Differential spectral responsivity measurements of large bifacial solar cells

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We report on measurements of large bifacial solar cells using a new LED-based measurement setup for wavelength range 290 – 1300 nm. The measurement uncertainty in visible is 1.7% (*k*=2). Main challenges in the measurements are the spatial uniformity and the measurement of short circuit current. These topics are discussed in detail.

INTRODUCTION

Differential spectral responsivity is needed for solar cell development and analysis. It can also be used in testing to correct for the spectral mismatch between the light source used in the measurement and the standardized reference spectrum. Spectral responsivity has to be measured for a cell under biased conditions due to possible nonlinearity [1], which poses challenges.

In this paper, we present our setup for differential spectral responsivity. We also discuss its use for and challenges in measuring large bifacial solar cells.

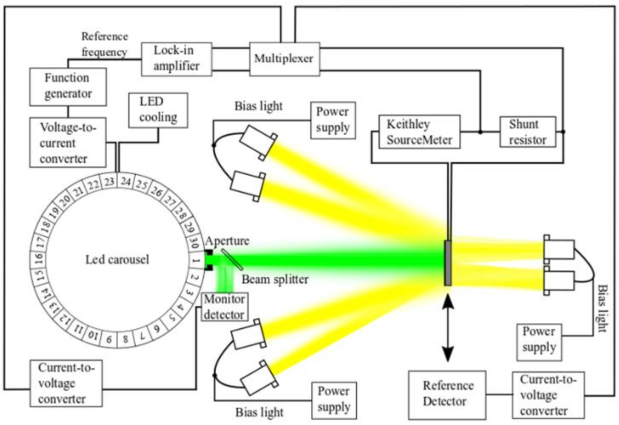

Figure 1. Setup for measuring differential spectral responsivities of bifacial solar cells. [2]

MEASUREMENT SETUP

Our setup for measuring differential spectral responsivity of solar cells [2] is presented in Fig. 1. Bias lighting is provided by towers of halogen lamps, 7 x 50 W in each tower. Four towers in the front provide up to 1000 W/m^2 irradiance on the cell. Two additional towers are used to light the back side of bifacial cells e.g. with 1/3 of the intensity on the front side.

Quasi-monochromatic radiation for measuring the spectral responsivity is provided with 30 temperature-stabilized LEDs assembled on a rotatable carousel, covering the wavelength range of 290 – 1300 nm. LEDs are driven with pulsed current at a frequency of 177 Hz. The signal produced is measured from the cell current using a lock-in amplifier and a shunt resistor.

The relative spectra of the LEDs have been measured. In cell measurements, the absolute levels of the spectra are measured with a silicon trap detector and an aperture with a diameter of 3 mm. The relatively large bandwidths of the LEDs are taken into account in the data analysis using a recursive iteration process, similar to the method used earlier for analysing spectral irradiance of halogen lamps from filter radiometer measurements [3]. The method gives accurate values for spectral responsivity at the effective wavelengths of the LEDs, and an interpolation function.

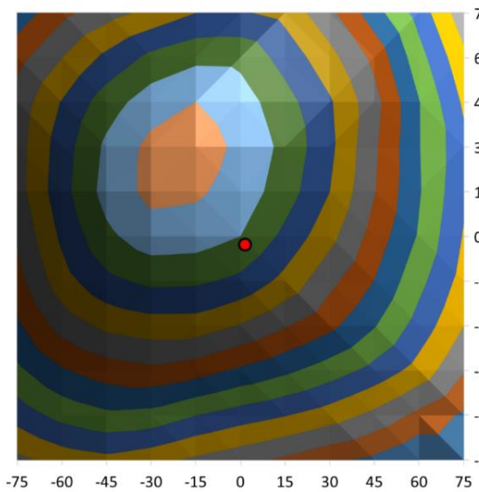

Figure 2. Spatial uniformity of the 727 nm LED irradiance. The axis values are given in mm. The difference between the contour lines is 2.5%. The red circle in the center shows the size and location of the 3 mm aperture of the trap detector used in measuring the spectral irradiance.

RESULTS AND DISCUSSION

The setup has been used to measure the spectral responsivities of bifacial solar cells with a large area of 15 x 15 cm^2. The large size poses challenges due to non-uniformities of the measurement beams and the large dynamic range of the measurement signal.

Radiation field in the sample location was scanned for spatial uniformity for all the 30 LEDs used. Figure 2 shows the spatial uniformity of the 727 nm LED which had the largest non-uniformity. The radiation field of this LED is narrow and slightly misaligned. The uniformity is taken into account in data analysis by dividing the irradiance measured in the center of the field with the average of the irradiance measured across the large cell area.

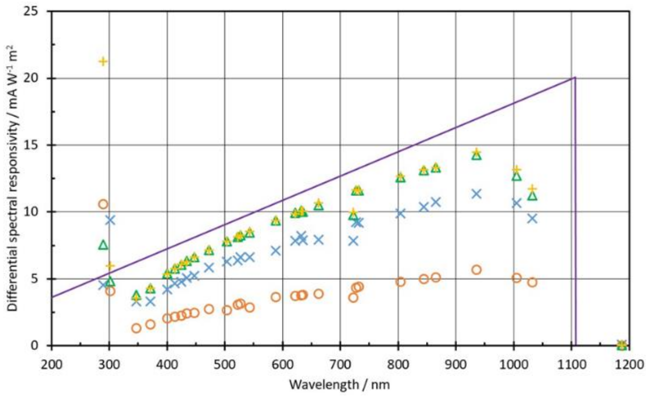

Figure 3. Differential spectral responsivity for a 15 x 15 cm^2 bifacial solar cell at different bias light conditions. Green triangles indicate results with no bias, yellow plusses with 500 W/m^2 on the front surface, blue crosses with 1000 W/m^2 on the front surface, and red circles with 1000 W/m^2 on the front and 300 W/m^2 on the back. The solid purple line represents the ideal responsivity assuming 100% quantum efficiency. [2]

Despite the large area and bifaciality, the open circuit voltage of the bifacial solar cell is only 0.565 V. Yet the current produced exceeds 7 A with the front surface exposed to 1000 W/m^2 and even higher with the back-side exposed. According to [1], the voltage over the cell should remain below 3% of the open circuit voltage, thus, the maximum impedance for the measurement electronics is 2.4 mΩ.

For currents smaller than 3 A, we have a Keithley source meter forcing the voltage across the cell to zero as seen in Fig. 1. For currents above 3 A, we have tested a zero-flux sensor DS200ID-CD1000 from Danisense, and a newly acquired source meter from Hehkulab providing zero voltage up to 10 A.

Figure 3 shows measurement results obtained with the zero-flux current sensor. With zero-flux, the solar cell is short circuited with a cable going through the sensor, and the sensor gives out a current without loading the cell.

The measurements without bias lights and with 500 W/m^2 applied on the front surface are in good agreement indicating linearity. The current level at the latter condition is 3.5 A. With the higher irradiance levels producing currents of 7.1 A and 8.4 A, the responsivity drops due to nonlinearity. One cause of this nonlinearity is the resistance of the wire used to short circuit the cell, 15 mΩ. The results indicate that active control of the cell voltage is needed to reach these high irradiance levels. Another possible reason is heating of the cell due to bias light.

The uncertainty of the measurements is shown in Fig. 4. The expanded uncertainty of the obtained differential spectral responsivities over the visible region 400 – 730 nm is on the average 1.7% (k = 2). In the UV and IR regions the uncertainties are significantly higher. The main components are the standard uncertainties of the alignment and distance (0.25 – 0.5%), gain of the lock-in amplifier (0.5 %), short term stability of the LED sources (0.02 – 0.9%), absolute spectral irradiance (0.11 – 15%), relative spectral irradiance (0.5 – 8%), data analysis (0.1%), resolution of the current measurement (0.02 – 30%), and the spatial uniformity measurement (0.03 – 0.9%).

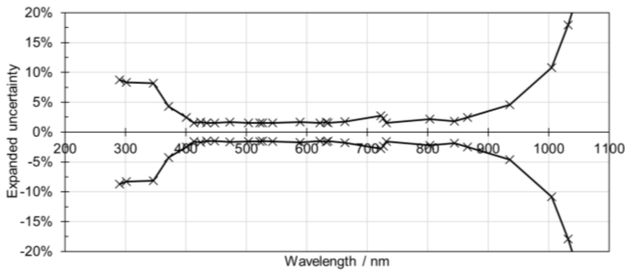

Figure 4. Expanded uncertainties (k = 2) of the obtained differential spectral responsivity values.

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