve can provide diagnostic information about defects and changes within the device. Before and after qualification testing, dark I-V curve can be carried out for the voltage and current ranges of interest. Electroluminescence images are not explicitly suggested through this document, but they could be of great help when captured for each device at different current injection levels before and after some qualification tests.

7.2 Light I-V measurement

This is a compulsory characterization method. All test samples shall be measured at 25 °C, under AM1.5D spectrum as specified in IEC 62670-1, and at an overall light intensity representative of the intended application. For the purposes of this characterization method, 1 sun equivalent of the AM1.5D spectrum will have a total power density (irradiance) of 0,1 W/cm^2, so that a light intensity of 100 W/cm^2 = 1 000 suns. The parameters and measurement methods for the light I-V measurement are defined in IEC 60904-1-1:2017.

Illumination I-V curve has to be performed before and after qualification tests. The focus of the illumination I-V curve is on the relative power degradation, not on the absolute power output. The relative power degradation, P_d, is defined as follows:

$$P_{\mathrm{d}}(\%) = \frac{P_{\mathrm{i}} - P_{\mathrm{f}}}{P_{\mathrm{i}}} 100 \qquad (1)$$

where

P_{f} is the maximum power measured after the given test, and

P_{i} is the maximum power measured before the given test.

At a minimum, J_{sc} (short circuit current density), V_{oc} (open circuit voltage), FF (fill factor), P_{max} (maximum power) and efficiency should be used in this document and have to be included in the qualification report for pre/post stress test evaluation.

7.3 Dark I-V measurement

7.3.1 General

This is a compulsory characterization method for the Electrostatic Discharge (ESD) Damage Threshold test while is optional for the rest. The high operating current density of CPV devices, can sometimes mask detection of low level defects or the onset of degradation. Dark I-V measurements performed before and after a qualification test can provide a more sensitive measure of damage or degradation.

The dark I-V measurement is a cost-effective method to monitor and diagnose power degradation of bare solar cells and CoCs following intermediate stress tests, or to monitor the electric performance stability of the control samples.

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7.3.2 Procedure

If the dark I-V is used for diagnostic purpose, it should be measured during initial measurements to establish a reference for later dark I-Vs.

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a) Choose a suitable power source, which could be a conventional DC power supply, as long as it will generate current up to 1,5 times the rated current point corresponding to the photocurrent at the specified maximum concentration. The current should be adjustable so that there are at least 30 separate points in the range of 10^{-4} to 1,5 times rated I_{sc} at the specified maximum concentration. The interval of the points should be nearly equal-spaced with a lower pitch around I_{sc};

b) For CoCs, short the blocking diode by placing a jumper lead across the leads of the blocking diode, if there is one installed;

c) Connect the power source's positive lead to sample's positive lead, and the power source's negative lead to sample's negative lead;

d) Block completely the light impinging the cells;

e) Temperature shall be controlled and repetitive in order to comparing measured I-V results;

f) Apply current to the device and record current, voltage and temperature. Complete this procedure as quickly as possible to avoid significant heating of the devices during the test.

7.4 Electroluminescence (EL) mapping

This is an optional characterization method. Forward bias current injected into the cells can recombine at defects, or recombine radiatively. To capture the full range of information, EL images are recommended to be taken with current injection within the range from 1 % to 10 % of I_{sc} at maximum concentration in order to prevent false failures. No matter this recommendation, other current injection levels are allowed as well as to capture EL maps at different injected current levels. When characterizing bare solar cells they have to be properly heat sunk in order to avoid thermal runaway. Any spiking due to power source or circuit connection/disconnection has to be avoided. See IEC 63202-2 for guidance.

7.5 X-ray and Scanning Acoustic Microscope (SAM)

SAM is the characterization method preferred to know the state of the joint between the back of the solar cell and the carrier. So, its use is compulsory only for CoCs. Since the availability of SAM is not as widespread as X-ray, the following protocol is recommended:

– To measure by x-ray before the qualification test in order to measure the voids area. Only <5 % voids in total area and <1 % for the biggest void are allowed.

– After the qualification test, SAM is performed and no cracks are allowed.

