A fundamental experiment for discrete-wavelength LED solar simulator

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ABSTRACT

This paper is intended to report the possibility of an LED (Light-Emitting Diode) as a light source of a solar simulator for measuring solar cells. In our laboratory the LED solar simulator have made up as the test production, and characteristics of monocrystalline *Si* solar cell have been measured by using it. As a result, spectral response (SR) and I-V characteristics of solar cells can be measured by proposed method even though light intensity of the LED is in the range approximately up to 10 [mW/cm^2]. Moreover, I-V characteristics under standard test conditions (STC) can be estimated by compensation.

Keywords: Light-Emitting Diode (LED), Spectral Response, Measuring Method

1. Introduction

For further market deployment of photovoltaic systems (PV systems), solar cells and modules must maintain sufficient reliability; therefore, technologies of measuring solar cell performances are very important. At present, the solar cell measurement performance have been improved, but its cost has been still expensive since Xenon and Halogen lamp, of which the solar simulator is consisted, are short life and requires a lot of electric power. Meanwhile, it is widely recognized that LED is energy-saving, budget and small light-source, and recent technical innovation allows us to be easy to buy the high luminance LED. In a few studies, the solar simulator using LED as light sources has been proposed. Those simulators are used white light LED instead of previous lamps. However, their characteristics are not corresponding with characteristics of natural sunlight because the spectrum of LED is narrower and weaker than the spectrum of natural sunlight. Therefore, it seems to be required the suitable method in order to use the LED solar simulator.

This paper is intended to propose that the LED solar simulator is available to obtain the performance of solar cell, I-V and SR characteristics, by the methodological measurement. As for SR characteristic, discrete spectral response can be measured in such a way that white and plural monochromatic light illuminate the solar cell each other due to fact that monochromatic light LED except white light has bright line spectrum. SR curve can be estimated by using discrete spectral response and least-squares method with physical model, and photocurrent under STC is obtained from SR curve. Moreover, the LED solar simulator is able to measure I-V characteristics of STC by assuming that I-V characteristic of Si solar cells are independent of light intensity.

2. Theory and Experimental

2.1 Measuring method using LED

Figure 1 shows the measurement procedure of SR using LED. A test cell is irradiated by monochromatic light together with white light as bias light, and its short circuit current (I_{sc}) is measured. Secondly, the cell is only exposed to white light and I_{sc} is measured in the same way. The difference of I_{sc} in two conditions divided by incidence monochromatic irradiance is SR at the wavelength of the illuminating light. Spectral responses at discrete wavelength are derived by three monochromatic LED (this time, Blue, Red and Infrared). Experimental discrete spectral responses are supplemented by a theoretical curve of photocurrent, and then the whole SR curve of the test cell is calculated [1]. The SR curve multiplied by the reference solar spectral distribution calculates photocurrent under STC. I-V characteristics are measured under two different irradiation and calculated those under STC by correction.

2.2 Specification of LED solar simulator

LED solar simulator for a 100*100 [mm^2] solar cell is manufactured for trial (Fig. 2). This equipment has LED in 4 colors (Blue, Red, Infrared and White), and the specification is shown in

