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CALIBRATION OF PRIMARY REFERENCE SOLAR CELLS AT KRISS

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Abstract: The capability of KRISS, Korea, for the SI-traceable calibration of primary reference solar cells according to the IEC standards is presented. The method is based on measurement of absolute spectral irradiance of a solar simulator combined with differential spectral responsivity measurement for spectral mismatch correction. The uncertainty is evaluated to be less than 2 % (k = 2) for short-circuit current measurement, and its validity is tested by comparison with other realizations.

Keywords: reference solar cell, conversion efficiency, standard test condition, SI traceable calibration.

INTRODUCTION

Accurate measurement of conversion efficiency of photovoltaic cells and modules begins with reference solar cells which are to be calibrated according to the IEC standards [1]. Specifically, for the terrestrial solar application, the reference cell should be calibrated in the standard test condition (STC) at a total irradiance of 1000 W/m^2 (= 1 sun) with the reference solar spectrum of Air Mass 1.5 Global (AM 1.5G) and at a cell temperature of 25 °C. The IEC reference solar cells are disseminated to the customers in the photovoltaic industries and testing laboratories as a working standard for calibration, test, and certification of photovoltaic products. Figure 1 shows examples of the reference solar cell packages. The size of active area is limited to 2 cm x 2 cm, and the package includes a temperature sensor.

Fig. 1. Examples of IEC reference solar cells available in the market.

A reference solar cell is referred to be as “primary” when its calibration is performed directly traceable to the international unit system (SI) or to the international solar reference, the World Radiometric Reference (WRR) [2]. Moreover, the claimed relative uncertainty as well as its relative deviation from the international scale such as World Photovoltaic Scale should be smaller than 2 % [3].

Korea Research Institute of Standards and Science (KRISS) has established the capability for the SI-traceable calibration of the reference solar cells based on the crystalline Silicon according to the IEC standards. In this presentation, we summarize the method, the facilities, and the accuracy of the KRISS primary reference solar cells.

CALIBRATION METHOD AND TRACEABILITY

The calibration method at KRISS is based on the measurement of absolute spectral irradiance under illumination of solar simulator [1]. A calibrated spectro-radiometer is used to measure the absolute spectral irradiance $E(\lambda)$ at the position of the test reference cell provided by a Xe-lamp solar simulator. Any deviation from the STC is either corrected or considered as an uncertainty component. The most dominant correction is the spectral mismatch between the solar simulator spectrum and the AM 1.5G reference solar spectrums. For this correction, the relative spectral responsivity $r(\lambda)$ of the test reference cell should be additionally measured based on the differential spectral responsivity method [4,5].

Figure 2 shows the traceability chart for the calibration of reference solar cells at KRISS. The spectral responsivity measurement of the test reference solar cell is traceable to the spectral responsivity scale of KRISS, while the spectral irradiance measurement by using a spectro-radiometer is traceable to the spectral irradiance scale of KRISS. Note that both the scales are independently realized at KRISS based on an absolute cryogenic radiometer and a high-temperature blackbody, respectively.

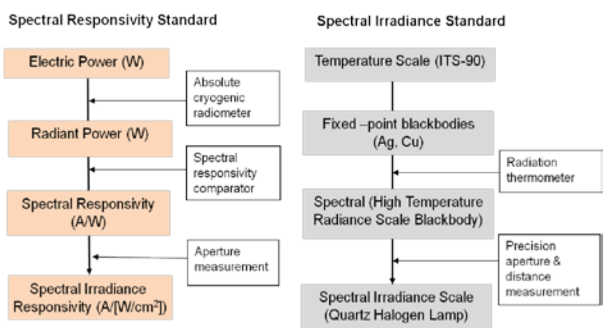

Fig. 2. Traceability chart for calibration of primary reference cells at KRISS.

CALIBRATION FACILITIES

Figure 3 show the schematic diagram and the photograph of the calibration setup based on the solar simulator. A class AAA solar simulator is used to illuminate the test reference solar cells at an irradiance level of 1000 W/m^2. A precision spectro-radiometer calibrated by using a spectral irradiance lamp is used to measure the absolute spectral irradiance $E(\lambda)$ of the simulator light at the position of the test cells. Under the illumination, the I-V characteristics of the test cell are measured by using a digital source-meter. The cell temperature is controlled at 25 °C. The most fundamental quantity to be calibrated is the short-circuit current I^*_{sc} of the cell at the STC. The measurement equation for I^*_{sc} is given by

$$I^*_{sc} = I_{sc} \cdot k_{STC} \equiv I_{sc} \frac{\int E_s(\lambda) r(\lambda) d\lambda}{\int E(\lambda) r(\lambda) d\lambda} = I_{sc} \frac{\sum E_{si} r_i \Delta_i}{\sum E_i r_i \Delta_i}, \quad (1)$$

where $E_s(\lambda)$ denotes the AM 1.5G reference solar spectrum in the unit of W/(m^{2}nm) and $r(\lambda)$ the relative spectral responsivity of the test reference cell to be measured also at the STC. The factor k_{STC} is the spectral mismatch correction factor, which corrects the deviation of the reading short-circuit current I_{sc} from the STC value I^*_{sc} due to deviation of the simulator spectrum from the AM 1.5G.

