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Low and wide gap organic solar cells parameters extraction from illumination current-voltage

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ABSTRACT

An improved method based on Matlab code for the simultaneous determination of the different solar cells parameters from illumination current-voltage characteristics has been developed. These parameters are the ideality factors, saturation current, photocurrent, the series and shunt resistance. The validity of this method has been checked by comparing the results obtained here from two pin organic solar cells based on low and wide gap structures which can strongly improve the performance of organic solar cell. The method is very convenient to use and the reasonable agreement between experiment study and calculation results confirms the model.

KEYWORDS

Solar cells;
Extraction;
Low-gap;
Wide-gap;
Physical parameters;
I-V plot.

INTRODUCTION

Organic semiconductors are heralded for their simple processing and extraordinary chemical customizability, and emerging low-cost and flexible devices based on these materials are expected to revolutionize the role electronics have in our everyday lives[1]. Organic thin-film solar cells are the focus of intense research efforts owing to their potential applications in low cost, colorful, and flexible electric power sources. Up to now, several materials and device structures have been developed to obtain high power conversion efficiency by using different structures and architecture, organic solar cell with low and wide-gap, bulk-heterojunction organic thin-film solar cells of semiconducting polymers and p–i–n junction organic thin film solar cells for small-molecular-weight materials[2]. Recently, a power conversion efficiency of 1.9% has been shown by using a mixed layer of phthalocyanine zinc (ZnPc) and the fullerene C60 as photoactive layer[3].

Extraction and optimization of solar cells device parameters is an important step in device modelling and simulation. Extraction the physical parameters of solar cell: series resistance and ideality factor, saturation current (I_s), shunt resistance (R_{sh}) and photocurrent (I_{ph}) is of a vital importance for quality control and evaluation of the performance of solar cells when elaborated and during their normal use on site under different conditions temperature and illumination. Series and shunt resistance in solar cells is parasitic parameters, which affect the illuminated I-V characteristics and efficiency of otherwise good cells. In organic solar cells the series resistance R_s is mainly the sum of contact resistance on the frond and back surfaces. So, it is very necessary for solar cells, to obtain a low series resistance and to be able to determine it with accuracy because it is an important parameter of fill factor and efficiency improvement. The diode ideality factor has been introduced for a *p-n* junction solar cell after consideration of the physical phenomena that occurs in diode. Several theories have been published to account for the introduction of ideality factor.

In the literature several methods have been suggested for extracting solar cell parameters[4-6] and applied to different solar cells. Priyank et al[4] method gives the value of series R_s and shunt resistance R_{sh} using illuminated I-V characteristics in third an fourth quadrants and the V_{oc}-I_{sc} characteristics of the cell. In the work of Bashahu et al[5], up to 22 methods for the determination of solar cell ideality factor (n), have been presented, most of them use the single I-V data set. Jain and Kapoor[6] present an accurate method using the Lambert w-function to study different parameters of organic solar cells. Kaminski et al. used a simulated I–V curve with one exponential model, considering the series resistance to extract the solar cell parameters under dark conditions. Here, Kaminski's method[7-12] has been extended to cover the case of solar cells under illumination and used to extract the parameters of interest using experimental I–V characteristics of two pin organic solar cells with low and wide gape. The method has been successfully applied to the measured I–V data of organic pin solar cells under 100 mW/cm^2.

METHOD AND ANALYSIS

At a given illumination, the current-voltage relation for a solar cell is given by

$$I = I_{ph} - I_d - I_p$$

$$= I_{ph} - I_s\left[\exp\left(\frac{\beta}{n}(V + IR_s)\right) - 1\right] - G_{sh}(V + IR_s) \qquad (1)$$

I_{ph}, I_s, n, R_s and G_{sh} ($=1/R_{sh}$) being the photocurrent, the diode saturation current, the diode quality factor, the series resistance and the shunt conductance, respectively. I_p is the shunt current and $\beta = q/kT$ is the usual inverse thermal voltage. The shunt resistance is considered $Rsh = (1 / G_{sh}) >> R_s$.

