Designation: E 1021 – 95 (Reapproved 2001)

Standard Test Methods for Measuring Spectral Response of Photovoltaic Cells[1]

This standard is issued under the fixed designation E 1021; 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 cover the determination of either the absolute or relative spectral response of a single, linear photovoltaic cell. These test methods require the use of a bias light.

1.2 These test methods are not intended for use with interconnected photovoltaic devices.

1.3 There is no similar or equivalent ISO standard.

1.4 *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:*

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[2]

E 772 Terminology Relating to Solar Energy Conversion[3]

E 892 Tables for Terrestrial Solar Spectral Irradiance at Air Mass 1.5 for a 37° Tilted Surface[2]

E 927 Specification for Solar Simulation for Terrestrial Photovoltaic Testing[3]

E 973 Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell[3]

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion[3]

3. Terminology

3.1 *Definitions*—Definitions of terms used in these test methods may be found in Terminology E 772 and in Terminology E 1328.

3.2 *Symbols:*

3.2.1 The following symbols and units are used in these test methods.

a—illuminated cell area, m^2,
A—irradiance normalization constant,
c—speed of light in vacuum, ms^{-1},
E—monochromatic source irradiance, Wm^{-2},
E_o— reference spectral irradiance, Wm^{-2},
h—Planck's constant, JHz^{-1},
I—current, A,
I_{sc}—solar cell short-circuit current, A,
K—relative-to-absolute spectral response conversion constant,
M—spectral mismatch parameter,
q—elementary charge, C,
Q—external quantum efficiency,
R_a—absolute spectral response, AW^{-1},
R_r—relative spectral response, and
λ—wavelength, nm or μm.

3.2.2 Symbolic quantities that are functions of wavelength appear as $X(\lambda)$.

4. Summary of Test Methods

4.1 The spectral response of the photovoltaic cell is determined by the following procedure:

4.1.1 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 entire device at an irradiance approximately equal to normal end use operating conditions intended for the cell.

4.1.2 The spectral dependence of the ac (chopped) component of the short-circuit current is monitored as the wavelength of the incident light is varied over the response band of the cell. The total energy in the beam of chopped light as a function of wavelength is determined with an appropriate detector.

4.2 The absolute spectral response of a cell requires the knowledge of the absolute energy in the chopped beam. The detector must, therefore, be traceable to a National Institute of Standards and Technology (NIST) Detector Response Package,[4] or other standards for blackbody detectors as appropriate.

[1] These test methods are under the jurisdiction of ASTM Committee E44 on Solar, Geothermal, and Other Alternative Energy Sources and are the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.
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[2] *Annual Book of ASTM Standards*, Vol 14.02.

[3] *Annual Book of ASTM Standards*, Vol 12.02.

[4] Zalewski, E. F., et al., "The NBS Detector Response Transfer and Intercomparison Package: Its Characteristics and Use," National Bureau of Standards, Radiometric Physics Division, Washington, D.C., 1980.

The absolute spectral response of the cell can then be computed using the measured cell response and the irradiance of the chopped source.

5. Significance and Use

5.1 The spectral response of a photovoltaic cell is required to interpret laboratory measurements on devices and is useful for theoretical calculations. The reference cell method of photovoltaic device performance measurement, for example, requires spectral response measurements for computing the spectral mismatch parameter (see Test Method E 973).

5.2 The methods described herein are appropriate for use in either research and development applications or in product quality control by manufacturers.

6. Apparatus

6.1 *Spectral Detector*:

6.1.1 The following detectors are acceptable for use in the calibration of the monochromatic light source:

6.1.1.1 Pyroelectric radiometer, and

6.1.1.2 Calibrated photodetector.

6.2 *Monochromatic Light Source*:

6.2.1 A variety of different laboratory apparatus are available for the generation of a monochromatic beam of light. Prism or grating monochromators using tungsten or other light sources are most commonly used. Discrete and tunable continuous-wave lasers offer another source of monochromatic light. The wide range of wavelengths available coupled with the high optical quality of laser beams renders them attractive. Another source is narrow-bandpass optical filters in conjunction with a broad spectrum light source such as tungsten.

