A FUNDAMENTAL EXPERIMENT OF SOLAR CELL'S I-V CHARACTERISTICS MEASURMENT USING LED SOLAR SIMULATOR

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A solar simulator using LED (light-emitting diode) lamps can measure low-cost to current-voltage (I-V) characteristics compared with using Xenon lamp. Until now, we calculated the crystalline silicon's (c-Si) I-V characteristics under the standard test condition (STC) using two I-V characteristics measured under the different irradiance using white LED. However, calculated current is too small compared with using Xenon lamp. In this paper, we added new methods for calculating I-V characteristics of c-Si using dark current and absolute spectral responses. As the results, accuracy of the calculated I-V characteristic was improved compare with the previous method.

Keywords: LED, solar simulator, I-V measurement

INTRODUCTION

Current-voltage (I-V) characteristics under the standard test condition (STC) are important data to evaluate c-Si cell's performance. Normally, I-V characteristics are measured by 1-Sun solar simulator using Xenon lamp. However the cost of measurement is expensive because the facility is so large and electric power consumption is also large. Additionally, it has spectral mismatch because Xenon has characteristic spectrum in infrared band. Therefore, we have been proposed a solar simulator using LED (light-emitting diode) lamps which take advantage of its lifetime, electric power consumption and cost. Characteristics of LED ,for example spectrum and irradiance, are different from reference solar spectrum, so we also have been proposed calculation method that can calculate the c-Si's I-V characteristics under the STC by interpolation method using bilinear I-V characteristics measured with White LED or monochromatic LED irradiance source [2]. The method of I-V characteristic measurements using LED solar simulator is able to measure without spectral mismatch because it uses reference solar spectrum and monochromatic lights to calculate absolute spectral response [1]. However, irradiance of the White LED is very weak, so it was extrapolated to calculate 1-Sun I-V characteristic using bilinear I-V characteristics (approximately 1.5 and 1.0[mW/cm²]). In other words, the difference of irradiance is so small (approximately 1/70 of the 1-Sun) that an error of measurement is too much expanded. It is also difficult to stabilize LED's irradiance and temperature during measurement of two I-V characteristics. Therefore, calculated 1-Sun I-V characteristic is smaller than nominal I-V characteristics. In this paper, we improve the accuracy of calculated I-V characteristic including spectral response using LED solar simulator by using I-V characteristics which measured with all LED and dark current. The irradiance of all LED is approximately 1/9 of the 1-Sun.

EXPERIMENTS

Spectral responses at discrete wavelength are derived by three monochromatic LED. Experimental discrete spectral responses are supplemented by a theoretical characteristic of photocurrent, and the whole spectral responses characteristic of the test cell is calculated. Total output power under the STC (calculated short circuit current (I_{sc})) is obtained in integrating spectral responses and reference solar spectral irradiance distribution. Flow chart to calculate I_{sc} is shown by figure 1.

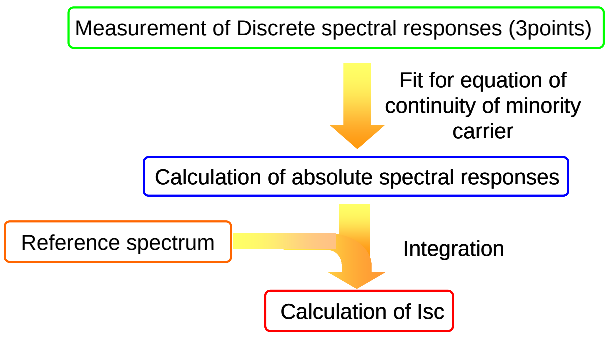

Fig.1. Flow chart to calculate I_{sc}.

I-V characteristic on STC (nominal I-V characteristic) is obtained from two I-V characteristics, which measured by LED solar simulator and dark current. Dark current and one I-V characteristic measured by 1/9 of the 1-Sun are used. To stabilize LED's irradiance and temperature is easier than using two measured I-V characteristics, which measured with different irradiance.

Experimental Details

The detail of experiment for measuring I-V characteristics of c-Si cell using LED solar simulator is shown in figure 2. C-Si cell that used experiment is packaged one. The cell size is 10×10 [cm^2]. Irradiance is measured with an optical power meter, c-Si cell's back-surface temperature is measured with thermocouples and power supply is used bipolar DC source. Temperature of the cell is stabilized at 25 [deg. C] by airflow. It takes around one half hour to warm up LED solar simulator to stabilize irradiance.

LED solar simulator has 4colors of irradiance sources (Blue, Red, Infrared and White), which are designed for uniform power distribution. The detail of LED's property is shown in table 1.