The shunt conductance G_{sh} is evaluated from the reverse bias characteristics by a simple linear fit[8]. The calculated value of G_{sh} gives the shunt current $I_p = G_{sh}V$. Before extracting the ideality factor and the series resistance, Our measured I-V characteristics are corrected considering the value of the shunt conductance as obtained and for $V+R_sI>>kT$, the current voltage relation becomes:

$$\mathbf{I} = \mathbf{I_{ph}} - \mathbf{I_s}\left[\mathbf{exp}\left(\frac{\beta}{\mathbf{n}}(\mathbf{V} + \mathbf{IR_s})\right)\right] \qquad (2)$$

Which is equivalent to:

$$\ln(\mathbf{I_{ph}} - \mathbf{I}) = \ln \mathbf{I_s} + \frac{\beta}{\mathbf{n}}(\mathbf{V} + \mathbf{IR_s}) \qquad (3)$$

By taking a point (V_0, I_0) of the I-V curve, we can write the following relation:

$$\ln(\mathbf{I_{ph}} - \mathbf{I_0}) = \ln \mathbf{I_s} + \frac{\beta}{\mathbf{n}}(\mathbf{V_0} + \mathbf{I_0R_s}) \qquad (4)$$

By subtracting Eq. (3) and Eq. (4) and after a simplification we get a linear equation given by:

$$\mathbf{Y} = \frac{\beta}{\mathbf{n}}(\mathbf{R_s} + \mathbf{X}) \text{ For } I >> I_s \qquad (5)$$

Where: $$Y = \frac{1}{I - I_0}\ln\frac{(I_{ph} - I)}{(I_{ph} - I_0)} \qquad (6)$$

and $$\mathbf{X} = \frac{(\mathbf{V} - \mathbf{V_0})}{(\mathbf{I} - \mathbf{I_0})} \qquad (7)$$

The linear regression of equation (5) gives n and R_s but we must initially calculate the whole of the values of X-Y as follows: We consider a set of I_i-V_i data giving rise to a set of X-Y values, with i varying from 1 to N. Then, we calculate X and Y values for $I_0 = I_{i0}$ and $I=I_{i0+1}$ up to $I=I_N$. This gives (N-1) pairs of X-Y data. We start again with $I_0 = I_{i0+1}$ and $I = I_{i0+2}$ up to I_N and get (N-2) additional X-Y data, and so on, up to $I_0 = I_{N-1}$.

For most practical illuminated solar cells we usually consider that $I_s << I_{ph}$, the photocurrent can be given by the approximation $I_{sc} \sim I_{ph}$, where I_{sc} is the short-circuit current. This approximation is highly acceptable and it introduces no significant errors in subsequent calculations[9].

The saturation current I_s was evaluated using a standard method based on the I-V data by plotting $\ln(I_{ph} - I_{cr})$ versus V_{cr} equation (8). Note that I_{cr}-V_{cr} data were the corrected current voltage I-V data taking into account the effect of the series resistance where I-V are the measured current-voltage data.

$$\ln\left(I_{ph} - I_{cr}\right) = \ln\left(I_s\right) + \frac{\beta}{n} V_{cr} \qquad (8)$$

When we plot ln (I_c) where (I_c=I_{ph}-I_{cr}) versus V_{cr}, it gives a straight line that yields I_s from the intercept with the y-axis.

RESULTS AND DISCUSSION

Our method is applied on the two p-i-n solar cells where the photoactive layer is formed by a mixture of phthalocyanine zinc (ZnPc) and the fullerene C_{60} (ZnPc: C_{60}ZnPc :C_{60}, 1:1, 30 nm) either with wide-gap transport layers (40nm n-doped C_{60} (molar ration of 1:100) and 50 nm p-doped MeO-TPD (molar ration 1:25)) or with low-gap transport layers (50 nm n-doped Me-PTCDI and 200nm p-doped ZnPc)[10], in fact, the goal is extracting the five physical parameters (I_{ph}, n, R_s, G_{sh}, I_s) to show the advantage of using wide gap layer. The experimental current-voltage *(I-V)* data were taken from B. Maennig et al[10] for the two pin cells under 100 mW/cm^2 with low and wide gap.

