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Investigation of organic solar cell at different active layer thickness using electrical simulation

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Abstract: *Using GPVDM software, organic photovoltaic device have been electrically simulated at different active layer thickness. A composite of P3HT:PCBM is used as active layer material. ITO, PEDOT:PSS & Al is used as transparent electrode, electron blocking layer & back electrode respectively. Electrical simulation has been done at different active layer thickness 100,150,200,250 & 300 nm. In this study it has been observed that J-V characteristics are affected by active layer thickness. Fill Factor, Power conversion efficiency, short circuit current changes significantly with the change in active layer thickness. The best J-V characteristic is observed at 200 nm.*

Keywords: *GPVDM Software, Organic Solar cell, Bulk Heterojunction, J-V Characteristics, Fill factor*

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I. Introduction:

Today's civilization is fed by power that is being generated mostly by burning fossil fuels. Emission of green house gas due to burning fossil fuels, enhanced green house effect, global warming and self destructing processes created by human civilization are serious threats to life on earth. Advancement of civilization demands more power to be generated, but the stock of fossil fuel is diminishing very quickly. Therefore we search for renewable energy resources, of which PV seems to be one of the most promising and secure. Inorganic silicon based solar cells are efficient but the production cost is high enough to be utilized in large scale. Organic solar cell is a good choice for its low cost, relatively easy processing techniques etc. compared to most inorganic materials [1].

First organic solar cell (OSC) was reported by C.W. Tang in 1975, but its efficiency was quite low. A. J. Heeger, MacDiarmind and Shirakawa discovered that the conductivity of conjugated polymers can be increased by doping. They win noble prize(2000) in chemistry for their contribution. By 1986, the OSC efficiency over 1% was achieved by C.W. Tang. Recently maximum organic cell efficiency of 13% is achieved [2].

Bulk Heterojunction (BHJ) formed by an interpenetrating of a conjugate polymer & electron accepting molecules constitute an active layer that allows the maximum absorption of light. So it becomes a point of interest to study the device structure of OPV. As far as power conversion efficiency is concern, active layer width plays an important role. In this research article, we study the dependence of solar cell J-V Characteristics at different active layer thickness and trying to search the optimum active layer thickness to get the maximum efficiency using simulating software GPVDM (General Purpose Photovoltaic device model). Also we study the Fill Factor, Power conversion efficiency, short circuit current, open circuit voltage for each active layer width separately.

II. Organic Solar Cells:

Different types of OPV structures have been found in the literature which is given below.

2.1 Single layer: The basic structure of single layer cell of organic photovoltaic cell is shown in figure 2. Organic electronic material is kept in normally a layer of indium tin oxide (ITO) with high work function and Calcium, Magnesium or Aluminum with low work function.