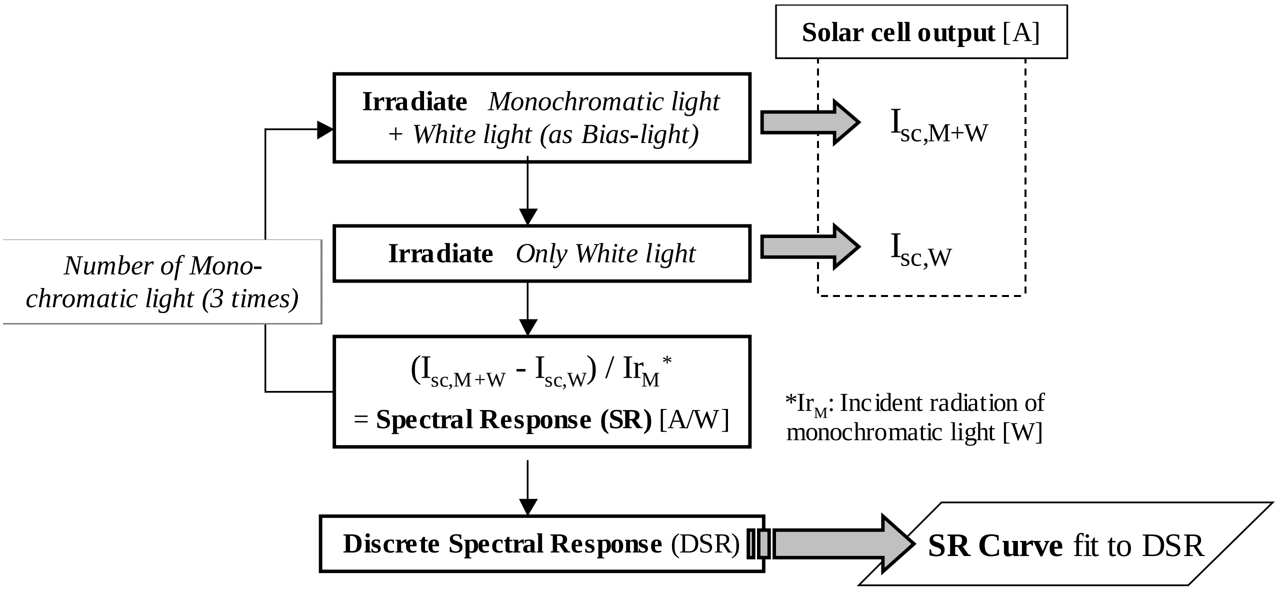

Fig. 1. Measurement procedure of spectral response using monochromatic light

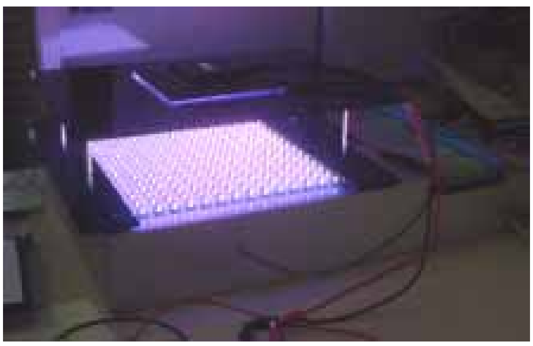

Fig. 2. Discrete-wavelength LED solar simulator

table 1. Their angle of beam spread is middle (about 30 [deg]), and lamp-type LED is used. Each LED is arranged equally (7.62 [mm] between each LED, and 15.24 [mm] between same color). Fig. 3 shows schematic illustration of the LED arrangement. 14*14 LED per color are laid out on a grid, and total number of LED is 784. The total area of light-source is about 205*205 [mm^2]. The distance of irradiation is adjusted with spacers. This time, light source irradiated a measuring object from a height of 84 [mm], and had illumination unevenness per color of about 5%. The arrangement has lower illumination unevenness calculated by illuminant simulation [2].

The simulator is electrically designed as follows. LED controlled at each color can be passed a voluntary current and voluntary light intensity is available. Typical forward current (I_F) of LED is 20 [mA] (in the case of infrared, I_F = 50 [mA]) in this SR measurement.

Table 1 Specifications of LED

Color	Peak wave-length [nm]	Spectral half bandwidth [nm]	Typical light intensity [cd]	Angle of beam spread [deg]	Typical forward current: IF [mA]	Typical forward voltage: VF [V]
Blue	470	25	1500	30	20	3.6
Red	644	18	800	30	20	1.9
Infrared	950	50	180 [mW/sr]	35	50	1.3
White	470 (570)	-	3100	35	20	3.6