The shunt conductance $\boldsymbol{G_{sh}=1/R_{sh}}$ was calculated using a simple linear fit of the reverse bias characteristics. The photocurrent has been taken directly as the short circuit current according to the approximation $I_{ph} = \left|I_{sc}\right|$. The series resistance and the ideality factor were obtained from the linear regression (5) using a least square method. In order to test the quality of the fit to the experimental data, the percentage error is calculated as follows:

$$e_i = \left(I_i - I_{i,cal}\right)\left(100 / I_i\right) \qquad (9)$$

Where $I_{i,cal}$ is the current calculated for each V_i, by solving the implicit Eq.(1) with the determined set of parameters (I_{ph}, n, R_s, G_{sh}, I_s). (I_i, V_i) are respectively the measured current and voltage at the *i*th point among *N* considered measured data points avoiding the measurements close to the open-circuit condition where the current is not well-defined[11].

TABLE 1 : Extraction parameters for the different solar cell using our method

	Wide-gap	Low-gap
G_{sh} (Ω^{-1})	1.45 x 10^{-3}	1.05 x 10^{-3}
R_s (Ω)	0.003	0.024
n	3.989	3.429
I_s(A)	0.124 x 10^{-3}	0.051 x 10^{-3}
I_{ph}(A)	6.1 x 10^{-3}	3.6 x 10^{-3}
FF (%)	45	47
η (%)	0.75	1.32

Statistical analysis of the results has also been performed. The root mean square error (RMSE), the mean bias error (MBE) and the mean absolute error (MAE) are the fundamental measures of accuracy. Thus, RMSE, MBE and MAE are given by:

$$RMSE = \left(\sum |e|_i^2 / N\right)^{1/2}$$
$$MBE = \sum e_i / N \qquad (10)$$
$$MAE = \sum |e|_i / N$$

N is the number of measurements data taken into account.

The extracted parameters obtained using the method proposed here for the pin organic solar cell with low and wide gap are given in TABLE 1. The statistical indicators for the method of this work are shown in TABLE 2. Figures 1 and 2 show the plot of *I-V* experimental characteristics and the fitted curves derived from eq(1) with the parameters shown in TABLE 1. Good agreement is observed for the different structure, especially for the wide-gap pin solar cells with statistical error less than 2%-1% for wide and low-gap respectively, which attribute mainly to lower parasitic losses. For the wide-gap we can observe a low series resistance of 0.003Ω compared to 0.024Ω for low gap. For the wide-gap cell, we observe a nearly doubled short-circuit current 6.1mA/cm^2 compared to the low-gap cell 3.7mA/cm^2, which is mainly attributed to lower parasitic absorption losses. The others corresponding values of the wide-gap open circuit voltage 0.46 V, fill factor 47% and power efficiency 1.32%, the parameters of the low-gap are a voltage of 0.45 V, a fill factor of 45% and a power efficiency of 0.75%.

The interesting point with the procedure described herein is the fact that we are successfully applying it for

TABLE 2 : Statistical indicators of accuracy for the method of this work.