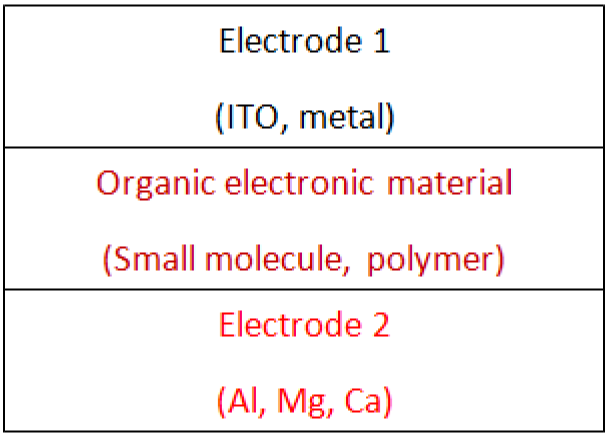

Figure 1: Single type Photovoltaic

2.2 Double layer: Figure 3 shows the schematic diagram of bilayer photovoltaic.

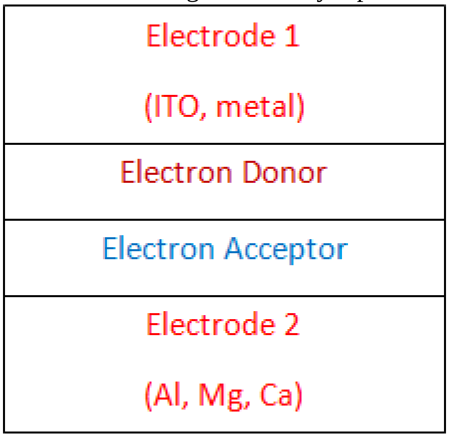

Figure 2: Bilayer type Photovoltaic

Here two layers are sandwiched in between the conductive electrodes as shown in figure. Electrostatic force are generated at the interface between the two layers due to the different electron affinity and ionization energies. This is also known as planer donor-acceptor heterojunction.

2.2 Bulk Heterojunction:

Structure of bulk heterojunction ITO/PEDOT:PSS/ P3HT:PCBM/ Al solar cell has been shown in the following fig. Al is used as counter electrode for easy collection of electron. PEDOT:PSS acts as buffer layer and P3HT:PCBM is used as active layer. Due to having high transmittance in visible region and ability of conduction, Indium Tin Oxide (ITO) film is used as a transparent front electrode.

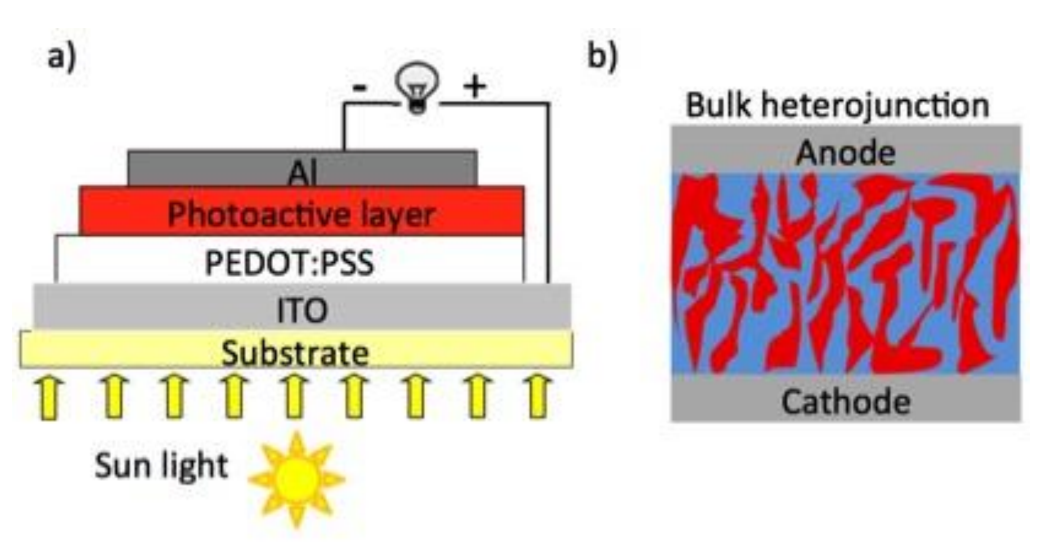

Fig 3: Bulk Heterojunction Solar cell

In BHJ, active material consisting of donor-acceptor blend allows light absorption and generation of excitons. Generated excitons are splitted at donor-acceptor interface. Also efficient transportation of positive and negative charges to opposite electrodes occurs at active material. The active layer material P3HT (3-hexyl thiophene) is a good electron donor that effectively transports positive holes and PCBM ([6, 6]-phenyl C61-butyric acid methyl ester) is a good electron acceptor. Thickness of active layer plays an important role in solar cell. To block the electron and hole transfer in the wrong direction an electron blocking layer PDOT: PSS may be used as buffer layers between the electrodes and active layer.

