Background Statement for SEMI Draft Document 5889
NEW STANDARD: TEST METHOD ON CELL LEVEL FOR POTENTIAL-INDUCED DEGRADATION SUSCEPTIBILITY OF SOLAR CELLS AND MODULE ENCAPSULATION MATERIALS

Notice: This background statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this Document.

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Background Statement

In 2010, surprisingly failures of silicon photovoltaic modules occurred under the influence of high voltage. The degradation effect was named as potential-induced degradation (PID). In the following years, PID became one of the most virulent risks for PV plant operators and manufacturers of solar modules. PID causes electric power loss, up to the total failure of PV power plants. As a triggering factor high negative electrical potentials between solar cells and the grounded module surface were determined. These potentials are due to the specific installation conditions. Affected solar cells show a drastic drop of the electrical characteristic value “parallel resistance”, called shunting. PID of the shunting type is called PID-s to distinguish from the other PID effects.

A number of workarounds against PID-s were developed in the PV industry. To date, PID tests on modules (for testing solar modules on their PID susceptibility) are performed in accordance with the recently published IEC 62804-1 technical specification. The electrical contact to the glass surface of the modules is realized either by the humidity or by laying an aluminum foil on the module glass. The increase of temperature (and possibly of the humidity) for accelerating the degradation is realized by large climate chambers. PID tests of solar modules on the laboratory scale cause correspondingly high investment and operating costs.

Small-scale PID tests on cell level were developed to test individual solar cells in the laboratory for PID. Non-encapsulated solar cells are used, whereby both expenses on module production as well as tests in large climate chambers are saved. This is a big advantage and hence a large demand for standardization of PID tests on cell level is noticed. As a consequence, the PID test method on cell level is currently gaining currency in PV industry. Thus, in order to obtain a standard for PID cell tests, we propose a SEMI Test Method on cell level for potential-induced degradation susceptibility of solar cells and module encapsulation materials.
The ballot results will be reviewed and adjudicated at the meetings indicated in the table below.

### Review and Adjudication Information

<table>
<thead>
<tr>
<th>Task Force Review</th>
<th>Committee Adjudication</th>
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<tbody>
<tr>
<td><strong>Group:</strong> PV Material Degradation TF</td>
<td>PV Materials Europe TC Chapter</td>
</tr>
<tr>
<td><strong>Date:</strong> June 23, 2016</td>
<td>June 23, 2016</td>
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<td><strong>Time &amp; Timezone:</strong> 9:00 AM – 11:00 AM CET</td>
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<tr>
<td><strong>Location:</strong> ICM, Intersolar Europe (Jun 21-24, 2016)</td>
<td>ICM, Intersolar Europe (Jun 21-24, 2016)</td>
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<tr>
<td><strong>City, State/Country:</strong> Munich, Germany</td>
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</tbody>
</table>

This meeting’s details are subject to change, and additional review sessions may be scheduled if necessary. Contact the task force leaders or Standards staff for confirmation.

Telephone and web information will be distributed to interested parties as the meeting date approaches. If you will not be able to attend these meetings in person but would like to participate by telephone/web, please contact Standards staff.

Check [www.semi.org/standards](http://www.semi.org/standards) on calendar of event for the latest meeting schedule.
NEW STANDARD: TEST METHOD ON CELL LEVEL FOR POTENTIAL-INDUCED DEGRADATION SUSCEPTIBILITY OF SOLAR CELLS AND MODULE ENCAPSULATION MATERIALS

1 Purpose

1.1 Potential-induced degradation (PID) is a serious reliability problem in PV power plants.

1.2 PID prone solar panels (modules) can suffer power loss within months or years of operation depending on environmental and installation conditions.

1.3 In particular, modules with silicon solar cells suffer from short circuiting (shunting), called PID-s.

1.4 A technical specification for PID tests at standardized conditions for testing of PID susceptibility of commercial silicon solar modules is available (IEC 62804-1 TS). PID tests on module level are effective as quality tests of final modules, but they are costly (require module manufacturing as well as large climate chambers for PID testing).

1.5 In order to ensure quality with respect to PID-s immunity, less expensive PID tests of upstream products such as solar cells and encapsulation materials are most desirable.

