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TANDEM AND SINGLE ORGANIC SOLAR CELLS PARAMETERS EVALUATION FROM ILLUMINATION I-V PLOT

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Abstract

The Tandem cell structure has certain advantages compared to single cells, due to the complementary absorption of the subcells. The Tandem cell can boost the efficiency of organic solar cell to more than 15%, compared to the 10% limit of single solar cells. This article will review the effect of the solar cells structures (tandem or single) on the physical parameters extraction employing numerical method developed in Matlab code. These parameters are the ideality factors, saturation current; photocurrent, the series and shunt resistance which are parasitic parameters affect the solar cells conversion efficiency.

Keywords: organic solar cell, Tandem, single, parameters extraction, illumination I-V plot.

I. Introduction

Today, energy is an important requirement for both industrial and daily life, as well as political, economical, and military issues between countries. While the energy demand is constantly increasing every day, existing energy resources are limited and slowly coming to an end. Due to all of these conditions, researchers are directed to develop new energy sources which are abundant, inexpensive, and environmentally friendly. Solar energy, which is limitless, clean, and renewable, can meet these needs of mankind. Organic solar cells have attracted widespread interest in both the academic and, increasingly, the commercial communities. These organic solar cells are promising in term of their electronic properties, low cost, versatility of functionalization, thin film, flexibility, and ease of processing [1-2]. Organic solar cell performances are strongly improved using PIN structure with doped wide-gap transport layers and phthalocyanine-fullerene blend as a photoactive layer, which is shown that this architecture is particularly useful for stacking several cells on top of each other. Where a high efficiency have been demonstrated by stacking two *p-i-n* cells both with a phthalocyanine-fullerene blend as photoactive layer [3-5].

Organic tandem cells have spurred much interest because of their advantage to harvest a greater part of the solar spectrum compared to single solar cell. However, the working mechanism of the interlayer that joins the two subcells in a tandem cell is less understood and is essential in achieving high efficiency, and which affect the physical parameters that describe the nonlinear electrical model of organic solar cell which are the series and shunt resistance, ideality factor, saturation current and photocurrent. So, an accurate extraction and optimization of organic solar cells parameters are very important in improving the device quality during fabrication and in device modelling and simulation under different conditions of temperature and illumination. These parameters are the series resistance (R_s), ideality factor (n), saturation current (I_s), shunt resistance (R_{sh}) and photocurrent (I_{ph}). The series resistance for instance, has a significant effect on both the fill factor and the conversion efficiency. The diode ideality factor has been introduced for a p-n junction solar cell after consideration of the physical phenomena that occurs in diode. In the literature several methods have been suggested for extracting solar cell parameters [6-12] and applied to different solar cells under different condition of temperature and illumination.

Here, the authors present a new method based on [13] to extract the five solar cell parameters of the single diode lumped circuit model under illumination using experimental I–V characteristics of different organic solar cells. These devices are a single and tandem p-i-n solar cells under 130 mW/cm^2 simulated AM 1.5 solar illumination and under temperature of 40°C, and we present the effect of these structures on the solar cell parameters.

II. METHOD AND ANALYSIS

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

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

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 β=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 or direct bias characteristics by a simple linear fit [14]. 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:

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

which is equivalent to:

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

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

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

By subtracting Eq. (3) and Eq. (4) and after a simplification we get a linear equation for $I>>I_s$ given by:

$$Y = \frac{\beta}{n}(R_s + X) \quad (5)$$

where:

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

and

$$X = \frac{(V - V_0)}{(I - I_0)} \quad (7)$$

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 $I_0 = I_{N-1}$. Finally, we obtain N(N-1)/2 pairs of X-Y data that means more values for the linear regression..

For most practical illuminated solar cells we usually consider that $I_s<<I_{ph}$, the photocurrent can be given by the approximation $I_{sc} \approx I_{ph}$, where I_{sc} is the short-circuit current. This approximation is highly acceptable and it introduces no significant errors in subsequent calculations [15].

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.

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

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.

II. RESULTS AND DISCUSSION

Our method is applied on the single and Tandem pin organic solar cells. I-V characteristics of single and Tandem p-i-n solar cells are taken under 130 mW/cm^2 simulated AM 1.5 solar illumination and under temperature of 40°C [16]. The Tandem cells are comprised of two single p-i-n cells with an ultrathin metal layer in between. The proposed type cell structure contains donor-acceptor blend of ZnPc and C_{60} (molar ration one-to-two) as photoactive part (bulk heterojunction) sandwiched between wide-gap transport layers of p-doped MeO-TPD and n-doped $C_{60.}$ In detail, the layer sequence is ITO/30 nm *p*-doped MeO-TPD/ 60 nm ZnPc:C60 blend (molar ratio of 1:2) /20 nm *n*-doped C60/0.5 nm Au/125 nm *p*-doped MeO-TPD/50 nm ZnPc:C60 blend (molar ratio of 1:2) /20 nm *n*-doped C60 /100 nm Al.

The experimental current-voltage *(I-V)* data were taken from Drechsel et al [16] work for the single and Tandem pin solar cells. The photocurrent has been taken directly as the short circuit current according to the approximation $I_{ph} = |I_{sc}|$.

The shunt conductance $G_{sh} = 1/R_{sh}$ was calculated using a simple linear fit of the reverse or direct bias characteristics. 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:

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

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 ith point among N considered measured data points. 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:

$$\begin{aligned} RMSE &= \left(\sum |e|_i^2 / N\right)^{1/2} \\ MBE &= \sum e_i / N \\ MAE &= \sum |e|_i / N \end{aligned} \tag{10}$$

N is the number of measurements data taken into account.

The extracted parameters obtained using the method proposed here for the single and Tandem pin solar cell are given in Table 1. The statistical indicators for the method of this work are shown in Table 2.

Table1: Extraction parameters for the different solar cell using our method.

	Single cell	Tandem cell
G_{sh} (Ω^{-1})	5.20 x 10^{-3}	1.25 x 10^{-3}
R_s (Ω)	4.778	5.226
n	4.180	7.548
I_s(A)	0.123 x 10^{-3}	0.070 x 10^{-3}
I_{ph}(A)	15.2 x 10^{-3}	10.8 x 10^{-3}
FF (%)	0.37	0.47
η (%)	2.11+/-0.20	3.80+/-0.20

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

	Single cell	Tandem cell
RMSE (%)	2.8679	1.3403
MBE (%)	0.2373	-0.4364
MAE (%)	1.9553	0.5289

Figures 1 and 2 show the plot of *I-V* experimental characteristics and the fitted curves derived from (1) with the parameters shown in Table 1.

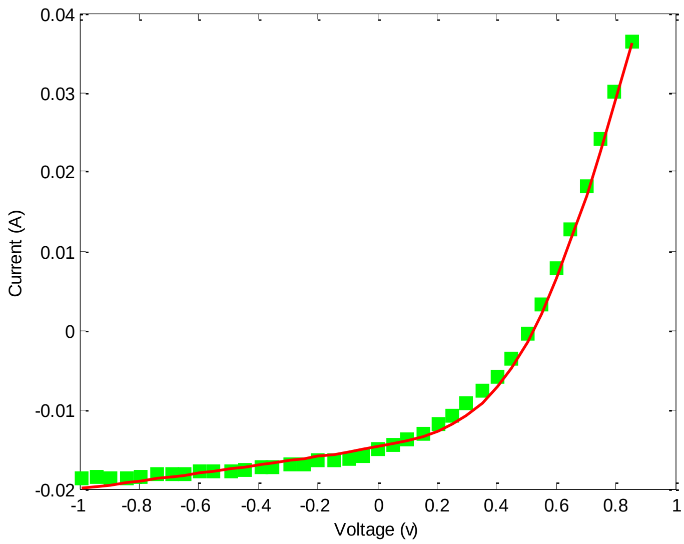

Figure 1: Experimental (■) data and fitted curve (—) for single solar cell with 60 nm active layer under 130mW/cm^2 and T=40°C.

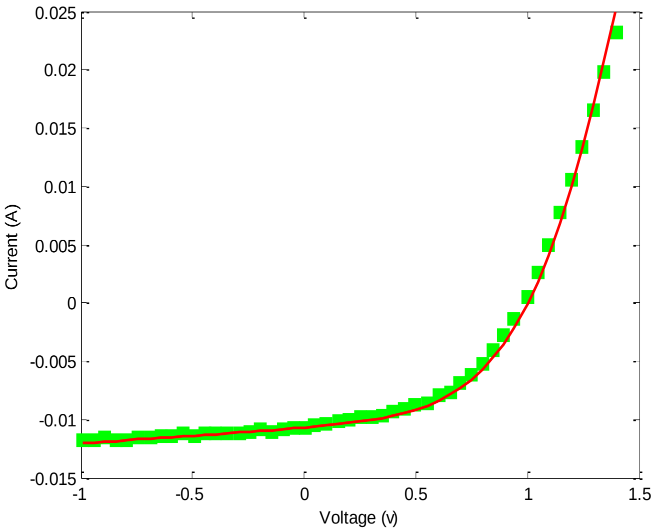

Figure 2: Experimental (■) data and fitted curve (▬) for Tandem solar cell with 60 nm active layer under 130mW/cm^2 and T=40°C.

Good agreement is observed for the different structure, especially for the Tandem pin solar cells with statistical error less than 2% for Tandem cells, which attribute mainly to lower parasitic losses due to the charge losses and recombination charge and presented by low series resistance 5.226Ω and low conduction shunt 0.00125Ω compared to statistical error less than 3% for single cells with high series resistance 4.778Ω and shunt conductance 0.00520Ω. So, this present the advantages of using Tandem structures compared to single cells.

The interesting points with the procedure described herein is the fact that it has been successfully applied to experimental I–V characteristics of different architecture of pin organic solar cells with completely different physical characteristics. Extracting this five parameters improve the work presented in [16], where The Tandem cell exhibits a significantly higher power efficiency of 3.8±0.2% compared to the single *p-i-n* cell (2.1±0.2%) under 130 mW/cm^2 simulated AM 1.5 illumination. The open-circuit voltage of V_{oc} =0.99 V is doubled as compared to the single p-i-n cell (V_{oc}=0.50 V). The short-circuit current of the Tandem is reduced, but still clearly exceeds one-half of the value of the single cell. We also note a remarkably improved fill factor of 0.47 for the Tandem cell, as compared to 0.36 for the single cell which we attribute mainly to the reduced impact of the series resistance. The interesting point with the procedure described herein is the fact that we do not have any limitation condition on the voltage and it is reliable, straightforward, easy to use and successful for different types of solar cells.

III. CONCLUSION

In summary, Tandem cell has certain advantage compared to single cell; due to the complementary absorption of the subcells present a higher optical density over a wider spectral range than single cells. Tandem cells have the advantage of reducing the parasitic losses given by the series resistance and shunt conduction which affect the conversion efficiency. So, a numerical simulation has been employed to determine the five solar cell parameters: series resistance, shunt conductance, ideality factors, saturation current and photocurrent of organic pin solar cells based on single or multiple structures using the illuminated I-V characteristics.

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