III. Electrical Simulation:

Electrical simulation of ITO/PEDOT:PSS/P3HT:PCBM/Al bulk heterojunction solar cell has been done at different active layer thickness using GPVDM Software which is developed for the simulation of BHJ solar cells based on P3HT:PCBM materials. Both optical & electrical simulation can be done using this software. Electrical simulation only covers the active layer of the device.

The electrical simulation window has been shown in the following figure.

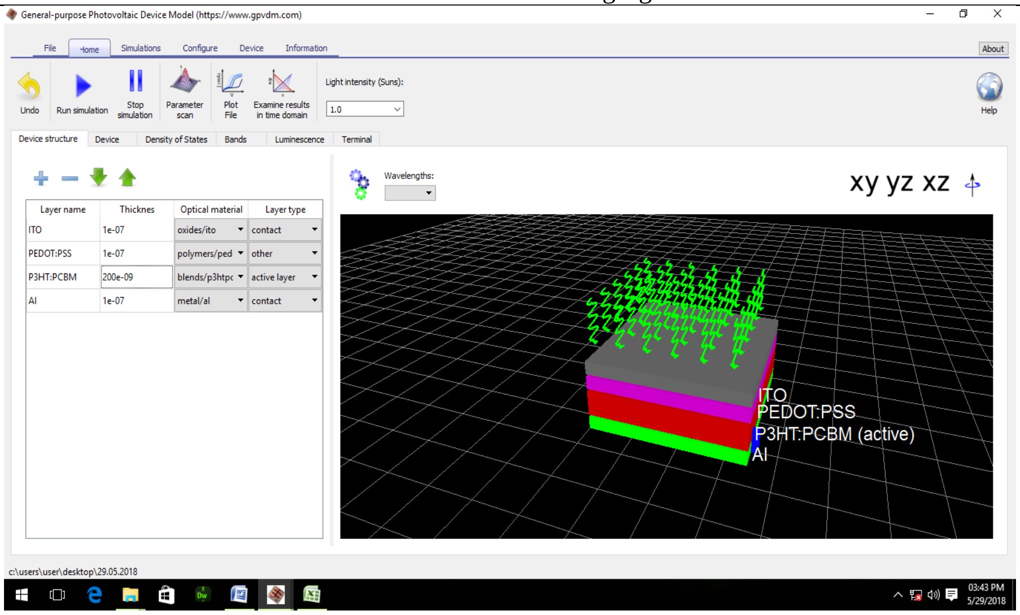

Fig 4: Electrical simulation window in GPVDM

We run the software for five active layer thickness 100,150,200,250 & 300 nm to get the J-V characteristic in one window. Simulation for each thickness separately has been done both for light of intensity 1 sun and in dark condition to get information like Fill factor, power conversion efficiency, open circuit voltage, short circuit current density etc. Width of all the layer used in the simulation is charted below.

Layer name	Thickness (nm)
ITO	100
PEDOT:PSS	100
P3HT:PCBM	100,150,200,250,300
Al	100

Table 1: Layer name with thickness

IV. Result & Discussion:

Dependence of active layer thickness on J-V Characteristics has been investigated in this research paper. Active layer thickness has been varied from 100 nm to 300nm in step of 50 nm. Best solar cell efficiency is achieved in the active layer 200 nm. Fig5 shows the j-v characteristics of ITO/PEDOT:PSS/ P3HT:PCBM/ Al device structure for active layer width 100,150,200,250 & 300 nm.

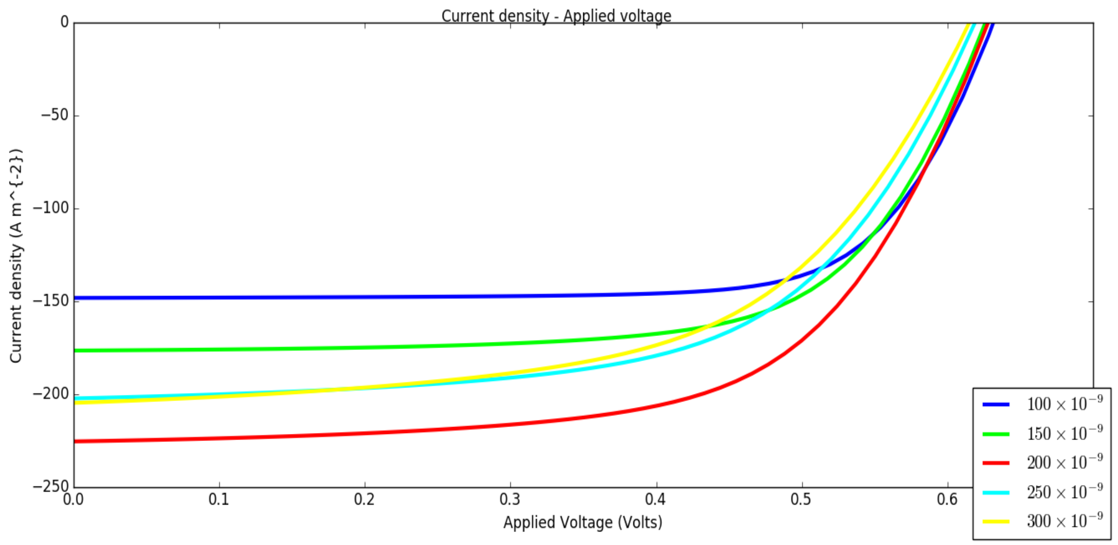

Fig 5: J-V characteristic for different active layer thickness

Various factors like Fill Factor, Power Conversion efficiency, Maximum Power, Open circuit voltage, Short circuit current density has been given in the following table for each active layer width separately. It is observed that maximum power conversion efficiency is achieved for active layer width 200 nm.

We have also investigated dark I-V characteristic of the same sample under the same thickness parameters and the result is shown in fig 8. It is seen that under dark condition the device acts as P-N junction diode. We have calculated the slope & threshold voltage (i.e voltage at which current jumps exponentially) for the I-V characteristic for different layer thicknesses and is shown in table 3. It is interesting to note that here also the threshold voltage is minimum for active layer length 200 nm, although the effect is quite small.

Active layer width (nm)	Fill Factor (a.u.)	Power conversion efficiency(%)	Max Power (Watt)	V_{OC} (V)	J_{SC} (A/m^2)
$100*10^{-9}$	0.727127	6.811870	68.118701	0.631660	-148.31
$150*10^{-9}$	0.669215	7.402435	74.024352	0.626108	-176.67
$200*10^{-9}$	0.621521	8.807847	88.078465	0.628057	-225.64
$250*10^{-9}$	0.597423	7.491144	74.911440	0.619064	-202.55
$300*10^{-9}$	0.565804	7.135782	71.357824	0.615135	-205.024

Table 2: Various parameters with active layer thickness:

A graph showing variation of power conversion efficiency vs active layer width has been shown in the figure 6.

