Modeling of photon absorption based colour dye for high performance of dye-sensitized solar cells (DSSCs)

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Modeling of Photon Absorption Based Colour Dye for High Performance of Dye-Sensitized Solar Cells (DSSCs)

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To achieve higher performances for solar cells based on organic dyes, comparable to those for solar cells based on color spectrum, light absorpsion of organic dyes is required. Based on the optical properties, the large absorption of light can be given in a colorless dye with a wavelength of the most extensive. Combination colors from three band basic colors, such as red (R), green (G) and blue (B) can create the optimum light absorption. If absorption spectrum graph of dye color is large then the Incident Photon-to-charge Carrier Efficiency (IPCE) is high too, therefore photon current (I_{ph}) or short-circuit current (I_{sc}) that is produced by Dye-Sensitized Solar Cell (DSSC) will be rise. The experiment showed that combination of three band colors of dye is obtained largest light absorption. This black color proved to have the greatest light absorption. Using circuit modeling with colors variation of dye-sensitized resulted in dye-sensitized solar cells that exhibit a high open-circuit voltage V_{OC} of 0.71 V, short-circuit current density J_{SC} of 20.1 mA cm^{-2}, fill factor (FF) of 0.74 and a power conversion efficiency of 10.1%.

Keywords: DSSC, Absorption of Light, Three Band Basic Colors of Dye, IPCE, Circuit Modeling.

1. INTRODUCTION

Over the last decade, dye-sensitized solar cells (DSSCs) have attracted much attention because these unconventional solar cells exhibit high performance and have the potential for low-cost production.[1] Recently, solar energy-to-electricity conversion efficiencies as high as 11% under AM 1.5 G irradiation have been attained with DSSCs.[2] In DSSCs, the photosensitizer is one of the most important components influencing solar cell performance, because the choice of sensitizer determines the photoresponse of the DSSC and initiates the primary steps of photon absorption and the subsequent electron transfer process.

This last category has made significant gains in efficiency but is the least understood and the less well developed. More fundamental research is necessary to understand the physics and material behavior in many cell types. There are many proposed cells involving nanostructures and organic materials. One can make some estimates of the potential cost of some of these cells, but others are not developed enough to estimate. We know that for space applications, there are significant qualification costs and the behavior of the new cells under radiation and other space conditions would have to be established.

On the other hand, the mechanism of conventional solar cells is well understood by way of equivalent circuits, which are considered to be useful tools to analyze cell devices and improve cell performance.[3]

Dye-sensitized solar cells (DSSCs) have been extensively evolved for the past two decades in order to improve their cell performance. From the commercialization point of view, the overall solar to electrical energy conversion efficiency should compete with other solar cells. But, due to structural restrictions of DSSC using the liquid electrolyte and a space requirement between two electrodes, the direct tandem construction of DSSCs by stacking of repeating units is highly limited. In this feature article, important research trials to overcome these barriers and a recent research trend to improve the light harvesting strategies mainly panchromatic engineering, various tandem approaches such as parallel tandem, series tandem, *p–n* tandem etc., have been briefly reviewed.

Therefore, it is necessary to obtain DSSC equivalent circuits to accelerate the development of practical DSSC based photovoltaic modules. Recently, electrochemical impedance spectroscopy (EIS) has been used to analyze internal resistance in DSCs, and at least three internal resistances have been found.[4] However, the performance of DSSCs based on organic dyes has not yet exceeded those based on color spectrum. To achieve higher performances for solar cells based on organic dyes,

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Adv. Sci. Lett. 23, 2370–2372, 2017

comparable to those for solar cells based on color spectrum, light absorpsion of organic dyes is required.

2. EXPERIMENTAL DETAILS

We performed simulation to examine the equivalent circuits reported in the literature and could not confirm their validation. We find that the transmission line and ladder circuit normally used as an equivalent circuit for modeling DSSCs does not exhibit a diode characteristic and is not able to conform to the typical I–V curves (Fig. 1).

A standard DSSC typically contains three interfaces formed by FTO/TiO_2, TiO_2/dye/electrolyte, and electrolyte/Pt-FTO. An equivalent circuit model is shown in Figure 1. The interfacial charge transfer at the TiO_2/dye/electrolyte is represented by a rectifying diode Di and a double-layer capacitance (C_i). A recombination diode D_r with an ideality factor generally considered is employed to denote the interfacial charge recombination losses to both the dye cation and the redox electrolyte. A shunt resistance R_{sh} takes into account all parallel resistive losses across the photovoltaic device including leakage current. An inductive recombination pathway as a result of a charge-transfer current is incorporated into the circuit, consisting of a recombination resistance (R_{rec}) in series with an inductor (L). The charge-transfer resistance and interfacial capacitance at the FTO electrode and electrolyte/Pt-FTO interface are represented by R_E and C_E, and R_{CE} and C_{CE}, respectively. The Nernst diffusion of the carrier transport by ions within the electrolyte is denoted by the Warburg impedance (W). A resistance element RS designates the bulk and contact resistive losses present in a practical DSSC, such as the sheet resistance of the FTO glass. The corresponding I–V characteristic based on the equivalent circuit model in Figure 1 is described by the following equations:

$$I = -I_{ph} + (V - R_s I)\left(j\omega C_i + \frac{1}{R_{sh}}\right) + I_1\left[\exp\left(\frac{q(V-R_s I)}{n_1 k_B T}\right) - 1\right] + I_2\left[\exp\left(\frac{q(V-R_s I)}{n_2 k_B T}\right) - 1\right] \quad (1)$$

where I_i and I_r are the saturation current density of the rectifying and recombination diodes, respectively, kB is the Boltzmann constant, T is the absolute temperature, q is the electron charge, ω is the angular frequency.