6.2.2 The monochromatic light source shall be capable of providing wavelengths that extend beyond the response region of the device to be tested.

6.2.3 A minimum of 12 wavelengths within the spectral response range of the cell to be measured is required.

6.2.4 Spectral bandwidth of the monochromatic light source shall not exceed 50 nm for a relative spectral response measurement and 20 nm for an absolute spectral response measurement.

6.2.5 The light source shall be capable of providing a spatial uniformity of ±2.5 % over the area of the test plane, and a temporal stability of ±1 % during the measurement period.

6.2.6 Care must be taken to ensure that scattered light or higher order light effects are negligible. The chopper (see 6.5) entrance and exit optics should be enclosed in a black cavity to minimize the modulation of stray light by the chopper blades.

6.2.7 It is recommended that the monochromatic light source be able to illuminate the entire area of the cell to be tested. If not, multiple measurements of the spectral response in different areas of the cell are required (see 8.2.5.1).

6.2.8 If a pyroelectric detector is used (see 6.1.1), the monochromatic source must illuminate the entire detector. If a calibrated photodetector is used, it is not necessary to illuminate the entire detector if detector response uniformity and linearity has been proven.

6.2.9 An optical shutter may be used to interrupt the monochromatic beam and, therefore, eliminate time delays involved with source and supply warm-up times.

6.3 *Monochromatic Light Chopper*:

6.3.1 A rotating mechanical light chopper or other device used to modulate the monochromatic light source.

6.3.2 The chopper blades should be non-reflective or black to minimize modulation of stray light.

6.4 *Bias Light Source*:

6.4.1 In order to measure the spectral response under conditions approximating those obtained under standard operating conditions, a bias light shall be used. The light should be of sufficient intensity to ensure the cell to be tested is operating in its linear response region, preferably within 30 % of its normal operating short-circuit current, when both the bias light and the monochromatic source are on.

6.4.2 The spectral distribution of the bias light should meet the criteria for a Class C simulator as given in Table 2 of Specification E 927. Generally, a spatial uniformity of ±10 % is adequate.

6.4.3 The bias source should contain no significant harmonics of the chopper frequency used with the monochromatic source. This can be done most easily by using a well regulated, dc power supply for the bias light. Care should be taken to prevent reflections of the bias light from the chopper blade from striking the sample. Mechanical vibrations, either from the chopper or other sources, shall not be allowed to modulate the bias light.

6.5 *Synchronous Detection Instrumentation*:

6.5.1 A pre-amplifier followed by a lock-in amplifier, ac voltmeter, or true-root-mean-square (RMS) voltmeter is used to detect the low-level, chopped signals from the photovoltaic device and thus measure the cell short-circuit current. Choice of pre-amplifier shall include consideration of the requirement that the photovoltaic cell must be operated in the short-circuit current mode and that both a low-level ac, as well as a high-level dc signal will be present. Under these conditions a pre-amplifier with a transformer coupled input circuit may saturate and result in inaccurate readings. If the pre-amplifier is not a low input-impedance, short-circuit current type and the photovoltaic device is loaded in the short-circuit mode with a four-terminal resistor instead, one must ensure that the drop across the load resistor is less than 20 mV. The dynamic range required of the instrument will depend on the chopped beam source used. For example, a tungsten source with a monochromator will usually require a dynamic range of four to six orders of magnitude, because of the wide range of intensity variation over the required spectral test range.

6.5.2 For relative spectral response measurements, it is not necessary for the synchronous detection instrumentation to output the short-circuit current in amperes. A lock-in amplifier, for example, might give the short-circuit current in microvolts which does not then need to be converted to the actual current in amperes.

6.5.3 True-RMS voltmeters respond to both the ac and the dc components of the short-circuit current which then must be separated to determine the ac component. An acceptable method uses the square root of the difference of the square of the signal and the background (or noise) signal.

6.6 *Test Plane*: