SPECTRAL RESPONSE MEASUREMENT FOR LARGE AREA SOLAR CELLS BASED ON FILTER METHOD

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Abstract−An apparatus for determining the spectral response of large area solar cells based on filter method has been introduced. Both of filter method and monochromator method have been used to measure the spectral response of different kinds of solar cells. The measurement result of monochromator method only represents the spectral characteristics of a certain part, while the measurement result of filter method is more suitable to describe the spectral response of the whole cell.

Keywords: solar cell, spectral response, filter method,monochromator method

1. INTRODUCTION

Spectral response has been widely used to characterize the photovoltaic performance of a solar cell [1]. The spectral response is the ratio of the current generated by the solar cell to the power incident on the solar cell, in units of A/W [2-4].

A conventional approach to measuring the spectral response is the monochromator method, which has the merit of a high wavelength resolution [5-6]. However, when the physical dimensions of the active area of the solar cell are larger than that of the monochromatic beam or the cell response is spatially nonuniform, the spectral response obtained by monochromator method may not be the representative of the entire cell [7-8].

In this paper, we propose a setup for determining the spectral response of large area solar cells based on filter method. We have compared the measurement result using our apparatus with that obtained by monochromator method. The significant differences between them for various kinds of solar cells highlight the advantages of our system.

2. METHODS

The spectral response of a solar cell is measured by irradiating it by means of 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 [9-10]. In this case, the spectral response of the test specimen S_t is computed as follows

$$S_t = \frac{J_t}{J_r} S_r \qquad (1)$$

Where J_t is the measured short-circuit current density of the test specimen; J_r is the measured short-circuit current density of the reference cell; S_r is the spectral response of the reference cell.

A schematic diagram of the apparatus for determining the spectral response of solar cells is shown in Fig. 1.
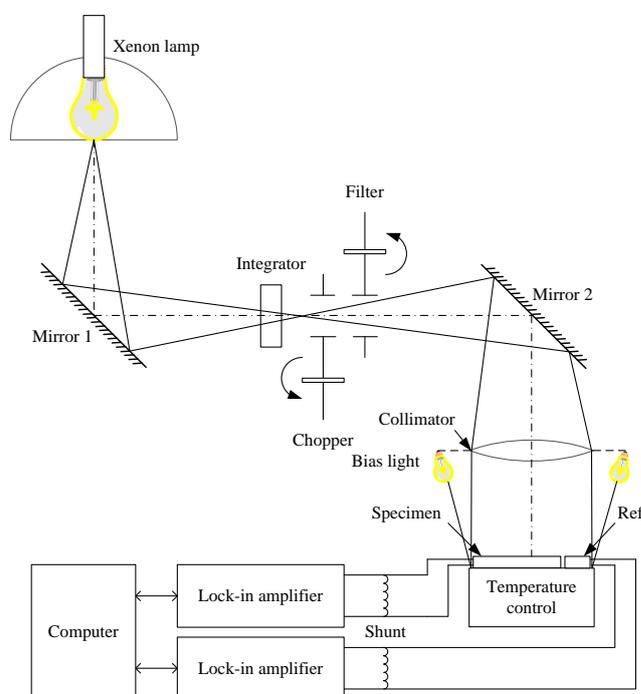

Fig. 1. The apparatus for determining the spectral response of solar cells

The light source is a 1000-W xenon lamp which has been installed at the focus point of the reflector cup to produce incident radiation. Light emitted directly from the lamp and collected by the reflector cup is focused by the mirror 1. Then, the white light beam, whose spatial uniformity has been corrected by an optical integrator, passes through an chopper and a filter to produce a quasi-monochromatic beam. A series of filters are mounted on a wheel whose center wavelengths cover a range from 337 to 1064 nm with an interval of 50 nm. The full width at half maximum (FWHM) is nearly 10 nm. The chopped monochromatic beam is then reflected by the mirror 2 and finally collimated by a lens directing toward the test specimen and reference cell. The

size of monochromatic beam can reach up to 180 mm × 180 mm. A 500-W solar simulator is utilized to provide the bias light. The temperature of the solar cells is controlled precisely during the measurement. The AC signal across the shunt generated by the test specimen and reference cell is measured by a lock-in amplifier respectively.

