Effect of Series Resistance and Layer Thickness on PCE and Fill Factor in Organic Solar Cell with P3HT: PCBM Active Layer

Pooja Sinha[1], Rahul Baghel[2]

[1]M.Tech scholar, Dept. of Electrical and Electronics Engineering, SSGI Durg-490001, Chhattisgarh, India
[2]Assistant Professor, Dept. of Electrical and Electronics Engineering, SSGI Durg-490001, Chhattisgarh, India

---***---

Abstract - *This paper reports a study on the effect of series and layer thickness on the performance of an organic photovoltaic cell which is based on polymer/fullerene P3HT: PCBM. Electrical simulation has been examined on ITO-PEDOT: PSS-P3HT: PCBM-Al structure with GPVDM (General-Purpose Photovoltaic Device Model) software. We used the GPVDM software to investigate the effect of series resistance and layer thickness on power conversion efficiency (PCE) and fill factor (FF) in an organic solar cell which is based on P3HT: PCBM as an absorbing layer. The changes were made by applying the different series resistance and layer thickness value. The results show that the power conversion efficiency can be increased by changing the value of the series resistance and layer thickness, in our case the power conversion efficiency has been increased from 11.66% to 13.84% and fill factor has been change from 66.29% to 70%.*

Key Words: Organic photovoltaic cell, P3HT: PCBM, GPVDM, series resistance, thickness effect.

1. INTRODUCTION

Organic photovoltaics (OPVs) have attracted considerable interest over the past two decades due to their advantages over inorganic solar cells. OPVs are lightweight, cheap and non-toxic compared to inorganic solar cells. They are also robust and versatile mechanically. Organic solar cells, as the name implies, transform light from organic molecules into electricity. For these solar cells, synthetic polymers and small organic molecules are widely used. Their long chain relocation via alternating double and single connections helps to effectively transfer the electron in the cell. The highest occupied molecular orbitals (HOMOs) and the lowest unoccupied molecular orbitals (LUMOs) are these orbits. An optical band gap in the half conductor area is the power disparity between the low-energy HOMOs and the high-energy LUMOs. Because of their versatile material properties and low-cost processing, organic solar cells have been a very remarkable area of research in recent years.

In the early 1950s, organic solar photovoltaic cells were developed. Since 1965, organic chemistry has had a fast growth and the first discovery of photoconductivity in organic compounds was published in 1906. The product, Solarmer, developed for the first time Organic Photovoltaic. BHJ-based organic solar cells (Bulk Hetro-junction) are composites of P3HT (Poly3-hexylthiophene) and PCBM (phynyl-C-70buteric acid methyl ester) [1-2]. Gpvdm (OPVDM's new name) is a free general-purpose device

simulation tool. Originally designed to simulate organic solar cells, it has now been expanded to simulate other system categories, including OLEDs, OFETs and many other forms of solar cells of 1st, 2nd and 3rd generation. The physical model solves drift-diffusion of electron and hole as well as continuity equations of the carrier in position space to describe the load movement within the device. The model also solves the equation of Poisson to calculate the potential of internal electrostatics. Recombination and carrier trapping are described in the model using Shockley-Read-Hall (SRH) formalism; it is feasible to arbitrarily define the distribution of trap states. Both equations can be solved in a steady state or in a time domain.

The model facilitates the study of the effect on system performance of product parameters such as mobility, energetic disorder, doping, and recombination cross-sections. All internal device parameters such as current density load frequency, position distribution of trapped carriers and energy storage can be controlled through either the graphical interface or directly from output data. The system includes both an electrical and an optical solver, allowing simulation of current / voltage characteristics and the optical model profile within the device. The model is available for Windows and Linux (x86 and ARM) and it is easy to use graphical interface. Gpvdm is a tool used to simulate and design solar cells to harvest the energy of the sun.
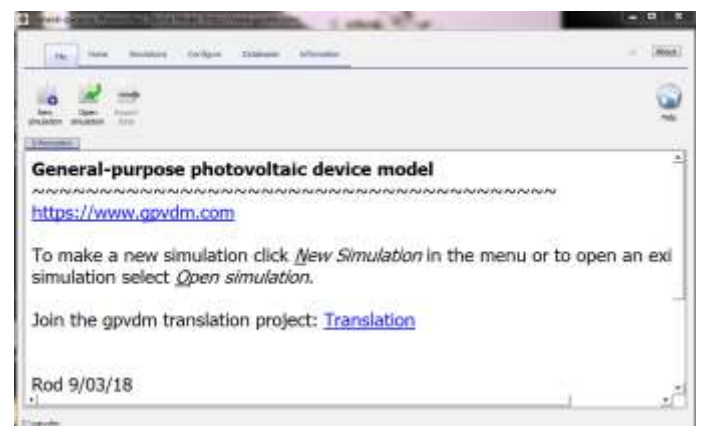

