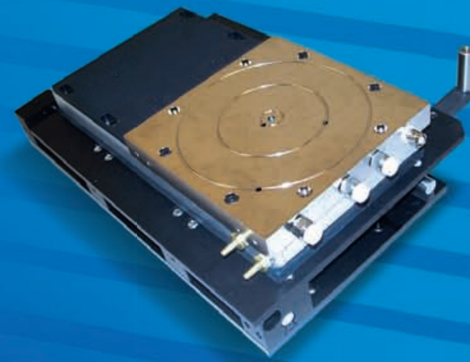
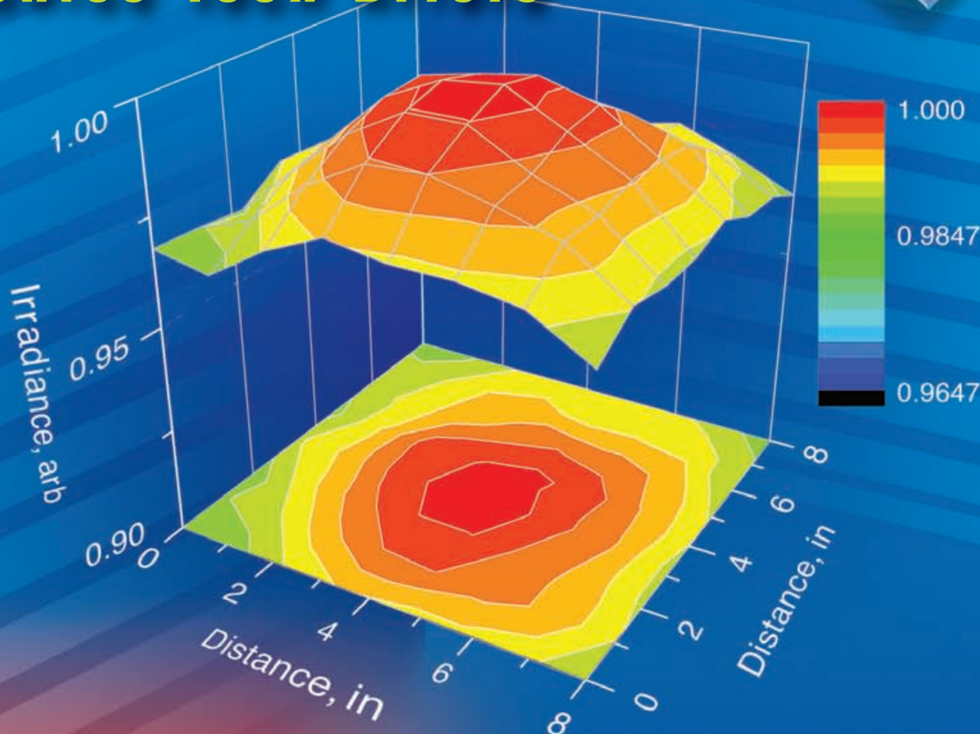
Photonics Solutions for the Design Engineer

September 2010



PTB™
Photonics Tech Briefs



On the cover: All photovoltaic (PV) cells convert sunlight into electricity, but some do it more efficiently than others. To find out how PV cells are calibrated, see the feature on page IIa.

(Image courtesy of Newport Corporation)

www.ptbmagazine.com

Calibrating Photovoltaic Cells

The basic function of a photovoltaic cell is to convert input — sunlight energy expressed in irradiance (W/m^2) — into output — useable electrical power — with as little loss as possible. To quantify the ability of the system to accomplish this conversion, one can simply compare the output to the input by forming a ratio of the two. This ratio, expressed in percentages, is known as the power conversion efficiency (PCE) of the device and it is a key parameter of electrical performance. Since the PCE is used to compare the performance of photovoltaic devices, it is critical that accurate estimates be made for the PCE. The estimate is dependent on knowing, with a high degree of accuracy, the actual conditions, including irradiance and cell temperature, under which the parameter is measured.

Irradiance

Irradiance is normally measured in the field with an irradiance sensor, or in a simulated environment using a solar reference cell. These devices are calibrated using the American Society for Testing and Materials (ASTM) and/or International Electrotechnical Commission standards. Calibration services are offered by a number of labs, including Newport Corporation's Technology and Applications Center (TAC) PV Lab; the National Renewable Energy Laboratory's (NREL) Device Performance Group; Sandia's Photovoltaic System Evaluation Laboratory (PSEL); the Fraunhofer Institute for Solar Energy (ISE) in Freiburg, Germany; and others.

Standard conditions for calibration are 25°C and 1000 W/m^2 of sunlight or simulated sunlight. The Newport TAC-PV Lab is ISO-17025 certified and A2LA accredited. We use simulated sunlight produced by a solar simulator, and the source of light in the solar simulator is a Xenon arc bulb. One of the challenges to making accurate calibrations is reproducing the standard conditions for a variety of photovoltaic materials in a variety of sizes and shapes.