3. EXPERIMENTS

3.1 (156 mm × 156 mm) monocrystalline silicon solar cell

To evaluate the performance of the apparatus, we choose thirteen filters, whose center wavelengths cover a range from 337 to 1064 nm, to produce the monochromatic light. The spectral response of a 156 mm × 156 mm monocrystalline silicon solar cell is measured. The measurement result is listed in table 1.

Table 1. The measurement result of a 156 mm × 156 mm monocrystalline silicon solar cell

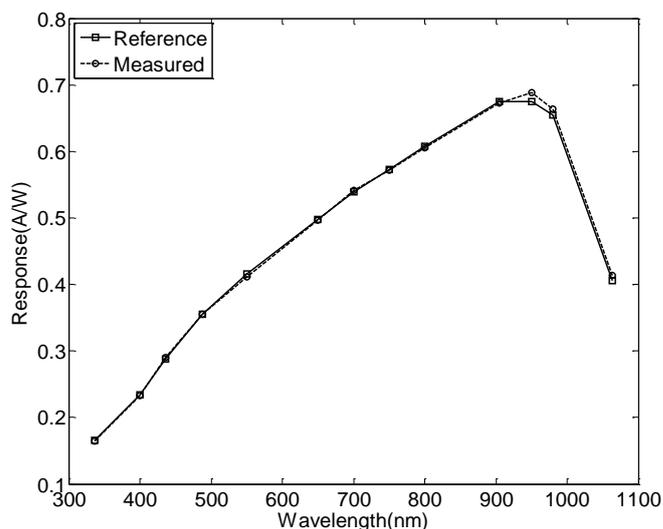| Wavelength (nm)	Measured (A/W)	Reference (A/W)	Relative error (%)
337	0.1646	0.1652	-0.38
400	0.2335	0.2346	-0.48
436	0.2904	0.2881	0.80
488	0.3554	0.3549	0.14
550	0.4114	0.4158	-1.05
650	0.4968	0.4981	-0.26
700	0.5412	0.5393	0.36
750	0.5715	0.5723	-0.14
800	0.6054	0.6073	-0.31
905	0.6723	0.6748	-0.36
950	0.6879	0.6749	1.93
980	0.6633	0.6543	1.37
1064	0.4138	0.4062	1.88

Fig. 2. The measurement result of a 156 mm × 156 mm monocrystalline silicon solar cell

Fig. 2 shows the spectral response measurement result of a 156 mm × 156 mm monocrystalline silicon solar cell. The estimate conforms closely to the reference value which can be traceable to the Fraunhofer institute for solar energy systems (ISE). To distinguish the fine differences, we compute the errors between the measured and the reference, which are plotted in Fig. 3. All of the errors lie between ±2%. Especially, errors of visible spectrum can be less than ±1%.
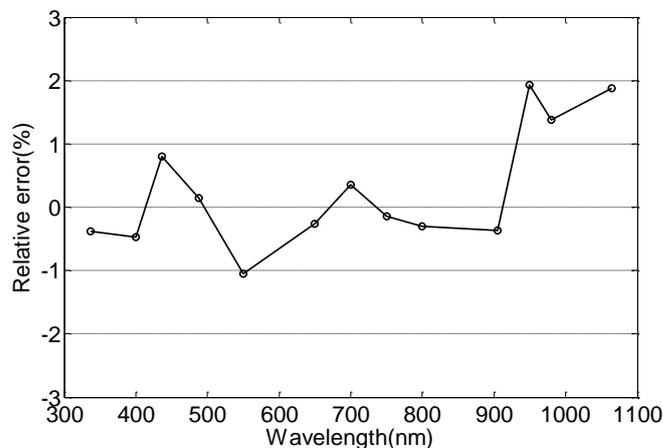

Fig. 3. Errors between the measured and the reference value

3.2 Filter method VS monochromator method

The monochromator method uses a monochromator to produce the chopped spectral irradiance within the wavelength range covering the spectral responsivity of the solar cell to be measured. In our experiments, the scan is performed from 250 to 1200 nm with an interval of 10 nm. The dimensions of the monochromatic beam are smaller than that of the area between two fingers.