1.6 The purpose of this Test Method is the standardization of experimental setup and procedures for PID tests on solar cell level based on non-encapsulated silicon solar cells instead of complete modules.

2 Scope

2.1 This Test Method defines procedures to test and evaluate the PID susceptibility of wafer-based silicon solar cells and module construction components.

2.2 The only type of PID that is considered within this Test Method is the shunting of silicon solar cells due to high voltage stress induced leakage currents. This type of PID is called PID-s.

NOTE 1: Different types of PID are the dissolution of antireflective layers, degradation of surface passivation or the degradation of metal contacts for crystalline silicon solar cells and the corrosion of transparent conductive oxide layers in thin film modules.

2.3 The Test Method is designed for silicon solar cells, having a front side emitter, a front side dielectric antireflective layer and front side contacts on top. For the sake of practicability and in order to minimize any border effects, solar cells tested with this Test Method must have edge lengths larger than 6 cm.

2.4 This Test Method is based on the fact that considered solar module designs comprise following layer stack (from top/sunny side to bottom): glass (or transparent polymer) cover sheet, polymeric encapsulation material and solar cells. The materials of the solar module back-side and their stacking order do not impact the measurement results.

2.5 Depending on which component is altered/exchanged for sampling, solar cells, polymeric encapsulation foils and glass sheets can be tested for their PID-s sensitivity. Following distinction is used in this Test Method:

   (1) PID test of solar cells
   (2) PID test of encapsulation polymer sheets
   (3) PID test of module (glass) cover materials

2.6 With this Test Method, two or more different PID test specimens (hereafter: test specimens) can be compared quantitatively with respect to their PID-s sensitivity.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.
3 Limitations

3.1 With this Test Method an absolute measure about the PID-s sensitivity of a specific material cannot be derived since the overall PID-s sensitivity depends on used PID auxiliary samples (see 8.1).

4 Referenced Standards and Documents

4.1 IEC Standard


NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

5 Terminology

(Refer to the SEMI Standards Compilation of Terms (COTs) for a list of the current Abbreviations, Acronyms, Definitions, and Symbols.)

5.1 Abbreviations and Acronyms

5.1.1 PID — Potential-induced degradation

5.1.2 PID-s — Potential-induced degradation of the shunting type

5.2 Definitions

5.2.1 Potential-induced degradation — change of physical properties of solar modules under high electrical potential drop between surfaces and encapsulated solar cells with (potentially) detrimental effect on the power output

5.2.2 PID sensitivity — qualitative and relative characteristic of solar cells that is used to describe how fast and how strong PID-s occurs under high voltage stress or qualitative and relative characteristic of encapsulation components (glass, polymer foils) that is used to describe their ability to promote PID-s when combined in solar modules with PID-s sensitive solar cells

5.2.3 PID test specimen — a sample whose PID sensitivity is to be probed in a specific PID test experiment

5.2.4 PID auxiliary sample — additional PID sensitive sample that is needed for probing of the specific PID test specimen

6 Summary of Test Method

6.1 General remarks

6.1.1 The IEC technical specification 62804-1 describes two different PID test methods for industrial scale solar modules. In the current Test Method the second method of IEC 62804-1 TS (‘Stress method b), contacting the surfaces with a conductive electrode’) is adopted for a PID test using individual solar cells.

6.1.2 Like in module-based PID tests, solar cells, polymer encapsulation foils and cover glass sheets can be tested with respect to their PID sensitivity.

6.2 Summary of test procedure

6.2.1 The sample stack, consisting of solar cell, polymer sheet and glass sheet, imitates the front side of a common solar module on an area smaller than a solar cell.

6.2.2 The PID sensitivity of one of the three components can be tested when the other two components are PID sensitive.

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1 International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH - 1211 Geneva 20, Switzerland
6.2.3 The sample stack is placed between a top electrode and base plate of the test setup and is subjected to an elevated temperature. Figure 1 shows the basic setup. During the PID test period, a high positive voltage is applied to terminal H with respect to grounded base plate (terminal G).