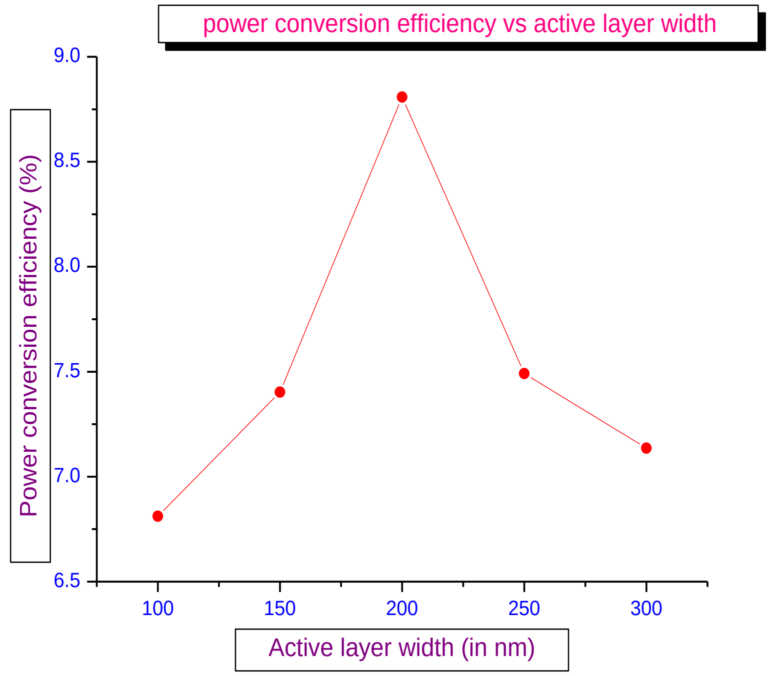

Fig6: Variation of power conversion efficiency with active layer width

Variation of short circuit current density vs active layer width has been plot in fig 7.

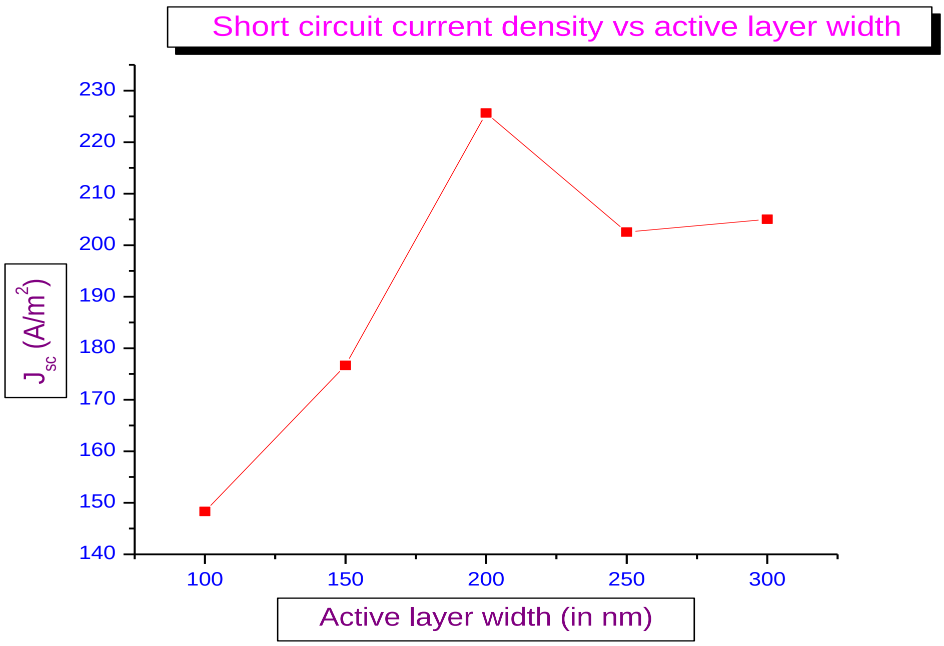

Fig 7: Variation of short circuit current density with active layer width

Fig. 8 shows log V vs log I curve for each active layer width.