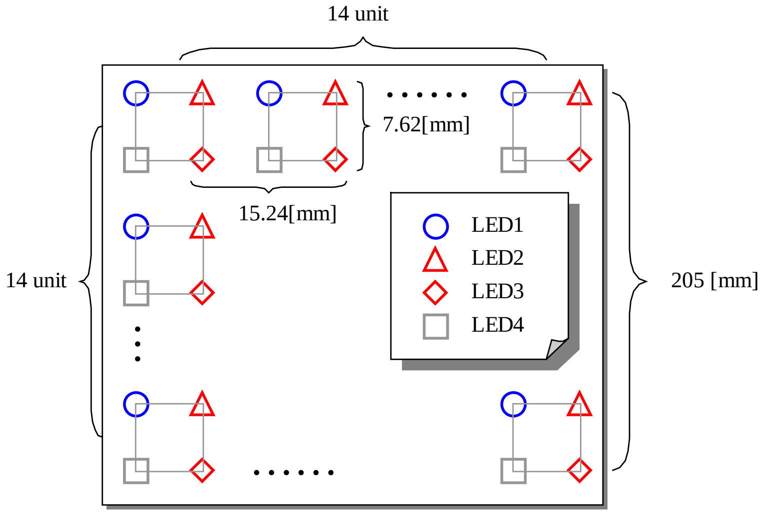

Fig. 3. Schematic illustration of LED arrangement

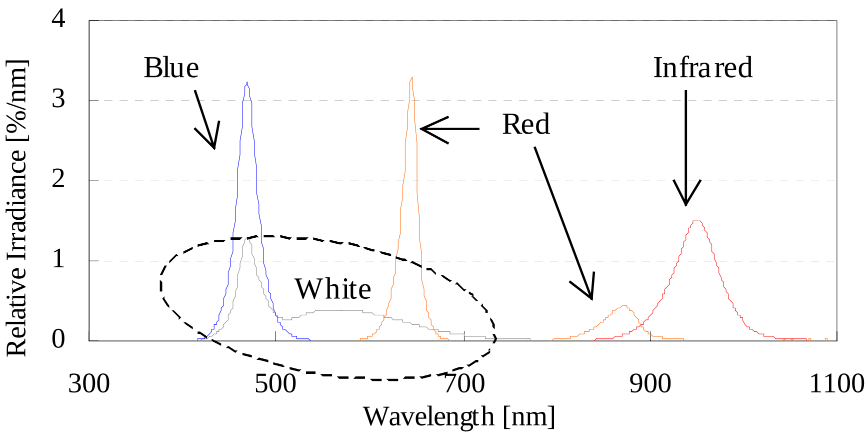

Fig. 4. Wavelength characteristics of LED built in solar simulator

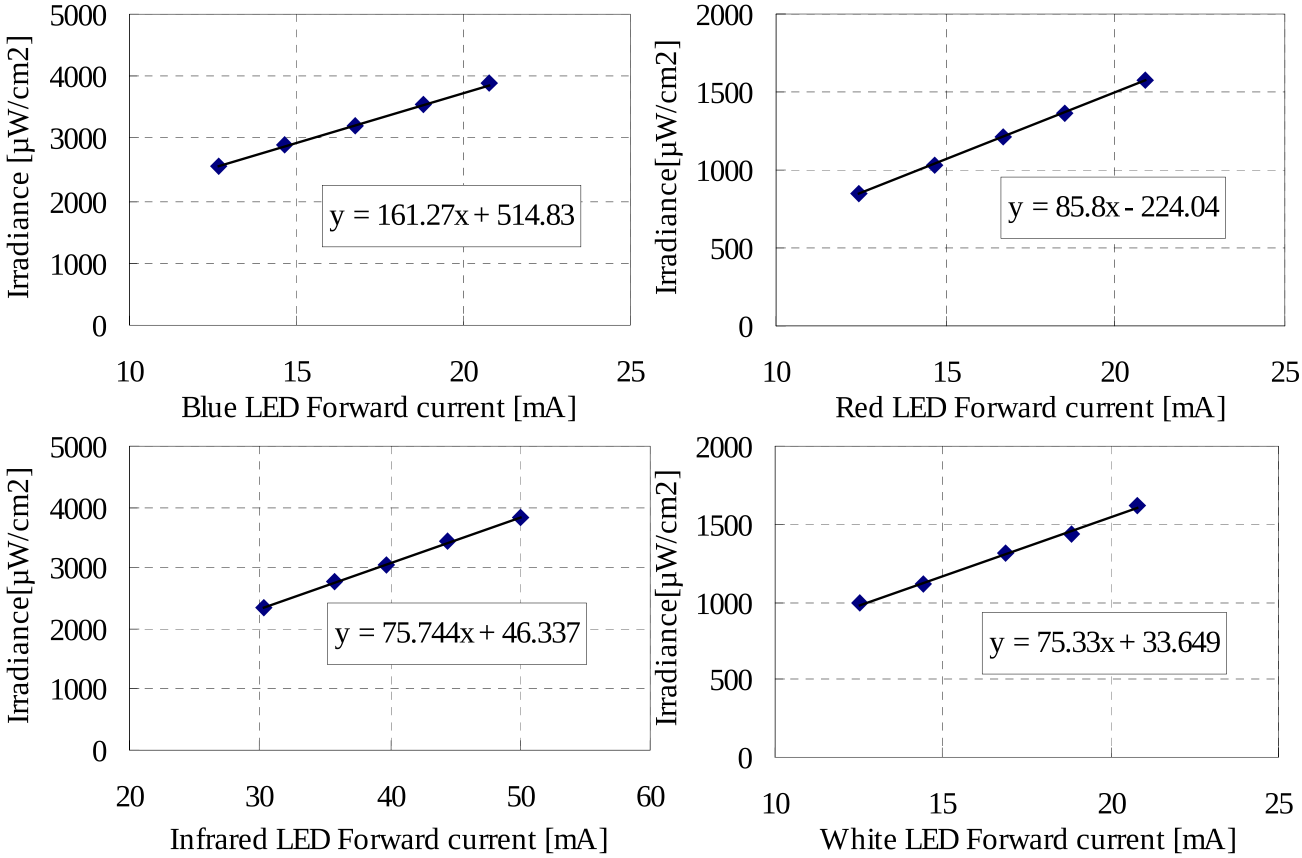

Fig. 5. Relations between each LED forward current (I_F) and irradiance

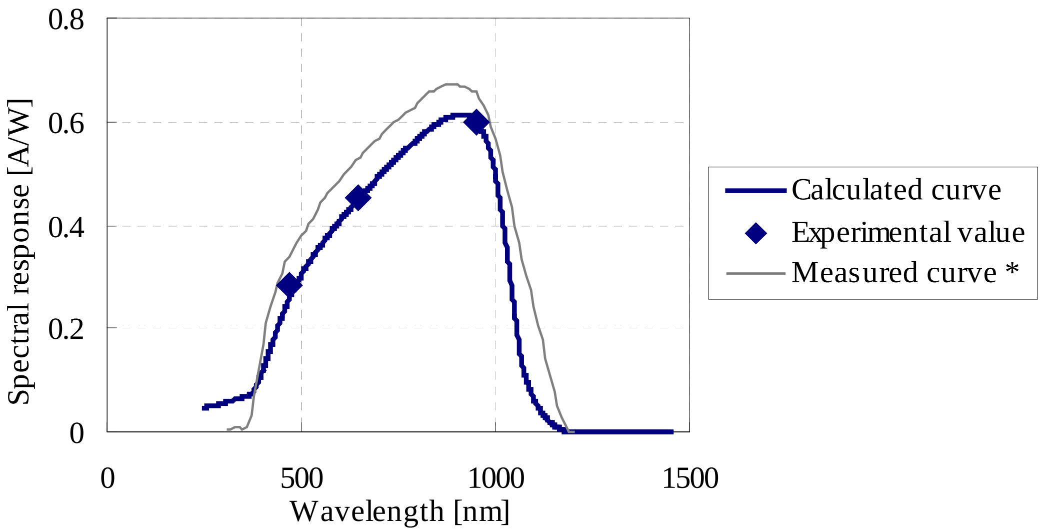

Fig. 6. Comparison of calculated and measured SR curve (* measured by AIST)

3. Results and Discussion

3.1 Measurement of spectral response

The relation between the I_F and the irradiance of LED light was examined with a spectroradiometer for grasping the irradiance in measuring (fig. 5). After this, the irradiance of LED light is derived from each I_F (It needs to be careful about the irradiance time change of LED.). Discrete SR measured by 3 LED were compensated with the photocurrent theoretical curve by least-squares method and the calculated and measured curve is compared (fig. 6). Consequently, the measured and calculated photocurrent under STC were respectively 3.76 [A] and 3.14 [A], and the estimation is lower than the measurement one. The current is derived SR multiplied by AM1.5G standard spectrum.