6.2.4 The progress of PID-s is determined by measuring the shunt resistance (parallel resistance) of the solar cell.

6.2.4.1 This is done either during the PID test through a resistance measurement between terminals F and G, contacting the front side (grid finger or busbar) and back side contact respectively (in situ).

6.2.4.2 Alternatively, the shunt resistance can be measured before and after the PID test (ex situ), respectively.

6.2.5 An evaluation of the shunt resistance behavior yields a quantitative result for the relative PID sensitivity of different test specimens.

7 Apparatus

7.1 The apparatus/setup used for this test method has to be able to apply a voltage (constant over time and laterally homogenous) across an imitated solar module layer stack, consisting of glass cover and encapsulant polymer on top of a solar cell (see Figure 1) at a defined temperature. The list below defines necessary devices and equipment. The corresponding wiring scheme is shown in Figure 2.

7.1.1 DC voltage source, capable of applying the maximum test voltage (e.g. maximum system voltage of the regarded module design) with positive polarity at the top electrode with a voltage tolerance of 1 %

7.1.2 Grounded base electrode, capable of contacting the solar cell

7.1.3 Top electrode, capable of contacting the glass surface without any gap, with a size between 4 x 4 and full solar cell area, preferably of square dimension

7.1.4 Equipment for applying a constant force between top and base electrode (pressure > 1 kPa)

7.1.5 Provisions for avoiding illumination of the solar cell under test

![Diagram of PID Sample Layer Stack and Electrical Contacts](image)
7.1.6 Heat source, capable of heating the solar cell and the overlying layer stack to a constant temperature level, with an accuracy of better than ± 2 °C; temperature sensor and controller with temperature indicator

7.1.7 Equipment for shunt resistance measurement of solar cell with an accuracy of better than ± 1 % for resistance values below 1000 Ohm (either method A or method B):

7.1.7.1 Method A: in-situ measurement and record of solar cell shunt resistance during PID test via contacts to the active layers (ohm-meter in Figure 2). Optional: measurement of additional electrical solar cell parameters (e.g. dark I-V curve)

7.1.7.2 Method B: ex-situ measurement of solar cell shunt resistance before and after the PID test, respectively. Optional: measurement of additional electrical solar cell parameters (e.g. V_{oc}, I_{sc}, P_{mpp}, I-V curve, dark I-V curve)

7.1.8 Optional: an appropriate device for resolving and monitoring the leakage current from the top electrode to the grounded base plate (ampere-meter in Figure 2)

Figure 2
Example Wiring Scheme Including Optional In-Situ Shunt Resistance and Leakage Current Measurement

8 Reagents and Materials

8.1 PID Auxiliary samples/consumables

8.1.1 This test method is based on the imitation of a solar module front layer stack on a small scale area on top of a silicon solar cell. The three test scenarios that are described in section 2, each require PID auxiliary samples (hereafter: auxiliary samples) with constant PID-s sensitivity.

(1) PID testing of solar cells requires PID sensitive polymer sheets and glass sheets as auxiliary samples.

(2) PID testing of polymer sheets requires PID sensitive solar cells and glass sheets as auxiliary samples.

(3) PID testing of glass sheets requires PID sensitive solar cells and polymer sheets as auxiliary samples.

8.1.2 Auxiliary samples need to be out of the same production batch for each experiment series, respectively. Their material parameters shall be spatially and temporally constant.

8.1.3 The choice of definitive materials (type, manufacturer) is not specified for reasons of worldwide and long-term availability that cannot be guaranteed for PV materials (polymer, glass sheets) or special solar cells since they are consumed during PID tests.

8.1.4 It is recommended to use a PID-prone EVA foil as polymer sheet (auxiliary samples).

8.1.5 It is recommended to use untextured (flat) soda lime float glass as glass sheets (auxiliary samples).

9 Safety Precautions

9.1 Precautions have to be taken against:

9.1.1 Electric shock in dealing with high voltages

NOTE 2: It is recommended to equip the test apparatus with a safety switch that breaks the high voltage when its cover is opened.
NOTE 3: Especially at voltages over 1.5 kV local safety regulations must be satisfied, e.g. by current limitation.

