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A fundamental experiment for discrete-wavelength LED solar simulator

Shogo Kohraku*, Kosuke Kurokawa

Tokyo University of Agriculture and Technology (TUAT), Naka-cho 2-24-16, Koganei, Tokyo 184-8588, Japan

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Abstract

This paper intends to report the possibility of using an light-emitting diode (LED) as a light source of a solar simulator for measuring solar cells. In our laboratory the LED solar simulator has been 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 the proposed method even though light intensity of the LED is in the range of approximately up to $10\,\mathrm{mW/cm^2}$. 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 for measuring solar cell performances are very important. At present, the solar cell measurement performance has been improved, but it is still expensive since Xenon and Halogen lamp, which consist of the solar simulator have short life and require a lot of electric power. Meanwhile, it is widely recognized that light-emitting diode (LED) is energy saving, within budget, and needs a small light source, and recent technical innovation allows us to easily buy the high luminance LED. In a few studies, the solar simulator using LED as light source has been

*Corresponding author. Tel./fax: +81 42 388 7445.
E-mail address: kohraku@cc.tuat.ac.jp (S. Kohraku).

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proposed. These simulators use white light LED instead of the 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, a suitable method is required in order to use the LED solar simulator.

This paper intends to propose that the LED solar simulator makes it possible to obtain the performance of solar cell, I–V and spectal response (SR) characteristics, by the methodological measurement. Discrete SR can be measured in such a way that white and plural monochromatic light and the solar cell illuminate each other due to the fact that monochromatic light LED except white light has bright line spectrum. SR curve can be estimated by using discrete SR and least-squares method with physical model, and photocurrent under standard text conditions (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 characteristics of Si solar cells are independent of light intensity.

2. Theory and experimental

2.1. Measuring method using LED

Fig. 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 the two conditions divided by incidence monochromatic irradiance is SR at the wavelength of the illuminating light. SR at discrete wavelength are derived by three monochromatic LED (this time, blue, red and infrared). Experimental discrete are supplemented by a theoretical curve of photocurrent, and then the whole SRs 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 irradiations and calculated under STC by correction.

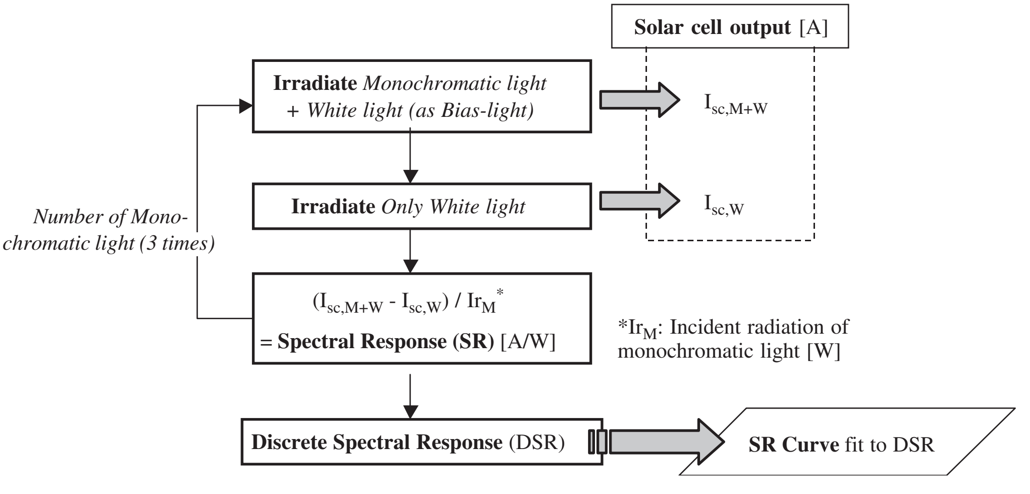

Fig. 1. Measurement procedure of spectral response using monochromatic light.

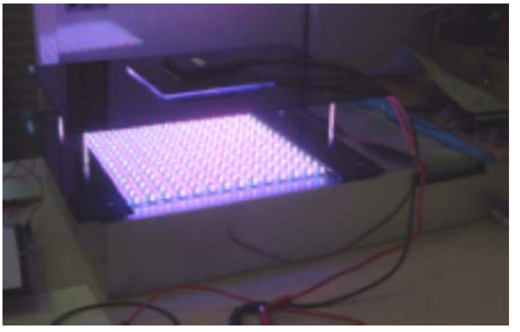

Fig. 2. Discrete-wavelength LED solar simulator.

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: I_F (mA)	Typical forward voltage: V_F (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

2.2. Specification of LED solar simulator

LED solar simulator for a $100 \times 100\,mm^2$ solar cell is manufactured for trial (Fig. 2). This equipment has LED in four colors (blue, red, infrared and white), and the specification is shown in Table 1. Their angle of beam spread is around the middle (about 30°), 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 the total number of LED is 784. The total area of light source is about $205 \times 205\,mm^2$. 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] (Fig. 4).

The simulator is electrically designed as follows. A voluntary current can be passed through the LED controlled at each color 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.

3. Results and discussion

3.1. Measurement of SR

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

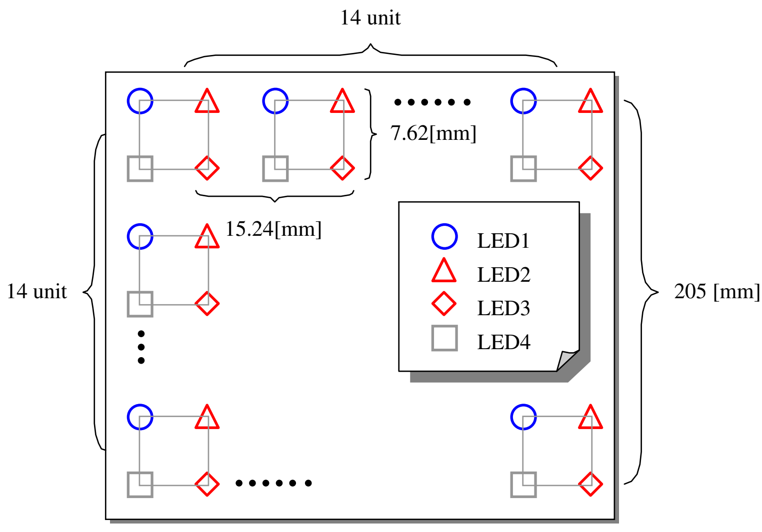

Fig. 3. Schematic illustration of LED arrangement.

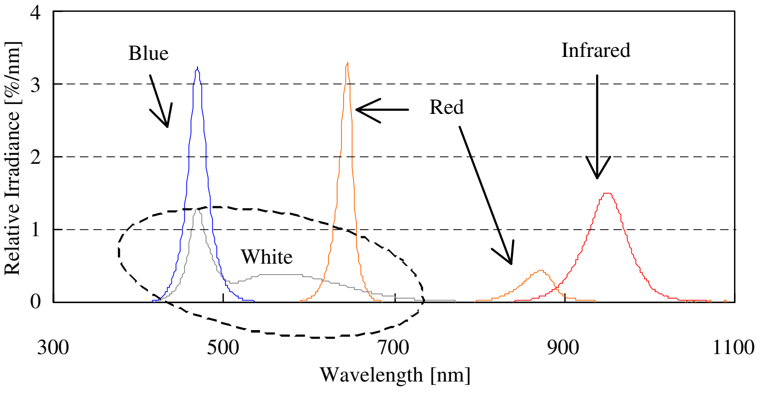

Fig. 4. Wavelength characteristics of LED built-in solar simulator.

irradiance of LED light is derived from each I_F (one needs to be careful about the irradiance time change of LED). Discrete SR measured by three LED was 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 photocurrents under STC were, respectively, 3.76 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 Fig. 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*

