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COMMUNICATIONS

PV cells electrical parameters measurement

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When measuring optical parameters of a photovoltaic silicon cell, precise results bring good electrical parameters estimation, applying well-known physical-mathematical models. Nevertheless, considerable re-combination phenomena might occur in both surface and intrinsic thin layers within novel materials. Moreover, rear contact surface parameters may influence close-area re-combination phenomena, too. Therefore, the only precise electrical measurement approach is to prove assumed cell electrical parameters. Based on theoretical approach with respect to experiments, this paper analyses problems within measurement procedures and equipment used for electrical parameters acquisition within a photovoltaic silicon cell, as a case study. Statistical appraisal quality is contributed.

K e y w o r d s: measurement, electrical parameters, photovoltaic cells, case study, statistics

1 Introduction

Optical parameters bring detailed information about structural features of a photovoltaic (PV) cell. Precise measurement and calculations allow estimating band gap energy, free carriers generation and photo-generation charge transfer kinematics to the respective electrode and from the electrode outflow. Thus, final electrical parameters like resistivity (thermal-dependent), open-circuit voltage V_0 and short-circuit current I_s can be estimated numerically, too. However, there exist uncertainties at quantum particles level. Thus, the only real measurements of electrical parameters bring a proofs about newly designed materials efficiency [1]. Current-voltage $I-V$ characteristics measurement and power-voltage $P-V$ conversion verify PV cell electrical efficiency. On that account, a real PV cell is measured at standard conditions, *ie* in the lab using solar simulator equipment, at known both irradiance intensity and standard spectral distribution specified by air mass AM1.5 Global filter usually at 1000 $\mathrm{W/m^2}$ light power. [1-4]

Based on theoretical approach with respect to experiments, this paper analyses $I-V$ electrical parameters acquisition needs when measuring a PV silicon cell, as well as $P-V$ and efficiency estimation, to reveal troubleshooting and accuracy of these procedures.

In a PV cell, solar photons bring their energy greater then band-gap energy into thin film semiconductors junction and create proportional quantity of electron-hole pairs to conduct the electrical current [5]. Besides of incident irradiation intensity, the material wafer band-gap energy determines electrical current value a lot [6]. While higher photons energy causes particles recombination and extinction of some pairs, lower photons energy causes energy transmission and temperature changes into material. Due to nonlinear $I-V$ characteristics of any PV cell, it is necessary to design it for maximum power or electrical efficiency [1 - 5, 7].

Due to wafer structure and surface finish thinning, different phenomena are observed with novel silicon materials. Computer modelling might be used to fill in discontinuities over $I-V$ characteristics, gaining in real PV cell sparse data matrix approximation and optimization [58]. Consequently, PV cell parameters can be obtained from accurate computer model for any supposed realistic conditions.

Generally, a PV cell as an elementary PV electrical energy source, is described by equivalent electrical circuit - a five-parameter model [1, 5 - 8]. Maximum electrical power P_m at the output of a PV cell and electrical efficiency η, with respect of its fill factor f are given as follows [1, 7]

$$P_m = V_m I_m = V_0 I_s f, \quad \eta = \frac{P_m}{P_{\mathrm{in}}} \tag{1,2}$$

Electrical parameters estimation of any real silicon PV cell is based on measurement of $I-V$ characteristics, by ASTM E948-09 standard test method using a reference PV cell under simulated sunlight [9].

Generally, each part of measurement equipment is a source of uncertainty in relating the measured and the true value including the statistical systematic error A (it outgoes from series of repeated determinations) and a random error B (associated with the instruments and calibration) [1]. The single-unit uncertainty U_{95} is expected to include 95% of correct results by Students t_{95} value,

$$U_{95} = \sqrt{B^2 + (t_{95}A)^2} \tag{3}$$

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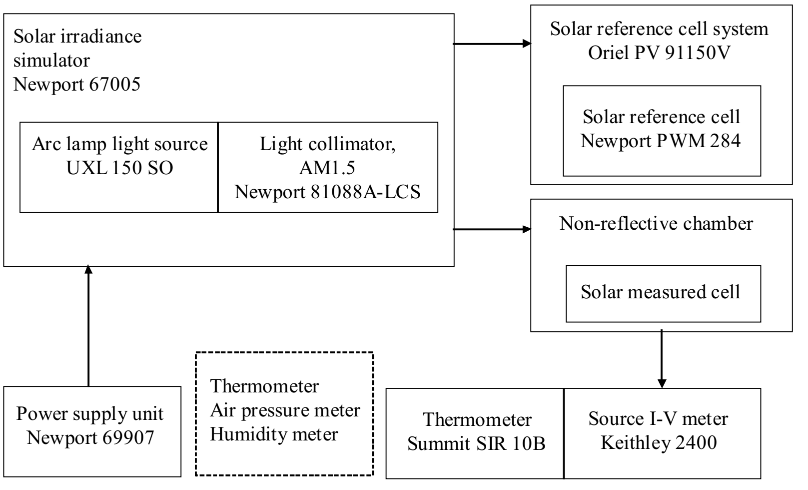