9.1.2 Burns in dealing with hot surfaces / hot media

9.2 Local regulations have to be attended. Safety precautions are within the user’s responsibility.

10 Test Specimens

10.1 Requirements for test specimens and auxiliary samples:

(1) Solar cells — Cells to be probed must be of the same size and same basic design. They must be intact, free of micro cracks and must be equipped with front and back side contacts/contact grid on the whole area.

(2) Polymer foils — Polymer sheets to be probed shall be of the same dimensions as the top electrode (cut to size before). Sheets need to be homogenous with respect to thickness and material properties.

(3) Glass sheets — Glass sheets to be probed shall be of the same dimensions as the top electrode (cut to size before). They need to be laterally homogeneous with respect to thickness and material properties. Both sides must be even and smooth. Coatings such as anti-reflective coating have to be laterally homogeneous as well. If one side of the glass sheet samples is dedicated to be outside, it should be placed this side up (towards the top electrode).

10.2 Table 1 shows the synopsis of requirements to the test specimens and corresponding auxiliary samples.

<table>
<thead>
<tr>
<th>Test scenario:</th>
<th>(1) PID test of solar cells</th>
<th>(2) PID test of polymeric encapsulant</th>
<th>(3) PID test of glass cover materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements for cells:</td>
<td>cell samples and reference cells of the same design and same size</td>
<td>identical solar cells out of same production batch with high PID susceptibility (must be tested with cell test before)</td>
<td></td>
</tr>
<tr>
<td>Requirements for encapsulating polymer:</td>
<td>fresh (unused), homogenous samples of a common encapsulant polymer with constantly high PID susceptibility / electrical conductance</td>
<td>fresh (unused) foils that shall be qualified with respect to promotion or repression of PID; samples and reference samples should be of the same size and thickness</td>
<td>fresh (unused), homogenous samples of a common encapsulant polymer with constantly high PID susceptibility / electrical conductance</td>
</tr>
<tr>
<td>Requirements for glass sheets:</td>
<td>homogenous samples of a common flat (untextured) float glass with elevated electrical conductance (always fulfilled for common soda-lime glass, i.e. standard low-iron PV glass); glass sheets may be used more than once</td>
<td>glass sheets that shall be qualified with respect to promotion or repression of PID; samples and reference samples should be of the same size, thickness and with comparable surface texture where possible</td>
<td></td>
</tr>
</tbody>
</table>

NOTE 4: Polymer foil samples may be used for a single PID test since their properties are subject to alteration. Glass samples (auxiliary samples) can be used repeatedly, as long as they are not fractured and free from contaminations.

10.3 In general, all test specimens each need to be of the same design.

10.4 All surfaces of test specimens and auxiliary samples must be free from large (>10 µm), loosely adhesive particles. This can be achieved by rinsing with deionized water (glass, polymer) or blasting with dry air or nitrogen (cell surface). Strong contaminations such as finger prints shall be avoided.

10.5 Pretreatment of the sample stack

10.5.1 At the beginning of the test procedure polymer foil and glass sheet are stacked on the solar cell surface like shown in Fig. 1. This sample layer stack now exhibits the same layer sequence as the front side of a solar module.
10.5.2 For a more realistic imitation of a real solar module front side, especially of the polymer foil properties, it is recommended that the polymer foil is cured like in a module lamination process. This can be done either in the test apparatus itself (if the curing temperature of the specific polymer can be reached), or on a hotplate, or in a small vacuum lamination tool as used for manufacturing of one-cell laminates (mini modules).

11 Preparation of Apparatus

11.1 No special preparation is needed. All surfaces, especially the top electrode and the base plate, must be free of dirt, particles or any visible contamination. Cleaning with solvents, e.g. ethanol is recommended.

12 Procedure

12.1 If method B (§7.1.7.2) is chosen to measure the shunt resistance: measure the shunt resistance of the solar cell before the PID test. Not necessary if method A (§7.1.7.1) is chosen.