3.2 Measurement of I-V characteristics

Shown in Figure 7 are the experimental I-V characteristics illuminated with white LED light, the calculated and the measured I-V curves under AM1.5G spectrum. I-V characteristic under STC can be calculated from

$$V_2 = V_1 (= V_3)$$

$$I_2 = I_1 + (E_2 - E_1) \cdot \frac{I_3 - I_1}{E_3 - E_1}$$

Where E_1, V_1, I_1 and E_3, V_3, I_3 are the irradiance, voltage, and current of the experimentally known $I_{out}(V)$, respectively. E_2, V_2 and I_2 are those of the unknown $I_{out}(V)$ [3]. The calculated and measured value is compared in table 2, the former has smaller curve than the latter. The difference is caused by the errors including each irradiance under experiment, because the compensation widens these errors over 10 times. Therefore, the accurate measurement of LED irradiance before the cell characterization is important. Any way, I-V characteristics can be estimated roughly by correction.

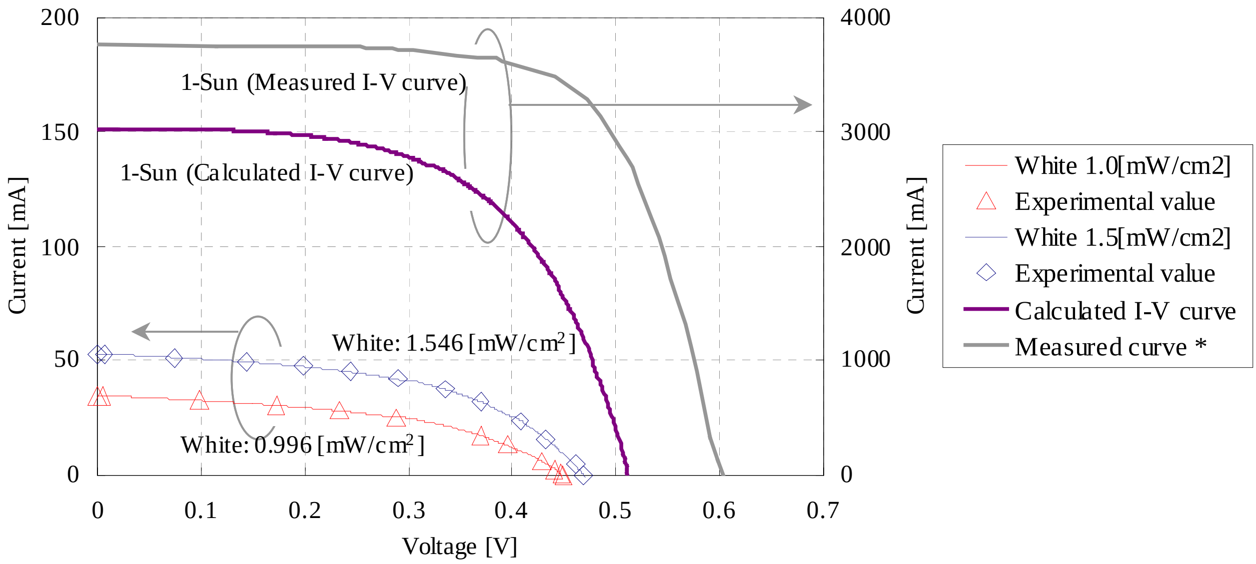

Fig. 7. Comparison of the results of calculated and measured I-V curve under 1-Sun (* measured by AIST)

Table 2 Measured and calculated value

	Calculated Value	Measured Value
Voc [V]	0.51	0.60
Isc [A]	3.02	3.76
Vmax [V]	0.37	0.46
Imax [A]	2.47	3.37
F.F. [%]	58.59	68.50

4. Conclusion

In the present work, the LED solar simulator used 4 colors LED (include 3 monochromatic) as light source was made and the measuring method of solar cells has been demonstrated by it. Assuming that SR and I-V characteristics of mono-crystalline Si solar cell do not depend on light intensity and wavelength, a test cell is measured. As a result, the estimated value is lower than the nominal one and to examine the dependence will be necessitated in the future. Nevertheless, it is notable that the low intensity light like LED can estimate the I-V characteristics under AM1.5G spectrum.

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