Fig 1: GPVDM Home Window

2. ELECTRICAL SIMULATION

The significant parameters that influence its performance should be explored in order to improve the power conversion

efficiency of organic solar cells. The GPVDM software simulates the organic solar cell at various layer thicknesses. This model consists of both electrical and optical properties and is specifically designed to mimic organic solar cells based on the P3HT and PCBM mixture of polymer material [7]. The electrical simulation just reaches the device's active layer. The current density-voltage curve (j-v) plotted for Voc and Jsc to be provided. The Voc is defined by the energy gap between the largest molecular orbital occupied (HOMO) representing the donor level and the lowest unoccupied molecular orbital (LUMO) describing the acceptor level [8]. The j-v curve provides the fill factor specified as the ratio between the maximum power point (Pmpp) and the device's theoretical maximum power (Pmax) [8-11].

$$FF = \frac{Vmax \times Jmax}{Voc \times Jsc}\frac{Vmax \times Jmax}{Voc \times Jsc}$$

Here, Vmax and Pmax are the voltage and current density in the maximum power point respectively. The power conversion efficiency for a solar cell is defined by the equation.

$$\eta = \frac{Pout}{Pin} = \frac{FF \times Vmax \times Jmax}{Pin}\frac{FF \times Vmax \times Jmax}{Pin}$$

Where, Pin is the power density of the light and Pout is the electric power generated by the bulk hetero junction solar device at maximum power point. [12]

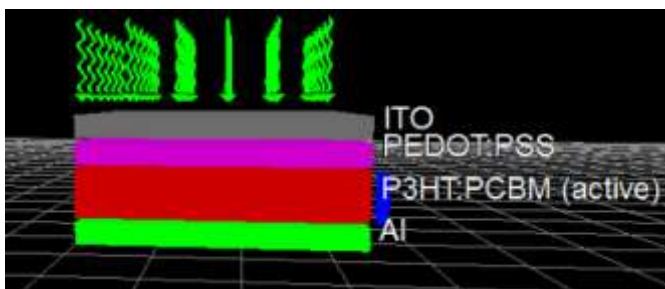Architecture of organic solar cell is shown in figure 2.

Fig.2: Organic Solar Cell Model

Fig.2 demonstrates the PEDOT: PSS / P3HT: PCBM-based organic solar cell design. In this example, the layer configuration followed is ITO / PEDOT: PSS / P3HT: PCBM / Al, where ETM (Electron Transfer Layer) is PEDOT: PSS and HTM (Hole Transfer Layer) is P3HT: PCBM [5]. The Indium Tin Oxide (ITO) film is used as a transparent electrode because it has strong visible region transmittance and conductive capacity [12]. Original parameters chosen from OSC electrical parameters are shown in Table 1. The electrical and optical parameters of organic solar cells are derived from the ITO layer and Al dependent gpvdm software database, and the layer thickness values are taken as 1e-07 and 1e-07 respectively [13].

Our analysis is focused on the observation of different layer thickness effects on the efficiency of power conversion [14]. Table 1 displays the reference value of the simulation parameters.

S.No.	Parameters	PEDOT:PSS	P3HT:PCBM
1	Layer Thickness (m)	1e-07 (variable)	2.2e-07(variable)
2	Relative permittivity	3.8	3.8
3	Electron tail slope (ev)	4.00E-002	4.00E-002
4	Hole tail slope (ev)	6.00E-002	6.00E-002
5	Doner Concentration (m-3)	1.28E+027	1.28E+027
6	Acceptor Concentration (m-3)	2.86E-025	2.86E+025

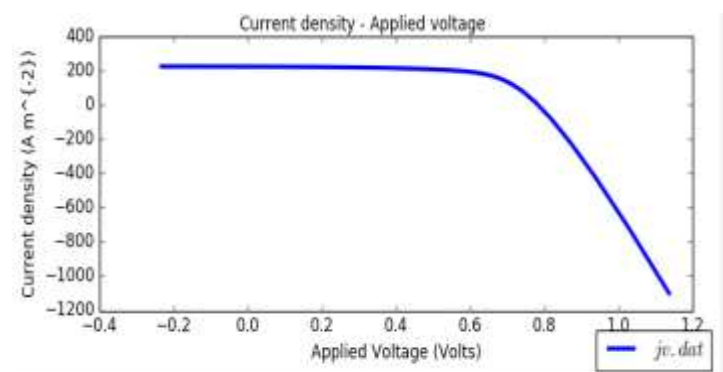**Table.1:** Simulation Parameters

Fig.3: J-V Characteristics for initial layer values

The j-v curve is shown in Fig 3, in which PCE (Power conversion efficiency) is 11.66%, fill factor is 66.29%, short circuit density of current is -224A/m and open circuit voltage Voc is 0.78V [15].

3. RESULTS AND DISCUSSIONS

In our simulation, optimization method is used to fix all parameters and modify the values one by one until we have the parameters that give maximum Power Conversion Efficiency. Figure 4 represents the curve effect of PEDOT: PSS layer thickness on PCE in organic solar cell.
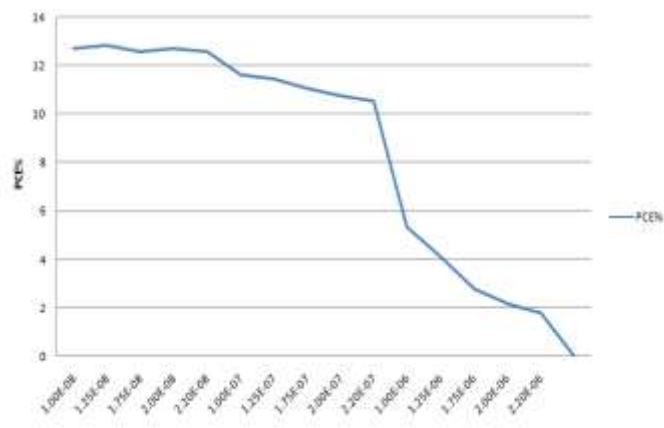
Fig 4. Effect of PEDOT: PSS layer thickness on PCE

In Fig 4, it is shown that a PEDOT:PSS layer thickness of 1.25×10-8 m gives the maximal value of PCE which is 12.86%, with a fill factor of 65.29%, an open circuit voltage of 0.78V and a short-circuit density of current of -251.27 A/m 2. Now we fix the value of PEDOT: PSS layer thickness at 1.25×10-8 m and change the value of P3HT: PCBM layer thickness to obtain curve in Figure 5.

Fig 5. Effect of P3HT: PCBM layer thickness on PCE

In Figure 5, it is shown that P3HT:PCBM layer thickness of 2.2×10-7 m gives the maximal value of PCE which is 12.86%, where fill factor is 65.29%, open-circuit voltage is 0.78 V and short-circuit density of current is -251.27 A/m. Fig 4 and Fig 5 presents different layer thickness effect on PCE for a PEDOT:PSS and P3HT:PCBM based planar organic solar cell where we see that the efficiency increased from 11.66 % in initial default parameters to 12.86 % with optimized parameters.
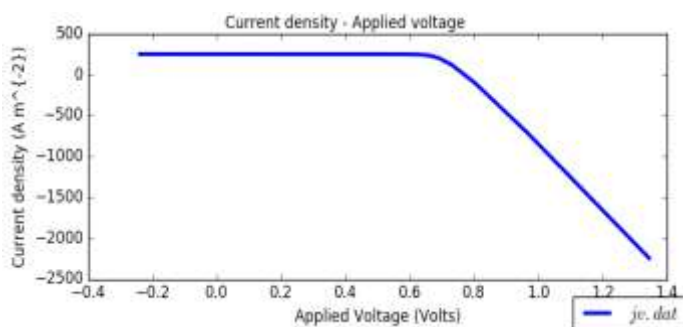

Fig 6. J-V characteristics for optimized layer values

In Fig 6, J-V characteristic of the organic solar cell is shown with optimized parameters.

In addition of this research work, the illumination J-V characteristics are simulated at different resistances 1Ω, 3Ω, 5Ω, and 7Ω. The J-V characteristic curves are shown in the fig 7. It is clear from the J-V characteristics curves that the short circuit current decrease with increase in the series resistance continuously, at 1Ω the short circuit current is maximum and minimum at 7Ω. As series resistance increases, the voltage drop between the junction voltage and the terminal voltage becomes greater for the same current. The result is that the current-controlled portion of the I-V curve begins to sag toward the origin, producing a significant decrease in the terminal voltage and a slight reduction in ISC, the short circuit current. Very high values of RS will also produce a significant reduction in ISC; in these regimes, series resistance dominates and the behavior of the solar cell resembles that of a resistor. These effects are shown for crystalline silicon solar cells in the j-v curves [16].
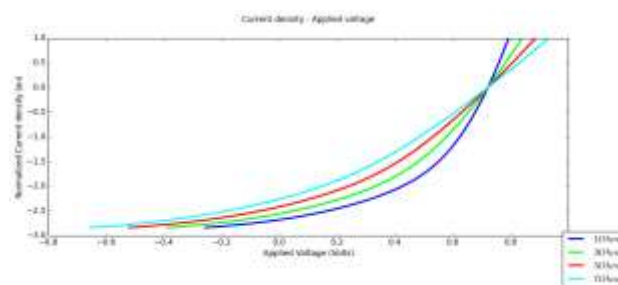

Fig 7. J-V characteristics at different series resistance 1Ω, 3Ω, 5Ω, 7Ω

4. CONCLUSION

Organic solar cell's power conversion efficiency was analyzed using the GPVDM solar cell software simulation. Results indicate that a good choice of series resistance and layer thickness of different materials used in the solar cell considerably increased the PCE ratio. From the simulation results it is found that an improvement of 2.18% is made by setting layer thickness of PEDOT: PSS to 1.25×10-8 m and layer thickness of P3HT: PCBM to 2.2×10-7 m, and setting series resistance to 1 Ω .Further PCE enhancements can be done by changing layer structure and materials.

REFERENCES

[1] M.Erray, M.Hanine, E-M.Boufounas, and A.El Amrani, Effects of carriers charge mobility and work function on the performance of PEDOT: PSS and P3HT: PSS based organic photovoltaic cell, Journal of IEEE conference, 2018.

[2] G. Li, V.Shrotriya, Y. Yao, eT Y. Yang, Investigation of annealing effects and film thickness dependence of polymer solar cells based on poly (3-hexylthiophene), J. Appl. Phys, 2005.

[3] Electrical Simulation of Organic Solar Cell at Different Charge Carrier Mobility, IOSR Journal of Applied Physics (IOSR-JAP), Mar-Apr, 2017.

[4] S.R. Cowan, N.Banerji, W.L.Leong, A.J.Heeger, Charge formation, recombination, and sweep-out dynamics in organic solar cells, Adv.Funct, 2012.

[5] C.-T. Lee et C.-H. Lee, « Conversion efficiency improvement mechanisms of polymer solar cells by balance electron–hole mobility using blended P3HT: PCBM active layer.

[6] Roderick C. I. MacKenzie, Thomas Kirchartz, George F. A. Dibb, and Jenny Nelson, Modeling No geminate Recombination in P3HT: PCBM Solar Cells, J. Phys. Chem.2011.

[7] B.M.Omer, Understanding photo-degradation mechanism in P3HT: PCBM bulk heterojunction solar cells AMPS-1D simulation study: Photo-degradation mechanism in P3HT: PCBM bulk heterojunction solar cells, Phys. sept. 2016.

[8] A.B.walker, A. Kambili, et S.J.Martin, Electrical transport modeling in organic electroluminescent devices, 2002.

[9] R. Hanfland, M.A. Fischer, W.Brütting, U.Würfel, R.C.I.MacKenzie, The physical meaning of charge extraction by linearly increasing voltage transients from organic solar cells, Appl. Phys.,2013.

[10] F. Deschler, D. Riedel, B. Ecker, E. von Hauff, E. Da Como, R.C.I. MacKenzie, Increasing organic solar cell efficiency with polymer interlayers, Phys. Chem. Chem. Phys., 2012.

[11] R.C.I. MacKenzie, C.G. Shuttle, M.L. Chabinyc, J. Nelson, Extracting microscopic device parameters from transient photocurrent measurements of P3HT: PCBM solar cells, Adv. Energy Mater,2012.

[12] Nikhil Rastogi, Narendra Singh, Sandeep Saxena, Analysis Of Photovoltaic Dsevice at Different Series Resistances,Universal Journal of Materials Science,2017.

[13] Gpvdm manual Roderick C. I. MacKenzie April 6, 2018.

[14] Ball, J.M., et al., Optical properties and limitingphotocurrent of thin-film perovskite solar cells, Energy& Environmental Science,2014.

[15] A.Hima,A.Khechekhouche ,GPVDM simulation of layer thickness effect on power conversion efficiency of CH3NH3PbI3 based planar heterojunction solar cell, IJECA-ISSN, June 2018.

[16] J.Yan, Handbook of Clean Energy Systems, https://books.google.co.in/books, 1118388585. Vol. 6 (2015).