

SEMI PV69-0622

TEST METHOD FOR SPECTRUM RESPONSE (SR) MEASUREMENT OF ORGANIC PHOTOVOLTAIC (OPV) AND DYE-SENSITIZED SOLAR CELL (DSSC) AND PEROVSKITE SOLAR CELL(PSC)

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NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

1 Purpose

1.1 This Standard provides performance test method for organic photovoltaic (OPV)/dye-sensitized solar cell (DSSC) /perovskite solar cell (PSC) according to its spectrum response (SR) measurement and device qualification.

1.2 The major difference between OPV/DSSC/PSC and *p-n* junction solar cell is photoelectric conversion mechanism.

1.2.1 The operation principle of OPV/DSSC/PSC is using layers of organic molecules subject to lighting after excitation electron then pass to the inorganic/organic layer of the wide energy gap nanolayer and voltage.

1.2.2 OPV/DSSC/PSC has different spectrum and absorption range from a *p-n* junction solar cell.

1.2.3 OPV/DSSC/PSC needs more photoelectric conversion response time caused by specific material properties.

1.2.4 Therefore, OPV/DSSC/PSC shall need specific basis of reference to differ with STC condition (AM 1.5G, 25°C, 1000 W·m⁻²) used by *p-n* junction solar cell, and also make reserves extra time for SR test due to capacitance effect.

2 Scope

2.1 The objective is to focus on OPV/DSSC/PSC SR evaluation for either indoors or outdoors and provides the following:

2.1.1 Suitable statistic method to solve low response time issue for OPV/DSSC/PSC.

2.1.2 A guideline to correct OPV/DSSC/PSC data measured under STC.

2.1.3 A new isothermal platform standard for OPV/DSSC/PSC.

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 This Standard does not specify any kind of sample specification for OPV/DSSC; for example, 1 × 1 cm², 1 × 5 cm², 2 × 5 cm², 1 × 10 cm², etc.

3.2 SR measurement method does not provide the specifications of setting delay time and chopped frequency but the test time should be considered.

4 Referenced Standards and Documents

4.1 *SEMI Standards and Safety Guidelines*

SEMI PV57 — Test Method for Current-Voltage (I-V) Performance Measurement of Organic Photovoltaic (OPV) and Dye-Sensitized Solar Cell (DSSC) and Perovskite Solar Cell(PSC)

4.2 IEC Standards¹

IEC 60410 — Sampling Plans and Procedures for Inspection by Attributes

IEC 60904-2 — Photovoltaic Devices – Part 2: Requirements for Reference Solar Devices

IEC 60904-3 — Photovoltaic Devices – Part 3: Measurement Principles for Terrestrial Photovoltaic Solar Devices with Reference Spectral Irradiance Data

IEC 60904-4 — Photovoltaic Devices – Part 4: Reference Solar Devices – Procedures for Establishing Calibration Traceability

IEC 60904-7 — Photovoltaic Devices – Part 7: Computation of Spectral Mismatch Error Introduced in the Testing of a Photovoltaic Device

IEC 60904-8 — Photovoltaic Devices – Part 8: Measurement of Spectral Response of a Photovoltaic (PV) Device

IEC 60904-9 — Photovoltaic Devices – Part 9: Solar Simulator Performance Requirements

IEC 61646 — Thin-Film Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 *CI* — control interface

5.1.2 *DSSC* — dye-sensitized solar cell

5.1.3 *DUT* — device under test

5.1.4 *IPCE* — incident photon-electron conversion efficiency

5.1.5 *ITP* — isothermal test plane

5.1.6 *I-V* — current-voltage

5.1.7 *LIA* — lock-in amplifier

5.1.8 *MC* — monochromator

5.1.9 *NTC* — normal test conditions

5.1.10 *OPV* — organic photovoltaic

5.1.11 *PSC* — perovskite solar cell

5.1.12 *RD* — reference device

5.1.13 *RSD* — relative standard deviation

5.1.14 *SMU* — source measurement unit

5.1.15 *SR* — spectrum response

5.1.16 *SRI* — spectral response

5.1.17 *SR2* — spectral responsivity ($A \cdot W^{-1}$ or $A \cdot m^2 \cdot W^{-1}$)

5.1.18 *SRC* — standard reporting conditions

5.1.19 *SS* — solar simulator

5.1.20 *STC* — standard test conditions

5.1.21 *TM* — temperature monitor

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5.2 Definitions

5.2.1 *cell temperature* — the temperature (°C) of test sample.

5.2.2 *chopper* — a rotating blade or other device used to modulate a light source.

5.2.3 *current-voltage (I-V)* — the current-voltage curve of a test sample is the superposition of the curve with the light/dark-generated current.

5.2.4 *isothermal test plane* — the isothermal plane intended to contain DUT at the reference irradiance level.

5.2.5 *light source* — a source of radiant energy to simulate natural sunlight and used for cell performance measurement.

5.2.6 *monitor photo-detector* — a photo detector incorporated into the optical system to monitor the amount of light reaching the device under test, enabling adjustments to be made to accommodate varying light intensity.

5.2.7 *monochromatic beam* — a chopped light from a monochromatic source reaching the reference photo-detector or device under test.

5.2.8 *monochromator* — an optical device that allows a selected wavelength of light to pass while blocking other wavelengths.

5.2.9 *normal test conditions (NTC)* — for test sample. Sample temperature: 35°C, AM 1.5G, Irradiance: 1000 W·m⁻².

5.2.10 *quantum efficiency* — the number of collected electrons per incident photon at a specific wavelength in percent units.

5.2.11 *spectral bandwidth* — the range of wavelengths in a monochromatic light source, determined as the difference between its half-maximum-intensity wavelengths.

5.2.12 *standard test conditions (STC)* — for test sample. Sample temperature: 25°C, AM 1.5G, Irradiance: 1000 W·m⁻².

5.2.13 *standard reporting conditions (SRC)* — for test sample. Defined by temperature, spectral irradiance, and total irradiance. The term reporting, rather than reference or test, is used because a measurement can be performed at conditions other than SRC and then carefully corrected to be equivalent to being measured at SRC. As a matter of shorthand, the global and direct terrestrial reference spectra are often referred to as AM1.5G and AM1.5D, respectively.

5.2.14 *test sample* — test device of OPV/DSSC/PSC.

5.3 Symbols

5.3.1 λ — wavelength (nm)

5.3.2 A — cell area (m²)

5.3.3 c — speed of light (299,792,458 m/s)

5.3.4 e — charge of an electron (1.6021×10^{-19} C)

5.3.5 E — irradiance (W·m⁻²)

5.3.6 h — Plank's constant (6.626068×10^{-34} m² kg / s)

5.3.7 I — current (A)

5.3.8 I_{sc} — short-circuit current (A)

5.3.9 MMF — spectral mismatch parameter (or factor)

5.3.10 P — power incident on the test sample

5.3.11 T — temperature (°C)

5.3.12 V — voltage

6 Apparatus

6.1 The relative spectral responsivity of a test sample is measured by irradiating it by a narrow-bandwidth light source at a series of different wavelengths covering its response range, and measuring the short-circuit current density and irradiance at each of these wavelengths. The light source should irradiate the device uniformly, and the temperature of the device should be controlled. The current densities are then divided by the irradiances or a proportional parameter and plotted as a function of wavelength. Alternatively, the irradiance may be kept constant (for instance, by varying the length of a monochromator [MC] exit slit), in which case the relative spectral response is obtained directly from the current density readings. The irradiance monitor may be a vacuum thermocouple, a pyroelectric radiometer or other suitable detector. Another alternative is a previously calibrated reference photovoltaic device whose relative spectral response covers the required range. Apparatus includes reference device (RD), temperature monitor (TM), source measurement unit (SMU), isothermal test plane (ITP), lock-in amplifier (LIA), chopper, MC, shutter, and light source (LS) (refer to Figure 1).