In order to know the scientific background of SAM, some references[1] can be followed.

7.6 Visual inspection

In several tests of Table 1 and Table 2 the pass criteria is the absence of Major Visual Defects (MVD). Optical devices with magnification between 3x and 10x and large vision field shall be used. For the purposes of design qualification and type approval, the following are considered to be major visual defects:

- broken, cracked, bent, misaligned or torn external surfaces, terminals and contacts;
- broken or cracked solar cells;
- voids, pits, visible corrosion, contamination or delamination;
- loss of mechanical integrity;
- plate of CoC delaminated, peeling, dented or with detachments;
- hot spots and burnt parts;
- non-uniformity of the antireflection coating.

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For additional details about visual defects consider IEC 60749-3:2017 and also check the product specifications in the supplier brochure.

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Furthermore, some CoC qualification tests require the visual confirmation of some defects such as dice displacement, wire breakage, area of solder coverage, etc.

7.7 Thermal resistance measurement

This is a characterization method for CoC test at high temperature with current injection for identifying thermal defects that shall be carried out before and after test. The procedure is:

- Place the CoC in good thermal contact onto a carrier with a programmable temperature controller, under natural convection. Place a very thin thermocouple between the CoC and the carrier just beneath the solar cell location. The programmable temperature can be achieved by Peltier cooling module, liquid chiller, etc. Set the temperature at (40 ± 0,4) °C.
- Forward bias the CoC at 0,5 I_{sc} (achieved at maximum concentration). After a transient period the steady state solar cell temperature is achieved where the voltage of the CoC is measure so, the dissipated power of CoC (P_{CoC}) can be determined.
- Measure the backplate CoC temperature (T_{bp}) by the thermocouple.
- Take a picture of the solar cell with an Infrared Thermographic Camera (ITC), at the normal direction to the CoC surface. This ITC shall have a pixel resolution well below the solar cell size. Take the maximum solar cell temperature (T_{c}) shown by infrared picture.

———————

[1] M. Yazdan Mehr, A. Bahrami, H. Fischer, S. Gielen, R. Corbei, W.D. van Driel, G. Q. Zhang, "An Overview of Scanning Acoustic Microscope, a Reliable Method for Non-destructive Failure Analysis of Microelectronic Components", 2015 16th international Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems, DOI: 10.1109/EuroSimE.2015.7103077.

- Calculate the thermal resistance between the cell and the back plate of the CoC ($R_{th,c-bp}$) with formula (2).

$$R_{th,c-bp} = \frac{T_c - T_{bp}}{P_{CoC}} \qquad (2)$$

8 Pass criteria

A bare cell type should be judged to have passed the qualification tests and therefore to be IEC 62787 type approved, if all test samples meet the requirements of all tests shown in Table 1. Similarly, a CoC type should be judged to have passed the qualification tests and therefore to be IEC 62787 type approved, if all test samples meet the requirements of all tests shown in Table 2. Besides, bare solar cells used in manufacturing CoCs shall be previously qualified following this document.

Unless otherwise specified in the applicable test procedure, all failures observed in stress tests shall be documented regardless of the failure mode. Omission of any failures from the test analysis and results shall be clearly justified and the information related to those failures shall be available for review upon request (NCR – non-conformance report).

If there are some failures observed during the tests, the following judgment and re-test procedure shall apply:

a) Three or more tests failed of Table 1 or Table 2 are not allowed, the device shall be deemed not to have met the qualification requirements.

b) When one or two test types fail because of two or more samples do not meet the pass criteria of the same test of Table 1 (for bare cells) or Table 2 (for CoCs), the device shall be deemed not to have met the qualification requirements.

c) When one or two test types fail because one sample fails the same test, another two samples meeting the requirements could be subjected to test from the beginning.

d) In case c), if all samples pass the test, the device shall be judged to have met the qualification requirements.

e) In case c), if one or more of these samples also fails, the device shall be deemed not to have met the qualification requirements.

f) In case a), b) or e), all the tests described in Table 1 (for bare cells) or in Table 2 (for CoCs) shall be re-performed, usually after some design or processing improvement. A non-conformance report shall be required.

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