To compare filter method with monochromator method, we select three parts (up-right, middle and down-left) of a 156 mm × 156 mm monocrystalline silicon solar cell to measure the spectral response using monochromator method as shown in Fig. 4.
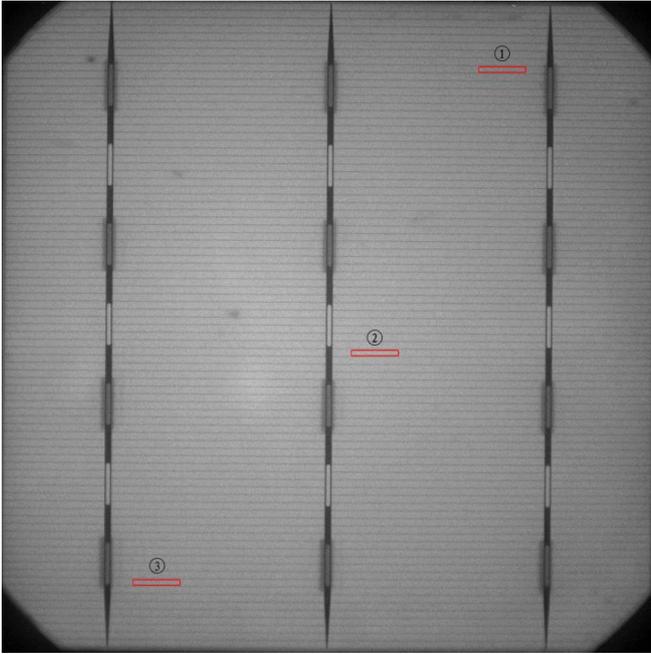
Fig. 4. Three parts of a 156 mm × 156 mm monocrystalline silicon solar cell to measure the spectral response using monochromator method

Fig. 5 shows the spectral response measurement results of a 156 mm×156 mm monocrystalline silicon solar cell based on filter method and monochromator method respectively. The estimate based on filter method is quite different from the others. The material of fingers is not a semiconductor, indicating that they do not contribute to the generation of current. However, the calculation of spectral response involves the area of the solar cell including the fingers, which results in a decrease of measurement value based on filter method.
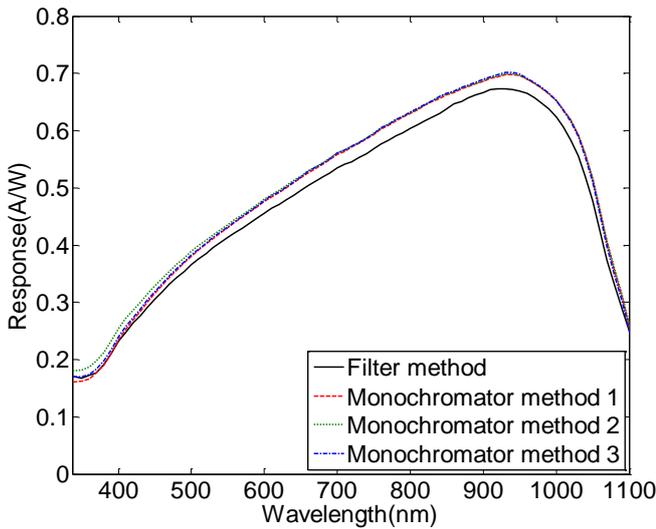

Fig. 5. Measurement results of a 156 mm × 156 mm monocrystalline silicon solar cell based on filter method and monochromator method