12.2 Cut polymer and glass sheet to size (same size as top electrode).

12.3 Assemble polymer sheet and glass sheet on top of the solar cell at the desired area.

12.4 Optional preconditioning (not preferred if method B (§7.1.7.2) is chosen):

12.4.1 Before beginning of the PID test, cure the polymer foil within the layer stack according to a standard lamination process (e.g. at 150 °C for 20 min for an EVA foil) for PID testing of solar cells (1) or glass (3).

12.4.2 When the polymer itself is subject to PID testing, cure the polymer foil within the layer stack according to a lamination process that is specific for the respective polymer.

12.5 Place the cell with the polymer/glass layer stack in the test apparatus.

12.6 If method A (§7.1.7.1) is chosen to measure the shunt resistance: Align the layer stack in relation to top electrode and the front contact pin(s) for shunt resistance measurement in relation to a busbar or grid finger.

12.7 Press the top electrode on the layer stack (min. pressure: 1 kPa).

12.8 Start tempering of the sample, wait for settling of temperature.

12.9 Start the measurement/recording of values to be measured (e.g. shunt resistance (method A, see §7.1.7.1), leakage current, temperature). Choose measuring intervals (time between two subsequent measurements) not longer than 5 minutes.

12.9.1 The in-situ shunt resistance measurement (method A, see §7.1.7.1) is realized through periodic current measurement under reverse bias between front side (emitter layer) and back side (base) of the solar cell:

12.9.1.1 Contact the front side (busbar or contact finger grid) by one or more contact pins (terminal F in Figure 1). The back side is contacted by the metallic base plate (terminal G).

12.9.1.2 Choose a measurement voltage between 0.1 and 0.3 V.

12.9.1.3 Choose polarity for shunt resistance measurement at reverse bias.

12.9.1.3.1 For p-type cells apply positive pole to the front side of the cell (emitter).

12.9.1.3.2 For n-type cells apply negative pole to the front side of the cell (emitter).

12.9.1.4 Perform current measurements at 0 V shortly before or after each biased current measurement for a correction by the photo-induced current if a measurement in perfect darkness cannot be guaranteed.

12.9.1.5 Set the voltage between front and back side to 0 V between subsequent resistance measurement events.

12.9.2 The optional leakage current measurement is realized through periodic measurement of the leakage current that flows between top and base electrode.

NOTE 5: The severity for PID test of cells (test scenario 1) can be monitored by measurement of the leakage current. Typical values of the leakage current are ~10...100 nA/cm²; it should be approximately constant within an experiment series at same test conditions.
NOTE 6: The leakage current varies for different encapsulant polymer materials (test scenario 2).
NOTE 7: The leakage current varies for different glass materials (test scenario 3).

12.10 Switch on the high voltage to start the PID test.
12.11 Apply/maintain the high voltage continuously over the test duration.
12.12 Switch off the high voltage at the end of the PID test.
12.13 Save all measured data to storage medium. The sample stack can be removed from the apparatus now.
12.14 If method B (¶7.1.7.2) is chosen to measure the shunt resistance: measure the shunt resistance of the solar cell after the PID test. Not necessary if method A (¶7.1.7.1) is chosen.

13 Test Conditions

13.1 Test conditions of the PID test:

13.1.1 Humidity: Dry conditions must be maintained over the test duration (relative humidity <60 %, no condensation of water, no additional humidity added).

13.1.2 Temperature: The temperature must be maintained constant over the test duration.

13.1.3 Voltage: The high voltage between top electrode H (+ pole) and base plate G (grounded) must be maintained constant over the test duration.

13.1.4 Test duration: If the test is performed at 25°C and with the rated system voltage of the module design the PID test is conducted for (e.g. 1500 V), the minimum required test duration is 168 hours. With these conditions the same stress level is obtained as present in the module test described in the IEC 62804-1 TS (stress method b).

