



Designation: **E2236–10** **E2236 – 10 (Reapproved 2015)**

Standard Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction Photovoltaic Cells and Modules¹

This standard is issued under the fixed designation E2236; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods provide special techniques needed to determine the electrical performance and spectral response of two-terminal, multijunction photovoltaic (PV) devices, both cell and modules.

1.2 These test methods are modifications and extensions of the procedures for single-junction devices defined by Test Methods **E948**, **E1021**, and **E1036**.

1.3 These test methods do not include temperature and irradiance corrections for spectral response and current-voltage (I-V) measurements. Procedures for such corrections are available in Test Methods **E948**, **E1021**, and **E1036**.

1.4 These test methods may be applied to cells and modules intended for concentrator applications.

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

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*²

E772 Terminology of Solar Energy Conversion

E927 Specification for Solar Simulation for Photovoltaic Testing

E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight

E973 Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell. <https://standards.iteh.ai/catalog/standards/sist/78eb800f-9973-41eb-a590-bdeb8f446018/astm-e2236-102015>

E1021 Test Method for Spectral Responsivity Measurements of Photovoltaic Devices

E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E1040 Specification for Physical Characteristics of Nonconcentrator Terrestrial Photovoltaic Reference Cells

E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum

E1328 Terminology Relating to Photovoltaic Solar Energy Conversion (Withdrawn 2012)³

E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells

G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance

G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

3. Terminology

3.1 *Definitions*—definitions of terms used in this standard may be found in Terminology **E772** and in Terminology **E1328**.

3.2 *Definitions of Terms Specific to This Standard:*

¹ These test methods are under the jurisdiction of ASTM Committee **E44** on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee **E44.09** on Photovoltaic Electric Power Conversion.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

3.2.1 *multijunction device, n*—a photovoltaic device composed of more than one photovoltaic junction stacked on top of each other and electrically connected in series.

3.2.2 *component cells, n*—the individual photovoltaic junctions of a multijunction device.

3.3 *Symbols:*

C	= reference cell calibration constant under the reference spectrum, $A \cdot m^2 \cdot W^{-1}$
E_o	= total irradiance of reporting conditions, $W \cdot m^{-2}$
$E_S(\lambda)$	= source spectral irradiance, $W \cdot m^{-2} \cdot nm^{-1}$ or $W \cdot m^{-2} \cdot \mu m^{-1}$
$E_R(\lambda)$	= reference spectral irradiance, $W \cdot m^{-2} \cdot nm^{-1}$ or $W \cdot m^{-2} \cdot \mu m^{-1}$
FF	= fill factor, dimensionless
i	= subscript index associated with an individual component cell
I_o	= current of test device under the reference spectrum, A
I	= current of test device under the source spectrum, A
I_{sc}	= short-circuit current, A
I_R	= short-circuit current of reference cell under the source spectrum, A
M	= spectral mismatch parameter, dimensionless
n	= number of component cells in the multijunction device
P_{max}	= maximum power, W
$Q(\lambda)$	= quantum efficiency, dimensionless
$R(\lambda)$	= spectral response, $A \cdot W^{-1}$
$R_T(\lambda)$	= test device spectral response, $A \cdot W^{-1}$
$R_R(\lambda)$	= reference cell spectral response, $A \cdot W^{-1}$
T	= temperature, °C
V_{oc}	= open-circuit voltage, V
V_b	= voltage applied by dc bias source, V
Z	= current balance, dimensionless
λ	= wavelength, nm or μm

4. Significance and Use

4.1 In a series-connected multijunction PV device, the incident total and spectral irradiance determines which component cell will generate the smallest photocurrent and thus limit the current through the entire series-connected device. This current-limiting behavior also affects the fill factor of the device. Because of this, special techniques are needed to measure the correct I-V characteristics of multijunction devices under the desired reporting conditions (see Test Methods E1036).

4.2 These test methods use a numerical parameter called the current balance which is a measure of how well the test conditions replicate the desired reporting conditions. When the current balance deviates from unity by more than 0.03, the uncertainty of the measurement may be increased.

4.3 The effects of current limiting in individual component cells can cause problems for I-V curve translations to different temperature and irradiance conditions, such as the translations recommended in Test Methods E1036. For example, if a different component cell becomes the limiting cell as the irradiance is varied, a discontinuity in the current versus irradiance characteristic may be observed. For this reason, it is recommended that I-V characteristics of multijunction devices be measured at temperature and irradiance conditions close to the desired reporting conditions.

4.4 Some multijunction devices have more than two terminals which allow electrical connections to each component cell. In these cases, the special techniques for spectral response measurements are not needed because the component cells can be measured individually. However, these I-V techniques are still needed if the device is intended to be operated as a two-terminal device.

4.5 Using these test methods, the spectral response is typically measured while the individual component cell under test is illuminated at levels that are less than E_o . Nonlinearity of the spectral response may cause the measured results to differ from the spectral response at the illumination levels of actual use conditions.