A typical solar reference cell is a 2cm × 2cm solar cell packaged in a metal housing and protected under a glass or fused silica window (Figure 1). Terminals for interfacing with a digital multi-meter are built into the package, and a temperature sensor is required for measuring the temperature of the cell. One of the important electrical performance parameters for a solar reference cell is its short-circuit current. The packaged cell can be used as a reference cell when its short-circuit current is known within some degree of accuracy at the standard conditions (25°C and 1000 W/m^2 of sunlight). Since the reference solar cell is a linear device, it can then be used to measure the irradiance under other combinations of temperature and irradiance, if the temperature coefficients are known.

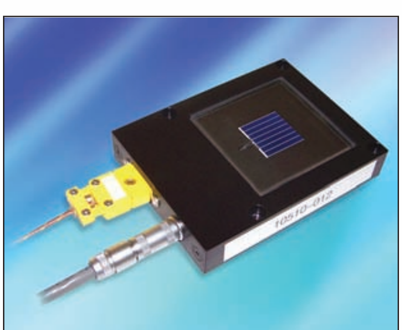


Figure 1. A Newport Oriel 2cm x 2cm solar reference cell package.

Thermal Issues

A significant source of uncertainty in PV testing is the lack of knowledge of the temperature, T_{cell}, at the space charge region of the cell. The package that houses a cell in a solar reference cell, for example, acts as a heat sink that cools the back of the cell (by conduction) faster than the top surface of the cell (by convection).This makes the bottom surface, generally speaking, a few degrees C cooler than the top surface of the cell. The built-in thermocouple in a solar reference cell measures the temperature at the back of the cell which is different from T_{cell}. A lack of knowledge of the temperature difference translates into uncertainty in the performance parameter, which is proportional to the temperature coefficient.

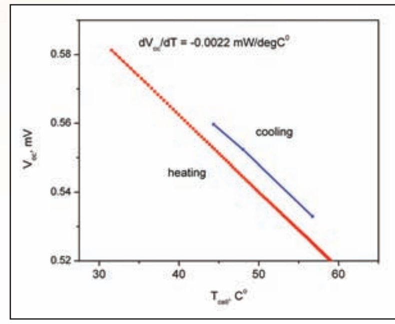


Figure 2. Open-circuit voltage plotted against temperature yields the respective temperature coefficients and exhibits hysteresis with temperature.

The difference in temperatures is apparent when the parameter (e.g. open-circuit voltage) is plotted against temperature (at the back of the cell) when the cell is heated or cooled (Figure 2). As the best estimate of the open circuit voltage, the two lines in Figure 2 can be extrapolated to 25°C using the temperature coefficient, and the midpoint of the two V_{oc} intercepts at 25°C can be calculated. For more accurate measurement, we let the cell equilibrate at room temperature and measure the parameters

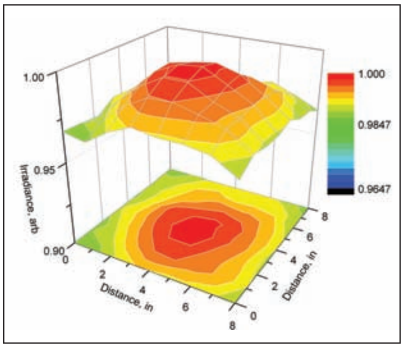


Figure 3. Irradiance distribution in the test plane of the Newport Oriel Sol3A, a Class AAA solar simulator, showing less than 2% nonuniformity.

using only momentary illumination (~ 1 sec). The measurement then is extrapolated to 25°C using their respective temperature coefficients.

Additional uncertainty (i.e. "error") arises from a mismatch of light source spectra and spectral response of the cell. This error source is known as the spectral mismatch error and is expressed in terms of the absolute deviation of the spectral mismatch factor *M* from unity. The mismatch refers to the relative differences in spectral distributions of the light used to measure the reference and the device under test, respectively, and the relative differences in the spectral responses of the two devices. Matching the spectra and responses as closely as possible minimizes this error. A value of $M = 1$ indicates a perfect match. Deviations from unity can be as much as 50%[1].

The Newport TAC — PV Lab uses a solar reference cell with a KG1 filter window (instead of the standard fused silica) to test organic devices. Doing so keeps the mismatch below 10%. Of course, there is error in the correction factor *M* itself due to inaccurate knowledge of the spectral distribution of sunlight and spectral response of either device. To meet this challenge, Newport's Oriel division has developed an instrument, the IQE-200, which can accurately measure the spectral response of most PV devices.

Another error encountered in PV measurements employing simulated sunlight is due to the spatial non-uniformity in the solar simulator beam (Figure 3).