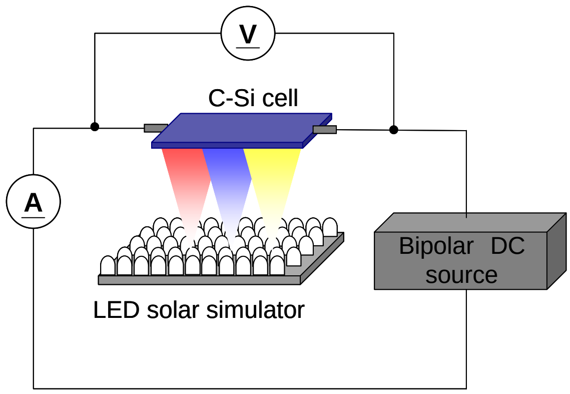

Fig 2. Configuration of measuring c-Si cell using LED solar simulator.

Table 1. The detail of LED's property.

	Blue	Red	Infrared	White
Peak wavelength [nm]	466	646	950	-
Irradiance [mW/cm^2]	3.0	2.5	4.0	1.5

RESULTS AND DISCUSSION

Spectral response

Figure 3 shows the packaged c-Si cell model. Packaged c-Si cell consist of grass, ethylene vinyl acetate (EVA) and Si. Spectral response which packaged c-Si cell is different from raw c-Si cell for ultraviolet (UV) absorber included in EVA, which absorbed UV band (>400nm). Hence, we made approximate expression from its characteristic and integrate it for improve calculation result of SR. Function of absorption feature $f(\lambda)$ is

$$f(\lambda) = 1 - \frac{1}{1 + e^{\frac{\lambda - \lambda_0}{a}}} \quad (1)$$

Here, a is rate of change and λ_0 is center of wavelength of absorption. These values are determined a is 2 and λ_0 is 395[nm] to fit the data sheet. Spectral response is calculated by integrating this function.

Figure 4 shows measurement of discrete spectral responses and comparison of integration result and previous result. At UV bands (<400nm), calculated spectral response is good at previous result. Additionally, discrete spectral responses are increased due to improve measuring device. The result of calculated I_{sc} is 3.41[A]. However, this result is smaller than nominal I_{sc} (3.76[A]). It is thought that spectral response at infrared band (>700nm) is underestimated.

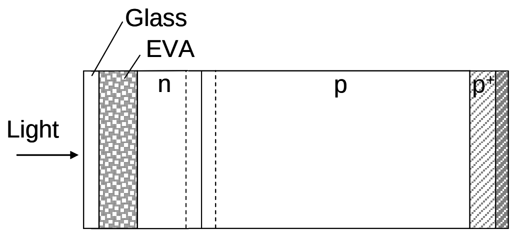

Fig. 3. Packaged c-Si cell's model.

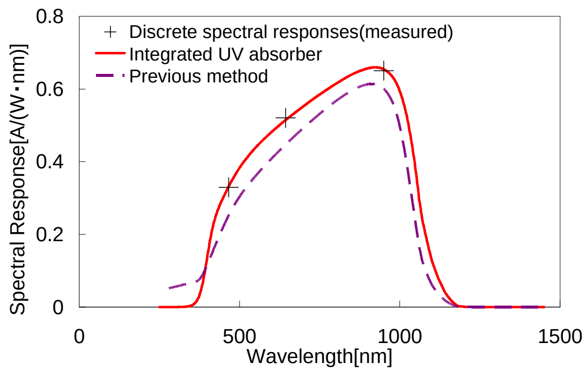

Fig. 4. Comparison of spectral responses between integration result and previous result.

I-V characteristics

Figure 5 shows measured I-V characteristics using white LED and the result of 1-Sun I-V characteristic calculation. The difference of two measured I-V characteristics is so small and close to zero that it can't measure using current meter. Thus, at higher bias voltages (>0.5[V]), the characteristics are need to supplement by theoretical characteristics of diode.

On the other hand, figure 6 shows measured I-V characteristic using all LED, dark current and the result of 1-Sun I-V characteristic calculation. Compared the result using white LED, the difference of two measured I-V characteristics is become clear. Calculated I-V characteristic doesn't become smooth line at higher bias voltages (>0.5[V]). It caused by increasing of current in cell from bipolar DC source that generates heat in consequence of internal resistance. Temperature controlled within ±0.5 [deg. C] when I-V characteristics measured, although the error of measurement was expanded due to extrapolate calculate method.

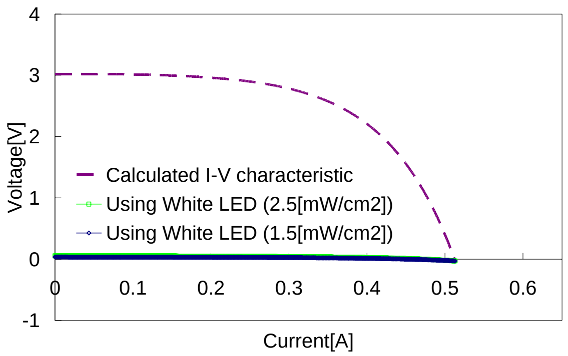

Fig. 5. Calculated I-V characteristic using different irradiance of White LED.