Fig. 1. Solar simulator equipment consisting of Newport 69907 power supply unit, Newport 67005 light source with UXL 150 SO Xenon arc lamp, Newport 81088A-LCS light collimator with AM1.5 filter, Oriel PV 91150V solar reference cell system with Newport PVM 284 solar reference cell, non-reflective chamber and Keithley 2400 I-V meter unit (left to right)

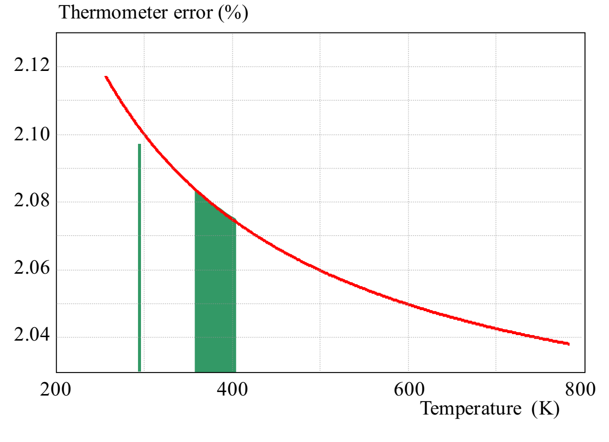

Fig. 2. Temperature instrumental random error along thermometer Summit SIR10B measurement range – the measuring interval error is coloured

thus, series multi-unit total uncertainty $U_{95}^{(T)}$ can be obtained

$$U_{95}^{(T)} = 1 - \prod_{i=1}^{n}(1 - U_{95,i}) \tag{4}$$

Temperature measuring error

Following external thermometer SIR10M datasheet, the instrumental random error B_T consists of the reading aberration ± 2 (%) and ± 3 digits across measurement range 255 to 783 (K). The instrumental random error spans from 2.10% to 2.073%, Fig. 2.

$$B_T = \pm 0.02T \pm 0.3, \tag{5}$$

where T is the temparature in Kelvins.

The temperature distribution at the measured cell surface is induced by the material structure. Here, 30×3 terms series of surface temperature measurement along middle, near-middle and border area of the measured cell is done. The ordinary laser beam fluctuations error rates about 0.14 (%) while the displacing error caused by PV cell thermal capacity non-homogeneity, insufficient temperature gradient elimination *etc*, rates about 3.4 (%). Thus the systematic error $A_{\rm T} = 0.03403$ and the total temperature measuring error is obtained

$$U_{95,T} = \sqrt{(B_{\rm T}^2 + (2A_{\rm T})^2} = 0.07115. \tag{6}$$

Sunlight spectral distribution error

Since Xenon arc lamp source spectral distribution differs from the real sunlight, AM1.5 Global filter is attached to the solar irradiance simulator. The instrumental random spectrum calibration error $B_{\rm S}$ for the multi-unit series can be expressed as follow

$$\begin{aligned} B_{\rm S} = 1 - [(1 - U_{95,a})(1 - U_{95,b})\times \\ \times (1 - U_{95,c})], \end{aligned} \tag{7}$$

where: a – is Newport 69907 power supply unit, b – is Newport PVM 284 solar reference cell and, c – is Oriel PV 91150 reference cell system. To compare Xenon arc lamp light source spectrum and the Sun spectrum, the comparative irradiation intensity charts per wavelength range are obtained, Fig. 3, using Ocean Optics USB 650 optical spectrometer. But, as from Xenon arc lamp datasheet, the instrumental random error is not available. Therefore, the systematic error $A_{\rm S}$, is obtained by 30 terms repeated short-period series of intensity measurement, by both the Sun as well as the solar simulator. In this manner, normalized standard deviation-to-median ratio are obtained from both measuring sets, Fig. 4.

The solar simulator curve seems quite linear with average median of 0.5225 % all over the wavelengths range. The statistical minimum optical spectrometer error is obtained about 0.1879 %. Hereof, subtracting last two, the