Fig. 6 shows the differences between filter method and monochromator method. The maximum error occurs at the wavelength around 1050 nm. It can be noted that the measurement results of different three parts based on monochromator method still have some small differences between each other even if they are made of the same materials.
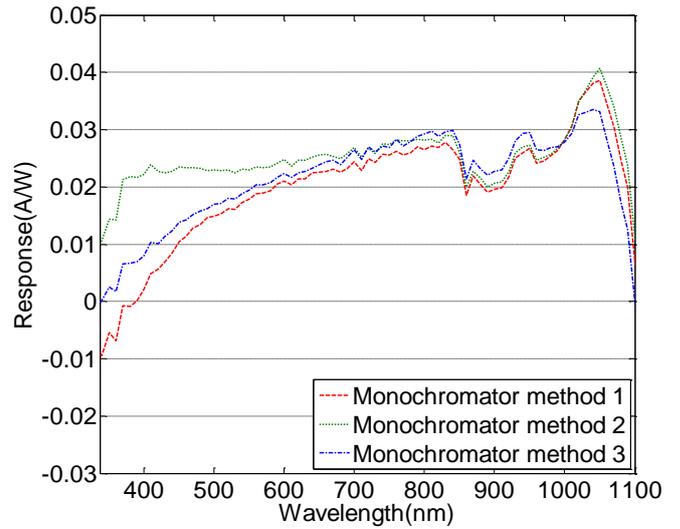

Fig. 6. Differences between filter method and monochromator method

Similarly, we compare filter method with monochromator method by a 156 mm × 156 mm polycrystalline silicon solar cell. Three parts (location 1, 2 and 3) selected to measure the spectral response using monochromator method are shown in Fig. 7. Different parts have different crystal boundary and orientation.
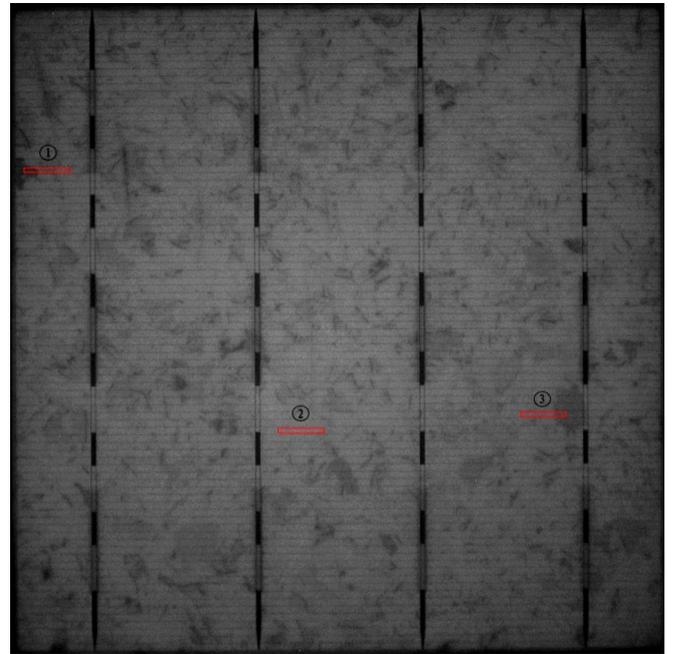

Fig. 7. Three parts of a 156 mm × 156 mm polycrystalline silicon solar cell to measure the spectral response using monochromator method

Fig. 8 shows the spectral response measurement results of a 156 mm × 156 mm polycrystalline silicon solar cell based on filter method and monochromator method respectively. Similar to the monocrystalline silicon solar cell, the estimate based on filter method is quite different from the others because of the cell fingers.
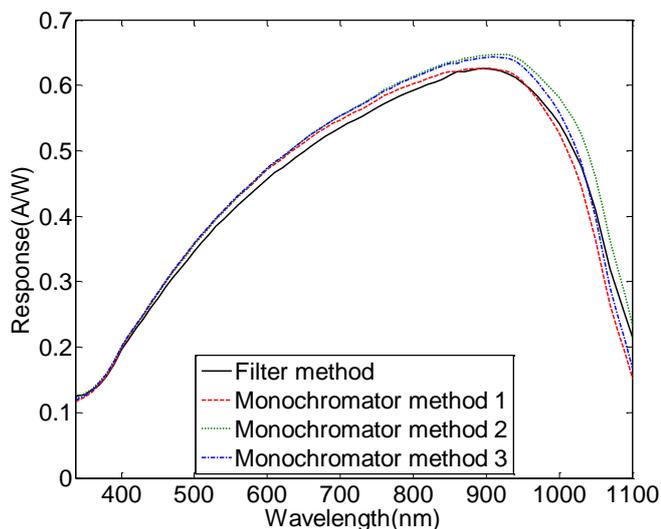
Fig. 8. Measurement results of a 156 mm × 156 mm polycrystalline silicon solar cell based on filter method and monochromator method