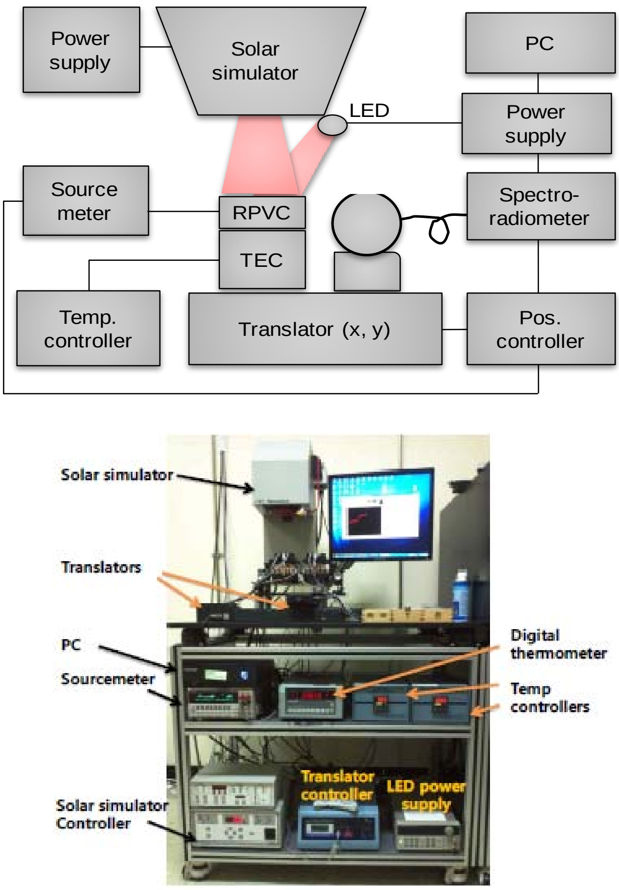

Fig. 3. Calibration facility for reference solar cells at KRISS.

Figure 4 shows the other experimental setup to measure the relative spectral responsivity $r(\lambda)$ of the reference cells required for Eq. (1). The measurement principle and performance of this facility is described in Ref. [5] in details. The measurement range for $r(\lambda)$ is currently from 300 nm to 1000 nm. An extension of the wavelength range is in progress.

Fig. 4. Photograph of the differential spectral responsivity measurement setup at KRISS.

Figure 5 shows the measured absolute spectral irradiance of the solar simulator $E(\lambda)$ together with the AM 1.5G reference solar spectrum $E_s(\lambda)$ and the relative spectral responsivity $r(\lambda)$. The spectral mismatch is clearly visible within the spectral range of Si responsivity.

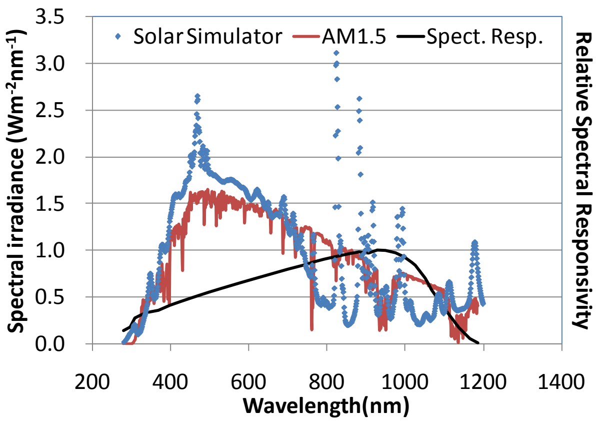

Fig. 5. Measured spectral irradiance at the solar simulator facility plotted together with the AM 1.5G spectrum and the relative spectral responsivity of a Si reference solar cell.

UNCERTAINTY ANALISYS AND VALIDITY TEST

Table 1 shows the representative uncertainty budget for measurement of the STC short-circuit current measurement I^*_{sc} of a bare Silicon reference solar cell based on Eq. (1). The expanded relative uncertainty is 1.9 % at a confidence level of approximately 95 % (k = 2). Note that the most dominant uncertainty component is the spectral mismatch correction based on the measurement of absolute spectral irradiance $E(\lambda)$ of the solar simulator.

The validity of the calibration result is tested by comparison with other primary calibration methods based on different traceability. A comparison with the method traceable to the WRR realized at KIER, Korea, confirmed the equivalence within 0.4 %, while a comparison with the SI-traceable method realized at PTB, Germany, within 0.3 % [6].

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Table 1. Uncertainty budget for the STC short-circuit current of a Si reference solar cell calibrated at KRISS.

uncertainty component	description	rel. std. uncertainty $u_r(x)$ (%)	probability distribution	sensitivity coefficient c	contribution $cu_r(x)$ (%)	DoF
$u_r(I_{sc})$						
$u_r(I_{sc})_{read}$	reading	0.1	t	1	0.1	19
$u_r(I_{sc})_T$	temperature	0.04	rectangular	1	0.04	∞
$u_r(I_{sc})_{nonlinear}$	nonlinearity	0.1	rectangular	1	0.1	∞
$u_r(I_{sc})_{stab}$	temp. stability	0.1	rectangular	1	0.1	∞
$u_r(I_{sc})_{nonuniform}$	nonuniformity	0.2	rectangular	1	0.2	∞
$u_r(k_{STC})$	STC mismatch	0.9	normal	1	0.9	∞
$u_{rc}(I_{sc}^*)$	combined std. uncertainty	0.94	normal			∞