13.1.4.1 Shorter test durations can be achieved by acceleration due to increased stress. The stress can be increased by temperature and/or voltage. With equation (1) the resulting acceleration factor for a specific temperature / voltage combination can be calculated. The equation is based on the assumption that PID-stress is increased linearly by voltage and exponentially (Arrhenius law) by temperature. Accordingly, the minimum required test duration may be divided by $f_{acc}$.

$$f_{acc}(V_{PID}, V_{system}, E_a, T) = \frac{V_{PID}}{V_{system}} \exp \left( \frac{E_a}{k_B \times 298.15 K} \left( \frac{1}{T} - \frac{1}{300 \times 298.15 K} \right) \right)$$

- $k_B$ … Boltzmann constant
- $V_{PID}$ … high voltage used for the PID test
- $V_{system}$ … rated system voltage of the module design the PID test is conducted for (e.g. 1500 V)
- $T$ … temperature at which the PID test is conducted
- $E_a$ … activation energy (realistic values are between 0.6 eV and 0.8 eV, the value used for calculation of $f_{acc}$ must be given in the report)

13.2 Applied severities and test durations shall be clearly logged in the report according to section 15.

NOTE 8: The PID stress level is only obtained for the tested cell area. Parts of the cell that are not covered with glass and encapsulant will not be stressed.

14 Calculations

14.1 Evaluation of the shunt resistance

14.1.1 Calculate the shunt resistance from the applied voltage and from the resulting current through the cell for each measuring point.

$$R_{shunt} = \frac{V_{appt}}{I}$$
14.1.2 Correction for photocurrent is necessary when the measurement is not performed in absolute darkness: Correct the measured current by subtraction of the current at 0 V for each measuring point.

\[ R_{\text{shunt\,(corr)}} = \frac{V_{\text{app}}}{I-I_{\text{qV}}} \]  

(3)

14.2 Evaluation of the PID-s related shunt conductance

14.2.1 The shunt resistance of a solar cell before a PID test (initial shunt resistance \( R_{\text{shunt,0}} \)) can vary from several \( 10^1 \) up to \( 10^4 \) Ohm. Therefore, it is not useful to express the actual severity of PID-s with relation to the initial shunt resistance value.

14.2.2 Cells with different initial shunt resistance can be compared with respect to their PID-s progress over time by means of the increase of the shunt conductance by PID-s (\( \Delta G_{\text{PID-s}} \)). Calculate the increase of the shunt conductance \( \Delta G_{\text{PID-s}} \) from the reciprocal of the shunt resistance \( R_{\text{shunt}} \) minus the reciprocal of the initial shunt resistance \( R_{\text{shunt,0}} \).

\[ \Delta G_{\text{PID-s}}(t) = \frac{1}{R_{\text{shunt}(t)}} - \frac{1}{R_{\text{shunt,0}}} \]  

(4)

14.2.3 Normalize the shunt conductance to the area of the top electrode and the polymer/glass layer stack. This yields the increase of the shunt conductance due to PID-s per sampled area (\( \Delta g_{\text{PID-s}} \)), which is a quantitative measure of the PID-s sensitivity of the respective sample stack.

\[ \Delta g_{\text{PID-s}}(t) = \left( \frac{1}{R_{\text{shunt}(t)}} - \frac{1}{R_{\text{shunt,0}}} \right) / A_{\text{top electrode}} \]  

(5)

14.2.4 Plot the diagram \( \Delta g_{\text{PID-s}}(t) \) (increase of shunt conductance due to PID-s as a function of the test time). This plot is the main outcome of a PID test according to this Test Method. Figure A1-2 in Appendix 1 shows an example of real measured \( \Delta g_{\text{PID-s}}(t) \) curves.

15 Report

15.1 The test report shall comprise following information and data:

15.1.1 title of the report

15.1.2 name and address of the test laboratory where the tests were carried out

15.1.3 unique identification of the report and of each page

15.1.4 date of issue

15.1.5 name and address of client, where appropriate

15.1.6 identification of the person accepting responsibility for the content of the report

15.1.7 unique identification of test specimens and auxiliary samples, including:

15.1.7.1 manufacturer

15.1.7.2 type

15.1.7.3 serial/batch number

15.1.7.4 production date

15.1.8 for prototypic test specimens made on pilot production equipment details of the deviation from the standard process shall be noted

15.1.9 date of receipt of test specimens and date(s) of test, where appropriate

15.1.10 description and photographs of the test specimens tested

15.1.11 description of test conditions, including:

15.1.11.1 test temperature

15.1.11.2 voltage level of high voltage
15.1.11.3 test duration
15.1.12 results obtained of the test specimens
15.1.12.1 data files that include acquired shunt resistance or voltage/current value records (raw data)
15.1.12.2 derived results and evaluations:
15.1.12.2.1 plot graph $R_{shunt}$ as a function of time for each measurement (example Figure A1-1 in Appendix 1)
15.1.12.2.2 plot graph $\Delta g_{PID-s}$ as a function of time for each measurement (example Figure A1-2 in Appendix 1)
15.1.12.2.3 optional: additional measurements (e.g. leakage current, $U_{oc}$, $I_{sc}$, $P_{mpp}$, I-V curve, dark I-V curve)
15.1.12.3 statement of the estimated uncertainty of the results (where relevant)
15.1.13 description of any deviations from, additions to, or exclusions from the test method and any other information, such as special test conditions (where relevant)

16 Precision and Bias

16.1 The precision of test results depends on the precision of the shunt resistance measurement and on the stability of the test conditions.
16.1.1 The shunt resistance is measured by voltage and current measurement between front and back contact of the solar cell.
16.1.1.1 The applied voltage may be influenced by high series resistance between contact pins and cell contacts or inside the solar cell, especially when low shunt resistance of the cell causes high currents.
16.1.1.2 The measured current may be influenced by unwanted illumination (generation of photo-current).
16.1.2 Test conditions (temperature and high voltage) have a high impact on the test results.
16.1.2.1 The temperature has a very high impact on the progress of PID-s. The temperature of the layer stack must be controlled with high precision.
16.1.2.2 The level of the high voltage applied to the top electrode is controlled at the output of the DC high voltage source. It is not trivial to apply this high voltage homogeneously over the whole surface of the glass sheet. Any gap between the top electrode and the glass surface would lead to an effectively reduced electric potential for parts of the sample area and must be avoided.

NOTE 9: The reproducibility of the test conditions can be monitored by acquisition of the leakage current. (see ¶ 12.9.2 ).

16.2 Poor repeatability of PID tests with same test conditions and same materials may result from the fact that the exact PID sensitivity of solar cells cannot be determined before a PID test. The PID sensitivity is subject to process related and random/statistical variations. Precise prediction of the PID sensitivity of solar cells even of the same batch is not possible.

16.3 Using materials of the same batches, the statistical variation of the normalized increase of the shunt conductance $\Delta g_{PID-s}$ can lie within ±30 % or below, when the test parameters are carefully monitored and kept constant. This is demonstrated in Figure A1-2. Deviations mainly result from slight variations of the PID sensitivity of the solar cells.

16.4 Under consideration of the fact that $\Delta g_{PID-s}$ is subject to variation over 2 to 3 orders of magnitude between PID sensitive and insensitive PID test specimens, the statistical variation mentioned above is acceptable.
APPENDIX 1
EXAMPLE MEASUREMENTS

NOTICE: The material in this Appendix is an official part of SEMI doc. 5889 and was approved by full letter ballot procedures on [A&R approval date].

A1-1 Example measurements

A1-1.1 Figure A1-1 shows the shunt resistance as a function of the test time for six individual PID tests using solar cells and materials out of the same production batches.

A1-1.1.1 The test temperature was 60 °C.
A1-1.1.2 The high voltage level was 1000 V.
A1-1.1.3 The test duration was 24 hours.
A1-1.1.4 The sampled (PID tested) area was 100 cm² and the cell area was 243 cm².

![Figure A1-1](image)

**Figure A1-1**
Plot of Shunt Resistance over Time for Six Example Measurements

A1-1.2 Figure A1-2 shows the diagram of the increase of the shunt conductance due to PID-s for six individual PID tests using solar cells and materials out of the same batches.

A1-1.3 The increase of the shunt conductance did not saturate within the test duration. There is an approximately linear increase of the shunt conductivity due to PID-s.

A1-1.4 The test conditions and the used test specimens and auxiliary samples were the same in every single PID test. The visible deviations of the curves results from inherent material deviations, mainly of the used solar cells.
Figure A1-2

Plot of the Increase of the Shunt Conductance Due To PID-S over Time

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