Fig. 9 shows the differences between filter method and monochromator method. The maximum error occurs at the wavelength around 1000 to 1100 nm. The significant differences among the three parts demonstrate that the crystal boundary and orientation plays an important role in the spectral response measurement using monochromator method.
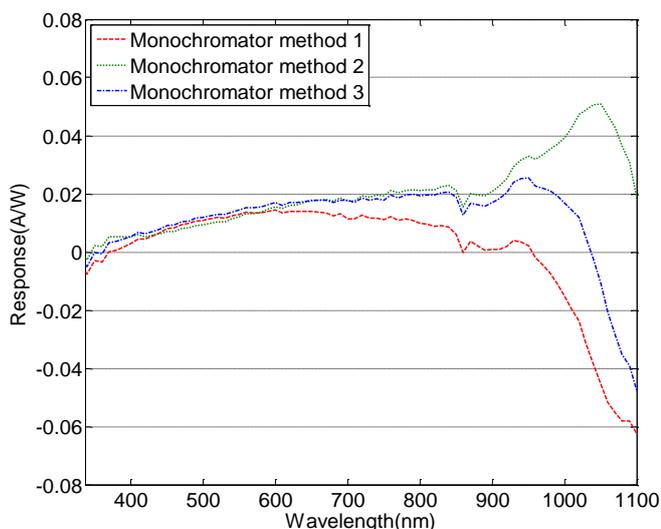

Fig. 9. Differences between filter method and monochromator method

According to the abovementioned discussions, the measurement result based on filter method always shows significant differences compared with that obtained by monochromator method. First, the differences may be attributed to the imperfection and the fingers of solar cells. On the other hand, especially for the polycrystalline silicon solar cell, crystal boundary and orientation affect the measurement result severely. Therefore, the measurement result of monochromator method only represents the spectral characteristics of a certain part, while the measurement result of filter method is more suitable to describe the spectral response of the whole cell.

4. DISCUSSIONS

There are several factors which can affect the spectral response measurements such as the full width at half maximum (FWHM) of filters, the stability and non-uniformity of monochromatic light.

The short-circuit current is the integration of the products of the spectral response of a solar cell multiplied by the spectral irradiance of the incident radiation [8]. The spectral irradiance of the monochromatic light is the products of the spectrum of the light source multiplied by the transmission of filters [11]. The transmission of filters can be characterized by the FWHM. Filters with different FWHM may lead to different spectral response measurement results.

Apparently, the monochromatic light produced by filters with less FWHM more approximates the ideal light of a single wavelength. As the FWHM of filters decreases, the spectral response measurement results approach the actual values. Otherwise, the measured spectral response is the weighted sum of the true value. Therefore, less FWHM of filters will result in a more accurate measurement theoretically.

The effects resulting from inhomogeneity of spectral response under non-uniform monochromatic irradiation are determined by measuring the spatial distribution of the irradiation and the spatially resolved spectral response [6]. Monochromatic light with different non-uniformity will lead to different spectral response measurement results.

Compared with the FWHM of filters, the influence of the non-uniform monochromatic irradiation is much more complicated. It is due to the different weighting of the local spectral response of the cell with the local irradiation. However, a more stability and uniformity of the monochromatic light is always preferred, which can reduce the measurement error.

The bias light source (spectral distribution, irradiance non-uniformity on the test plane and temporal instability of irradiance) and the temperature control of the cell also play important parts in the spectral response measurement, which must be considered carefully in the future uncertainty assessment.

5. CONCLUTIONS

We propose a setup for determining the spectral response of large area solar cells based on filter method. The measurement result conforms closely to the reference value. We have compared the measurement result using our apparatus with that obtained by monochromator method. The experiments demonstrate that the measurement result of monochromator method only represents the spectral characteristics of a certain part, while the measurement result of filter method is more suitable to describe the spectral response of the whole cell. The significant differences between them for various kinds of solar cells highlight the advantages of our system.

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