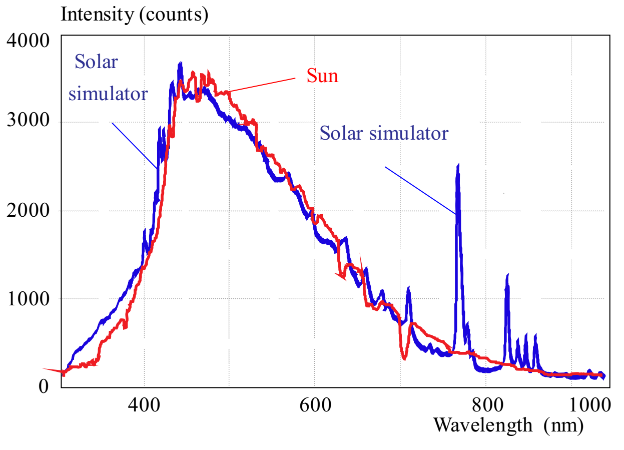

Fig. 3. Measured relative intensity spectra

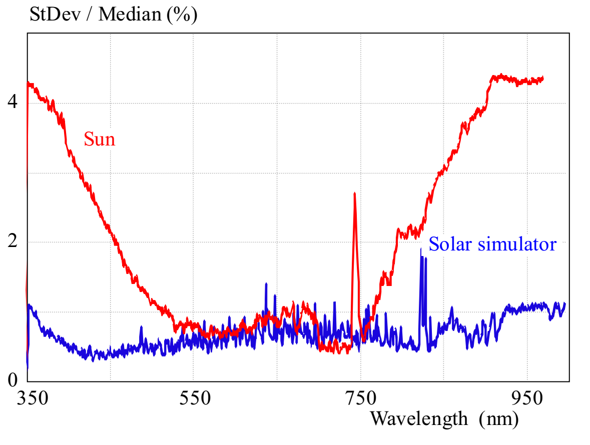

Fig. 4. Median of standard deviation-to-median ratio, by the Sun and solar simulator, obtained by 30 terms series, along measured spectrum

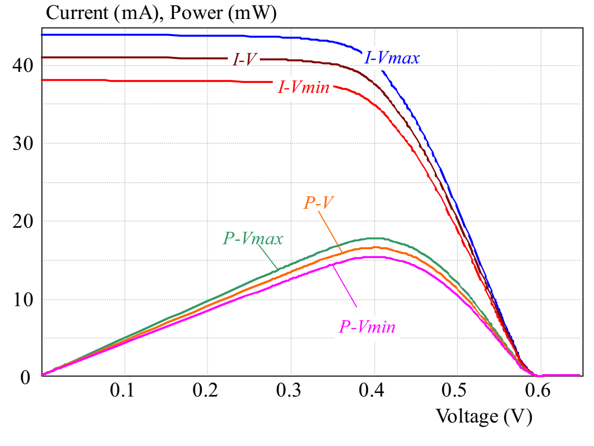

Fig. 5. The Si PV cell measured $I-V$ and calculated $P-V$ characteristics; error included

maximum systematic error A_{S} and the solar simulator spectral distribution measurement error $U_{95,\mathrm{S}}$ are obtained

$$A_S = \frac{StD}{Med}|_{SimMed} - \frac{StD}{Med}|_{SpecMin} = \\ = 0.03346, \tag{8}$$

$$U_{95,\mathrm{S}} = \sqrt{B_{\mathrm{S}}^2 + (t_{95}A_{\mathrm{S}})^2} = 0.03701. \tag{9}$$

If the perpendicular beam is used, photons strike upon the surface structure by the specified optical natural patterns. Here, the uncertainty $U_{95,\mathrm{S}}$ within a measuring unit or measurement device usually does not exceed the value of 0.5 %. This corresponds with the arc lamp non-stability. $I-V$ measuring error.

The Keithley 2400 source $I-V$ meter meets the highest standards by accuracy about 0.05 %. This represents instrument random error B_{IV}. Repeating of 30 term series of IV characteristics measurements, the measured current fluctuates at (pA) level. Therefore, systematic error $A)_{IV} \approx 0.00001\%)0$ is negligible. Summing B_{IV} and A_{IV} errors, the total IV measurements error, according (3) is

$$U_{95,IV} = \sqrt{B_{IV}^2 + (t_{95}A_{IV}^2)} = 0.0005. \tag{10}$$

Total measuring error

Taking into account all allowable errors within 30-repetition of measurement series, the total uncertainty, according to (4) is

$$U_{95}^{(T)} = 1 - [(1 - U_{95,\mathrm{T}})(1 - U_{95,\mathrm{S}})(1 - U_{95,IV})] = \\ = 0.0716 \tag{11}$$

P-V and efficiency estimation

For chosen standard Si-based cell, $I-V$ measured values are shown in Fig. 5. Thus, it is worth to prove the electrical efficiency by precise electrical methods and measuring units set. Calculated f of the cell is 56.47 %. Using (1), $P-V$ characteristics values are obtained. Similarly, electrical efficiency $\eta = 16.427\,\%$ of the PV cell is obtained using (2). Both these final parameters are probable at the calculated ± 7.16 % reliability interval.

3 Conclusion

No doubt that accurate five-parameter model of a PV cell is sufficient enough for most Si cells yet. Nevertheless, novel Si cells dispose of considerable phenomena that invoke electrical field intensity growth, charge transfer kinetics quantizing, tunnelling charge improving within dielectric layers and, electrical parameters modification. When measuring a real PV cell in the lab using solar simulator equipment, both irradiance intensity and irradiance spectra must be set well to achieve near-realistic measurement outputs. During $I-V$ electrical parameters measurement process, maximum preciseness is required. If $I-V$, $P-V$ characteristics, FF and efficiency calculation methods are applied to predict the behaviour of any unknown either experimental PV cell, panel or array under wide range of operating conditions and physical parameters changes, statistical analysis should be applied to validate reliability of obtained electrical parameters.

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