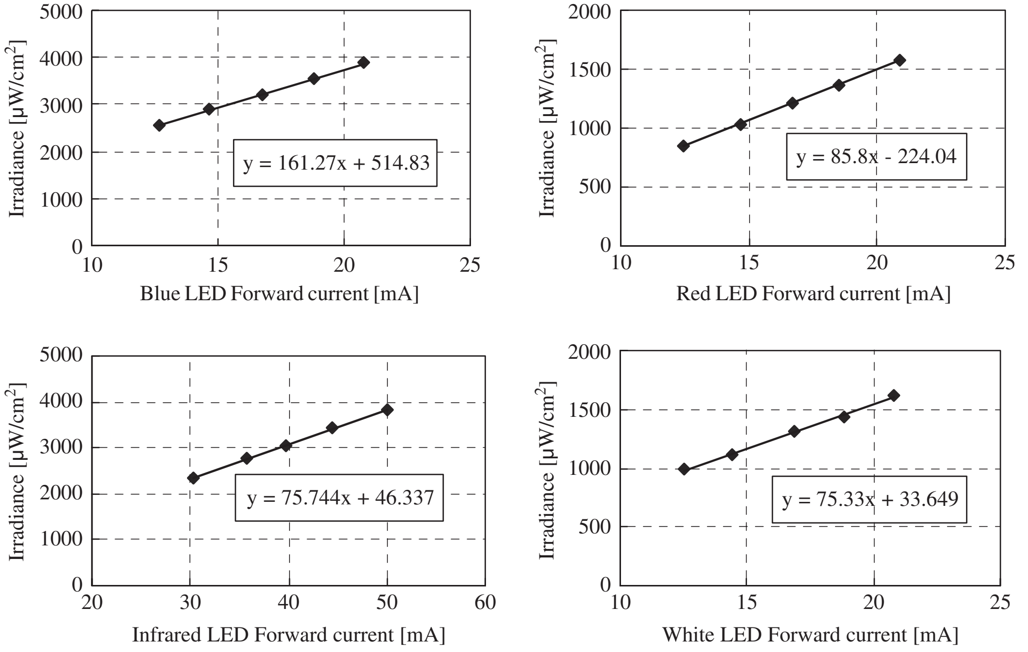

Fig. 5. Relations between each LED forward current (I_F) and irradiance.

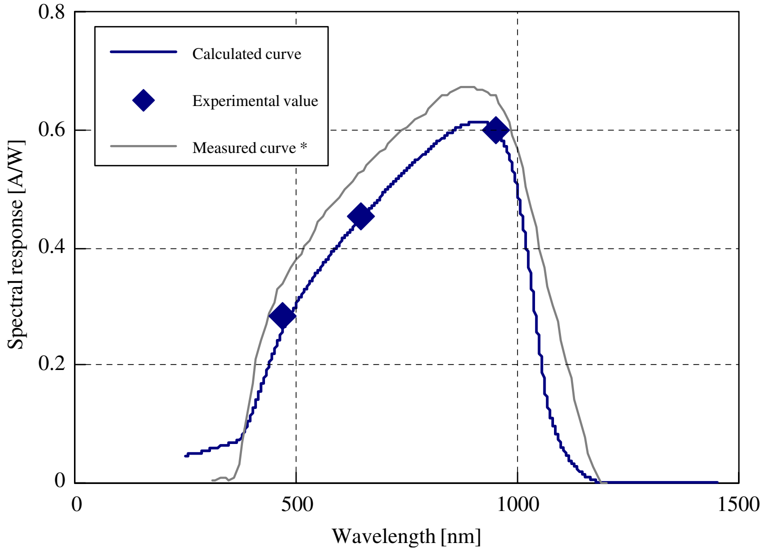

Fig. 6. Comparison of calculated and measured SR curve (* measured by AIST).

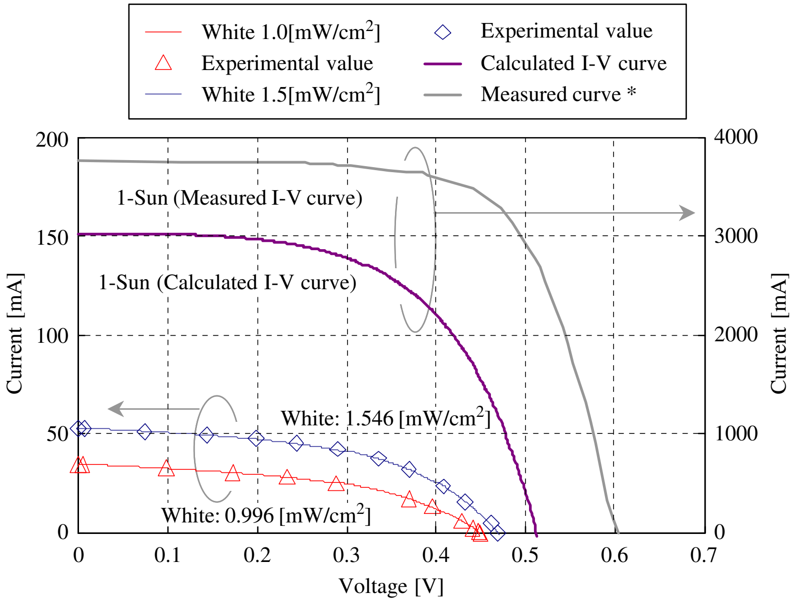

Fig. 7. Comparison of the results of calculated and measured I–V curve under 1-Sun (* measured by AIST).

Table 2
Measured and calculated value

	Calculated value	Measured value
V_{oc} (V)	0.51	0.60
I_{sc} (A)	3.02	3.76
V_{max} (V)	0.37	0.46
I_{max} (A)	2.47	3.37
F.F. (%)	58.59	68.50

characteristic under STC can be calculated from

$$V_2 = V_1 (= V_3),$$

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

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 by 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.

4. Conclusion

In the present work, the four color LED (including three monochromatic) solar simulator is used for as light source 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 examining the dependence will be required in the future. Nevertheless, it is notable that the low intensity light like LED can estimate the I–V characteristics under AM1.5G spectrum.

Acknowledgements

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