The photogenerated current I_{ph} is in parallel with the rectifying diode.

$$I_{ph} = \int qF(\lambda)\{1 - r(\lambda)\}\mathrm{IPCE}(\lambda)\,d\lambda = \int qF(\lambda)\Phi(\lambda)\,d\lambda \quad (2)$$

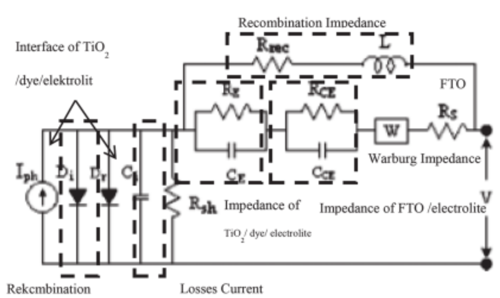

Fig. 1. An equivalent circuit model of DSSCs.

Where $F(\lambda)$ and IPCE (λ) are the incident photon flux density and the incident photon-to-current conversion efficiency at wavelength (λ), respectively, $r(\lambda)$ is the incident light losses due to the light absorption and reflection by the FTO glass, and $\Phi(\lambda)$ is the quantum yield.

3. RESULTS AND DISCUSSION

With the equivalent circuit (Eq. (1)) also incident photon flux density (Fig. 2) and Colors Spectrums Irradiances (Fig. 3), we obtain the graphs of characteristic (I–V) where the solar cell is a constant current source for low voltage values with a current approximately equal to current density of short-circuit J_{sc}. With the increase of the tension, the current begins to decrease exponentially to zero value where is equal to the tension of open circuit V_{oc} circuit.

The spectral response in the visible regions is higher in black dye than another colors dyes, resulting in higher short circuit photocurrent. The current–voltage characteristics of this solar cell are shown in Figure 3. A short circuit photocurrent density of 20.1 mA/cm^2, an open-circuit voltage of 0.71 V, a fill factor of 0.71 and an overall conversion efficiency of 10.1% is obtained. The overall charge carriers' motion gives rise to the macroscopic photocurrent, while the photoinduced electron transfer from the

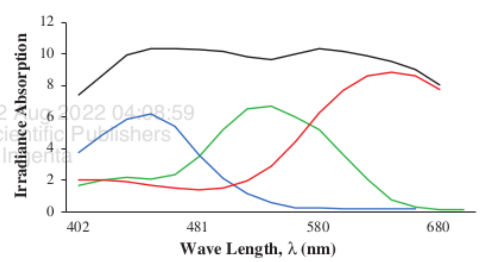

Fig. 2. Color simulated incident photon flux density for colors of red, green, blue and black spectrums.

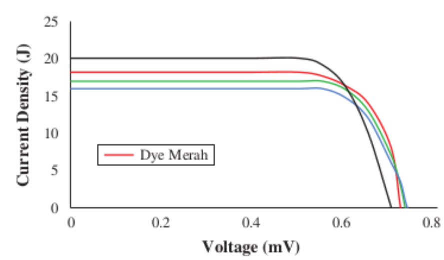

Fig. 3. Spectral respons for absorption of basic colors (red, green and blue) and black dyes.

Table I. Result of circuit model characteristics of DSSC.

Colour	J_{ph} (mA/cm^2)	I_{sc} (mA/cm^2)	V_{oc} (V)	FF	μ (%)
Red	24	18,2	0,73	0,73	9,7
Green	22	17,1	0,74	0,72	9,2
Blue	21	16,6	0,74	0,71	9,1
Black	30	20,1	0,71	0,74	10,1

dye to the semiconductor, increasing the electronic density in the oxide, gives rise to an electrochemical potential difference (i.e., a voltage) between the semiconductor and the electrolyte.

4. CONCLUSION

The modelling of a solar cell is the performing tool, which will allow us by simulation, to link the photovoltaic characteristics of this cell with the internal properties of the material and the manufacturing technology to improve the performances of the cell. The combination of three band colors of dye is obtained largest light absorption. This black color proved to have the greatest light absorption. Using circuit modeling with colors variation of dye-sensitized resulted in dye-sensitized solar cells that exhibit a high open-circuit voltage V_{OC} of 0.71 V, short-circuit current density J_{SC} of 20.1 $mA \cdot cm^{-2}$, fill factor (FF) of 0.74 and a power conversion efficiency of 10.1%.

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