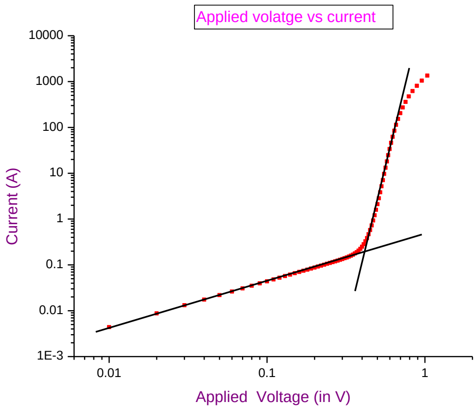

Figure 8a: I-V plot for active layer width 100 nm

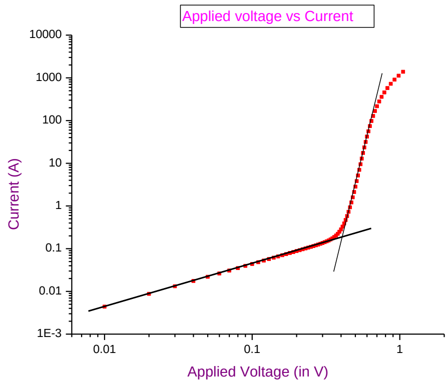

Figure 8b: I-V plot for active layer width 150 nm

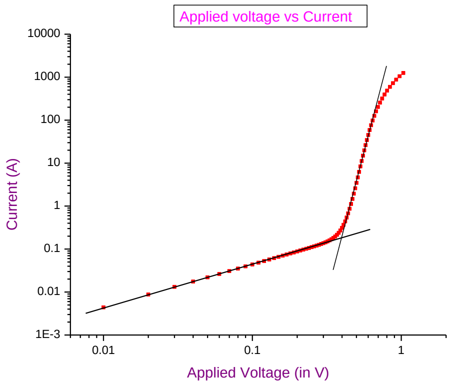

Figure 8c: I-V plot for active layer width 200 nm

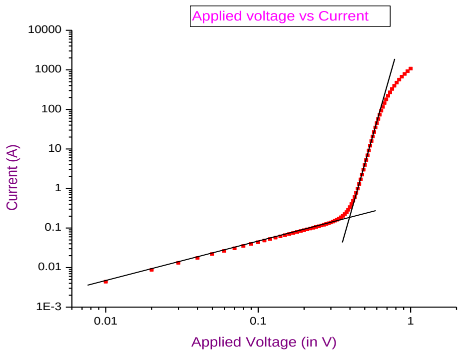

Figure 8d: I-V plot for active layer width 250 nm

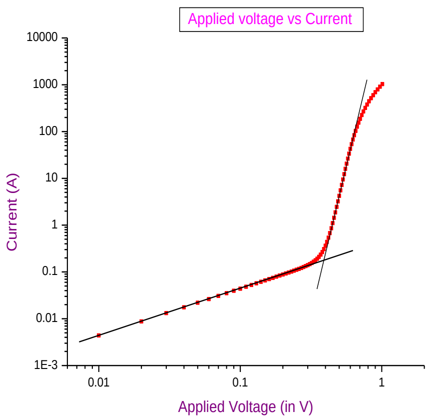

Figure 8e: I-V plot for active layer width 300 nm

Variation of slope and threshold voltage with active layer thickness has been tabulated in table 3.

Active layer width	Slope	Threshold Voltage (V)
100 nm	.47	0.552
150 nm	.532	0.542
200 nm	.463	0.531
250 nm	.457	0.532
300 nm	.4414	0.532

Table 3: Variation of slope and threshold voltage with active layer thickness

V. Conclusion:

Electrical simulation of the bulk heterojunction ITO/PEDOT:PSS/ P3HT:PCBM/ Al organic solar cell has been done at different active layer thickness using GPVDM Software. Efficiency will be low if the device is very thin as it cannot absorb so many photons. Again if the device becomes thicker then also efficiency decreases as the carriers has to travel a large distance from their generation to extraction leading to an increase in the probability of recombination. So there must be a balance between these two opposite effects on thickness. The optimum thickness of the active layer corresponds to maximum efficiency. Under dark condition carriers will be injected and drifted through the bulk of the material. At small voltages conduction is dominated by drift of carrier and I-V relation would be essentially ohmic. As voltage is increased injected carrier over numbers free carriers and the conduction will be controlled by diffusion. As holes are transporting through PEDOT:PSS & electron through active layer, layer thickness attains optimum when injected carrier meet at the junction and recombines which gives rises abrupt increase in the sample current. So active layer width plays an important role as far as power conversion efficiency is concern. Thus it is concluded that J-V Characteristics are affected by active layer thickness and best J-V characteristic is obtained at 200 nm.

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