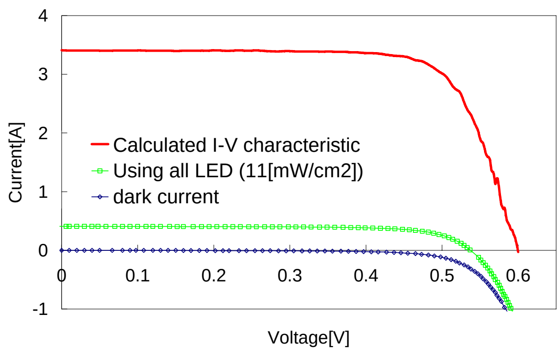

Fig. 6. Calculated I-V characteristic using dark current and all LED.

Table 2. Comparison of measured and calculated solar cell's property.

	Previous method	Calculated I-V characteristic	Nominal I-V characteristic
I_{sc} [A]	3.023	3.410	3.760
V_{oc} [V]	0.513	0.600	0.603
Maxmum Power (Pmax) [W]	0.907	1.535	1.554
Voltage at Pmax [V]	0.368	0.477	0.461
Current at Pmax [A]	2.467	3.219	3.370

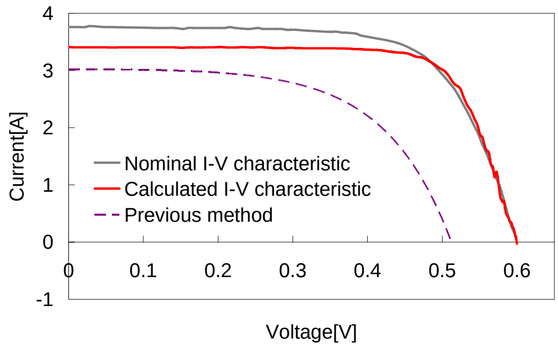

Fig. 7. I-V characteristics compared with measured by 1-Sun solar simulator and previous method data.

Figure 7 shows the comparison of I-V characteristics between calculated and nominal I-V characteristic. And the detail of I-V characteristics is shown by table 2. Calculated I-V characteristic is more approximate to the nominal I-V characteristic than previous method. Therefore, the value of Pmax is improved. However, calculated I-V characteristic is underestimated I_{sc} compared with the values that measured by 1-Sun solar simulator. Thus, fill factor was overestimated.

Verification using nominal I_{sc}

Accuracy of calculated I-V characteristics is verified by using nominal I_{sc}. Figure 8 shows the result of the I-V characteristic calculation. I-V characteristic which calculates previous method is underestimated at higher voltage. On the other hand, calculated I-V characteristic using all LED is improved compared with previous method. However, the I-V characteristic is overestimated near Pmax. Even though all LED used, its irradiance was much smaller than 1-Sun. Consequently, series resistance (R_s) might be ignored and the error of measurement was expanded.

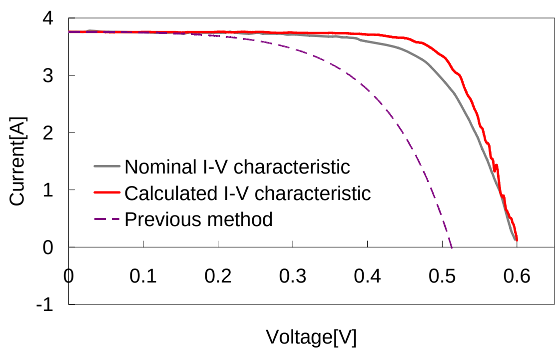

Fig.8. Comparison of nominal I-V characteristic and calculated I-V characteristics using nominal I_{sc}.

On this account, formula (2) is used for the correction of calculated I-V characteristic.

$$V_2 = V_1 - R_S(I_2 - I_1) \qquad (2)$$

Here, V_1 and I_1 are voltage and current of the former value, respectively. V_2 and I_2 are corrected value. The value of R_s (=0.01[Ω]) was determined to best fit the experience. Figure 9 shows the result of I-V characteristics using nominal I_{sc} and correction formula using R_s. The corrected result is almost same as nominal I-V characteristic so that it is important to improve the accuracy of calculated I_{sc} and to consider R_s.

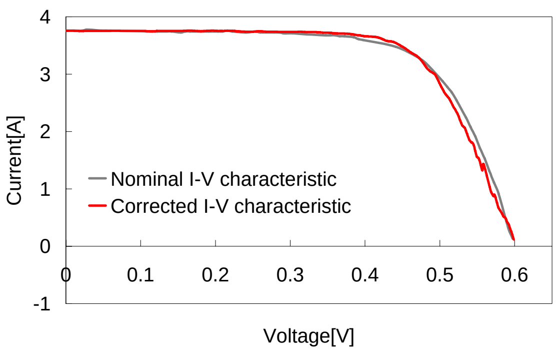

Fig.9. Comparison of corrected I-V and nominal I-V characteristics.

CONCLUSION

This paper describes calculation results with extrapolation method using LED solar simulator. Accuracy of the calculated I-V characteristic is improved using dark current and 1/9 of the 1-Sun irradiance compared with the previous method that is using two reference I-V characteristics measured with LED. It is obtained that the result using nominal I_{sc} and R_s correction is almost same to nominal I-V characteristic.

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