Solar simulator light is typically more concentrated in the center (around the optical axis) than at the edge of the illuminated area and maps into a domed surface, the height of which can be used as a metric for spatial non-uniformity. Spatial non-uniformity is minimized (under 2%) in Class AAA solar simulators like the Sol3A from Newport Oriel (Figure 4). The residual amount of spatial non-uniformity causes irradiance error that is proportional to the relative areas of the solar reference cell and device under test, and on the relative locations of the two cells within the working plane of the solar simulator. Alternatively, a factor (analogous to the spectral mismatch factor) can be calculated and applied to correct for this error[2].

Unlike packaged solar reference cells, experimental or prototype cells sometimes arrive at the Newport TAC-PV Lab unpackaged. In many cases, they degrade with exposure to air, light, heat and humidity. These are delicate structures as small as 0.04 cm^2 that may simply be sandwiched between two microscope slides. Light exposure during testing must be short to be non-invasive, but no shorter than the response time of the cell. There is often no convenient way to control or directly measure the temperature of these devices. The TAC-PV Lab tests experimental cells under short exposure to light (~ 1 sec) as produced by the Newport Oriel Sol3A solar simulator with a built-in shutter with 300 ms switching time. This technique perturbs the cell only slightly from being in equilibrium with room temperature. Variations in V_{oc} during the exposure to light can be used as a measure of deviation from equilibrium[3]. Repeating these short exposures at different bias voltages generates an I-V curve from which all the electrical performance parameters can be calculated.

Figure 4. The Class AAA Sol3A Solar Simulator by Newport s Oriel division.

This article was written by Ruben Zadoyan, PhD, Senior Director, and Matthew O Donnell, PV Lab Manager, Technology & Applications Center, Newport Corporation (Irvine, CA). For more information, contact Mr. Zadoyan at ruben.zadoyan@newport.com, or visit ***http://info.hotims.com/28057-200***.

References:

1. C. R. Osterwald, "Translation of device performance measurements to reference conditions." Solar Cells, 18, pp. 269-279 (1988).
2. Klaus Heidler, Heike Fischer, and Siegfried Kunzelmann, "New approaches to reduce uncertainty in solar cell efficiency measurements introduced by non-uniformity or irradiance and porr FF-determination." Proceedings of the 9^{th} EC Photovoltaic solar energy conference, Freiburg, Germany, pp. 791-4 (1989).
3. K. Emery and T. Moriarty, "Accurate measurement of organic solar cell efficiency," Proc. SPIE Optics + Photonics, session 7052-12, San Diego, CA, Aug. 10-14, (2008).

Reprinted from Photonics Tech Briefs, a supplement to NASA Tech Briefs, September 2010. On the web at www.techbriefs.com.

Newport's Technology and Applications Center's Photovoltaic Lab

The Newport Technology & Applications Center's Photovoltaic (TAC-PV) Lab in Irvine, CA is accredited by the American Association for Laboratory Accreditation (A2LA) to ISO/IEC 17025. We measure the electrical performance of photovoltaic cells under simulated sunlight according to the American Society for Testing Materials (ASTM) standard E948, and make spectral responsivity measurements of photovoltaic devices according to ASTM E1021. All measurements are performed under standard reporting conditions (SRC) with a temperature of 25°C, a total irradiance of 1 Sun (1000 W/m^2), and spectral irradiance AM1.5G (IEC 60904-3).

The Newport TAC-PV Lab practices quality control techniques for monitoring the validity of tests and calibrations undertaken including participation in interlaboratory comparisons or proficiency testing programs. All measurements made by the Newport TAC-PV Lab are traceable to the International System of Units (SI). All of the customer's data is kept confidential.

The Newport TAC-PV Lab uses state of the art equipment including the Oriel® Class AAA 8" x 8" Sol3A™ Solar Simulator and the Oriel IQE-200 system. Using these instruments, we perform the following measurements:

- Absolute or relative external quantum efficiency (300 nm to 1100 nm) with white light bias
- Precision total area measurement of device
- I-V measurements to derive standard electrical performance parameters (% efficiency, Fill Factor, P_{max}, I_{SC}, and V_{OC})

We welcome requests for prototype PV device performance measurements or for PV reference cell calibration. Expedited measurement service is available.

Your ISO/IEC 17025 Accredited Calibration Certificate will include:

- Measured total area of your device
- EQE and I-V curves of your device
- Irradiance spectrum of our solar simulator
- Spectral response of our reference detector
- Expanded uncertainties
- Electrical performance parameters of your device

In addition to the TAC-PV Lab's dedicated facility for PV cell calibration, Newport's Technology and Applications Center (TAC) is equipped with modern ultrafast lasers, spectroscopy and multiphoton imaging instruments that enable us to perform many advanced studies including transient absorption, pump-probe, non-linear ultrafast spectroscopy, multiphoton imaging, as well as other material characterization techniques. These tools and techniques have allowed us to understand the properties of materials used in photovoltaic cells at molecular and atomic levels.

Newport®
Experience | Solutions