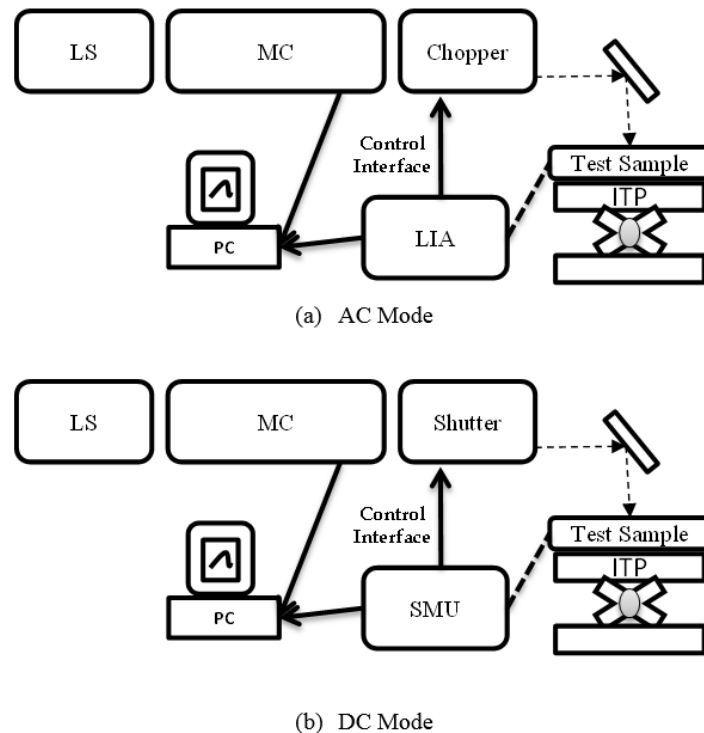


Figure 1
Testing Setup Equipment Diagrammatic Sketch

6.2 Testing Setup Equipment

6.2.1 AC Mode

6.2.1.1 The spectral responsivity of a test sample, defined as the output current per input irradiance or radiant power at a given wavelength, and normally reported over the wavelength range to which the device responds, is determined by the following procedure:

- A monochromatic, chopped beam of light is directed at normal incidence onto the cell. Simultaneously, a continuous white-light beam (bias light) is used to illuminate the DUT at irradiance levels between one-third and one-half of normal end use operating conditions intended for the test sample. Refer to Figure 1.
- The magnitude of the AC (chopped, refer to ¶ 6.6) component of the current at the intended voltage is monitored as the wavelength of the incident light is varied over the spectral response range of the test sample.

6.2.1.2 Measurement of the absolute spectral responsivity of a device requires knowledge of the absolute beam power or irradiance produced by the monochromatic beam. The total power or irradiance of the monochromatic beam incident on the device is determined by the reference device (refer to ¶ 6.3). The absolute spectral responsivity of the test sample can then be computed using the measured device photocurrent and the power or irradiance of the monochromatic beam.

6.2.1.3 The choice of power versus irradiance mode may depend on the spatial nonuniformity of the test device. Overall spectral response of a test sample with substantial spatial nonuniformity of response should be performed in irradiance mode.

6.2.1.4 The test procedure can be adapted to provide absolute or relative spectral responsivity measurements, depending on the calibration device used, its calibration mode and the relative sizes of the calibration device, the monochromatic beam size, and the device being measured.

6.2.2 DC Mode

6.2.2.1 The spectral responsivity of a test sample, defined as the output current per input irradiance or radiant power at a given wavelength, and normally reported over the wavelength range to which the device responds, is determined by the following procedure:

- (a) A monochromatic, chopped beam of light is directed at normal incidence onto the cell. Simultaneously, a continuous white-light beam (bias light [BL]) is used to illuminate the DUT at irradiance levels between one-third and one-half of normal end use operating conditions intended for the device. See Figure 1.
- (b) The magnitude of the DC component (e.g., SMU, refer to ¶ 6.5) of the current at the intended voltage is monitored as the wavelength of the incident light is varied over the spectral response range of the device.

6.2.2.2 Measurement of the absolute spectral responsivity of a device requires knowledge of the absolute beam power or irradiance produced by the monochromatic beam. The total power or irradiance of the monochromatic beam incident on the device is determined by the reference device (refer to ¶ 6.3). The absolute spectral responsivity of the device can then be computed using the measured device photocurrent and the power or irradiance of the monochromatic beam.

6.2.2.3 The choice of power versus irradiance mode may depend on the spatial nonuniformity of the test sample. Overall spectral response of a test device with substantial spatial nonuniformity of response should be performed in irradiance mode.

6.2.2.4 The test procedure can be adapted to provide absolute or relative spectral responsivity measurements, depending on the calibration device used, its calibration mode and the relative sizes of the calibration device, the monochromatic beam size, and the device being measured.

6.3 RD

6.3.1 RD is calibrated indoors using simulated sunlight or outdoors in natural sunlight by reference to the same desired reference spectral irradiance distribution.

6.3.2 Report need to commit traceability including measurement of I-V, SR and IPCE, which are determined in accordance with IEC 60904-2.

6.4 TM

6.4.1 TM shall record both the cell temperature and test plane temperature simultaneously while I-V is measured, and its accuracy need keep within $\pm 0.5^{\circ}\text{C}$.

6.5 SMU

6.5.1 SMU is used to measure current and voltage through DUT by using a biased voltage with numerous steps (refer to ¶ 9.7) to build SR spectrum.

6.6 LIA

6.6.1 An LIA (also known as a phase-sensitive detector) is a meter that can extract a signal with a known carrier wave from an extremely noisy environment. Depending on the dynamic reserve of the instrument, signals up to 1 million times smaller than noise components, potentially fairly close by in frequency, can still be reliably detected. It is