	RMSE (%)	MBE (%)	MAE (%)
Wide-gap	1.3104	-0.0308	0.7157
Low-gap	0.9902	0.0568	0.5353

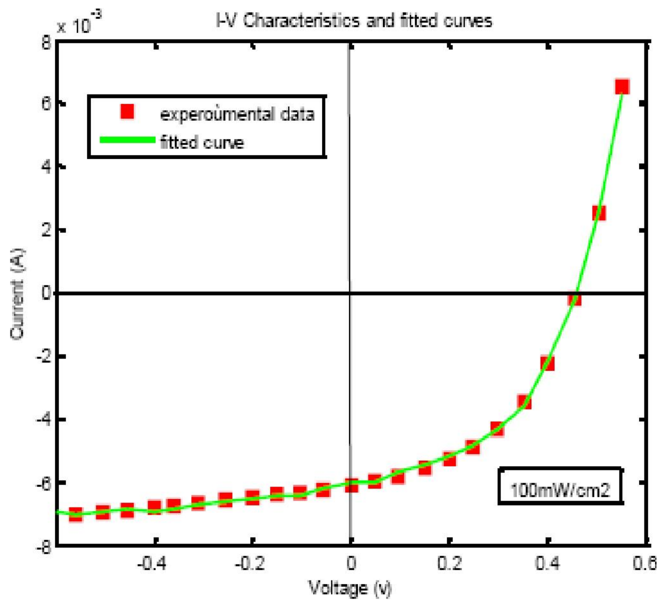

Figure 1 : Experimental (■) data and fitted curve (—) for wide-gap solar cell with 30nm active layer

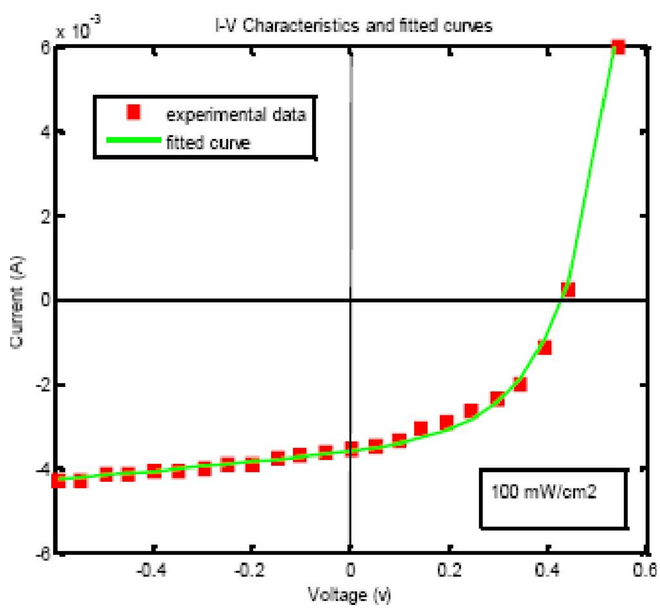

Figure 2 : Experimental (■) data and fitted curve (—) for low-gap solar cell with 30 nm active layer.

experimental I–V characteristics of different architecture of pin organic solar cells with completely different physical characteristics. The results obtained are in good agreement with those published[10], where, we improve the advantage of: firstly, the use of mixed layer of ZnPc and C_{60} as photoactive layer reached the power efficiency of 1.32% for wide-gap compared to 0.75% for lower gap under 100mW/cm^{2}[10]. Secondly, the benefit of using doped wide-gap materials is the freedom to optimize the cells in terms of thin-film, where no light is lost by absorption on its way to the active layer; also the light reflected at the back contact can efficiently be used. The procedure described herein not has any limitation condition on the voltage and it is reliable, straightforward, easy to use and successful for different types of solar cells.

CONCLUSION

In this contribution, a simple method for extracting the solar cell parameters based on measured current–voltage data is considered. The method has been successfully applied to p-i-n organic solar cells with low and wide-gap under different condition. The method is very simple to use and presents the advantage of being independent of the voltage step. A theoretical expression given in Eq.(5) has been employed to determine the series resistance and ideality factors values of organic pin solar cells using the illuminated I-V characteristics. the method require the value of photocurrent (I_{ph}) and shunt resistance (R_{sh}) which can be easily obtained from I-V characteristic with simple linear fit, finally we estimate the saturation current from I-V curve using a standard method. Good agreement is obtained between measured and simulated I-V characteristic. The reasonable agreement between the obtained results and experiment study confirms the model.

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