5. Summary of Test Methods

5.1 Spectral response measurements of the device under test are accomplished using light- and voltage-biasing techniques of each component cell, followed by determination of the spectral response according to Test Methods E1021.

5.2 If a spectrally adjustable solar simulator is available (see 6.1.1) the electrical performance measurements use an iterative process of adjusting the incident spectral irradiance until the operating conditions are close to the desired reporting conditions is used. This adjustment modifies a quantity known as the current balance. The I-V characteristics are then measured according to Test Methods E948 or E1036. Appendix X1 contains a derivation and discussion of current balance.

5.3 For the case of light sources where the spectral irradiance cannot be changed, such as outdoors or if a spectrally adjustable solar simulator is not available, the I-V characteristics are measured according to Test Methods E948 or E1036. However, the current balance in each component cell must also be determined and reported.

6. Apparatus

6.1 In addition to the apparatus required for Test Methods E948, E973, E1021, E1036, and G138, these test methods refer to the following apparatus.

6.1.1 *spectrally adjustable Solar Simulator*—A solar simulator that meets the requirements of Specification E927 and which has the additional capability of allowing different wavelength regions of its spectral irradiance to be independently adjusted. This may be accomplished by several methods, such as a multisource simulator with independent sources for different regions, or a multiple filter simulator.

6.1.1.1 Ideally, the adjustable wavelength ranges of the spectrally adjustable solar simulator should correspond to the spectral response ranges of each component cell in the multijunction device to be tested.

6.1.2 *Reference Cells*—Photovoltaic reference cells (see Specification E1040), calibrated according to Test Methods E1125 or E1362, are used to measure source irradiance in the wavelength regions that correspond to each component cell in the multijunction device to be tested. For best results, the spectral responses of the reference cells should be similar to the spectral responses of the corresponding component cells.

6.1.3 *Bias Light Source*—A dc bias light as specified by Test Methods E1021, that is equipped with appropriate spectral filters to block wavelength regions corresponding to the expected spectral response range of the individual component cell being tested.

6.1.3.1 Acceptable alternatives to filtered light sources are continuous lasers that emit at single wavelengths in the spectral response ranges of each component cell. Ideally, the selected laser wavelengths should not illuminate regions where the spectral responses of any two component cells overlap.

6.1.4 *Bias Voltage Source*—A variable dc power supply capable of providing a voltage equal to the open-circuit voltage of the multijunction device to be tested, and compatible with the synchronous detection instrumentation of Test Methods E1021.

7. Procedure

7.1 *Spectral Response:*

7.1.1 Place the device under test in the spectral response test fixture.

7.1.2 Select the component cell to be measured.

7.1.3 Apply light bias to component cells not being measured using the bias light source:

7.1.3.1 Choose spectral filters whose spectral transmittance, when combined, corresponds to the spectral response of the component cell or cells not being measured. Install the spectral filters in front of the bias light source.

7.1.3.2 If lasers are used, turn on the lasers that emit wavelengths corresponding to the component cell or cells not being measured.

7.1.3.3 Ideally, the illumination on the component cell being measured should be at E_o and the component cells not being measured should be illuminated at higher levels. Practically, the component cell to be measured should have some illumination, as device spectral responsivities can be a function of the illumination level.

7.1.3.4 Turn on the bias light source and illuminate, as a minimum, the region where the monochromatic beam illuminates the test device.

7.1.4 Measure the V_{oc} of the test device.

7.1.5 Calculate the bias voltage to use during the test:

7.1.5.1 For devices with component cells that contribute similar voltages, calculate the bias voltage according to Eq 1.

$$V_b = \frac{n-1}{n} V_{oc} \quad (1)$$

7.1.5.2 For devices with component cells contributing substantially different voltages, calculate the bias voltage as the sum of the expected voltage contributions from the component cells not being measured.

7.1.6 Set the V_b on the bias voltage source.

7.1.7 Connect the test device to the ac measurement instrumentation.

7.1.8 Maximize the ac signal from the component cell under test using a wavelength at which it is expected to respond:

7.1.8.1 Set the monochromatic light source to a wavelength in the expected spectral response region of the component cell to be measured.

7.1.8.2 Adjust the bias light intensity to saturate or maximize the test device signal.

7.1.9 Minimize the test device signal at wavelengths where the component cells not being measured are expected to respond:

7.1.9.1 Set the monochromatic light source for a wavelength in the expected spectral response region of the component cell not being measured.

7.1.9.2 Minimize or zero the test device signal by adjusting the bias light intensity.

7.1.9.3 Repeat 7.1.9.1 and 7.1.9.2 for additional component cells not being measured, if any.

7.1.10 As in 7.1.8 and 7.1.9, adjust V_b to further maximize the signal in 7.1.8 and further minimize the signal in 7.1.9.