Parametric Analysis of Carbon Nanotube Organic Solar Cells

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Abstract— **Different parameters of the organic solar cells have been analyzed and illustrated with necessary graphs and data. The analysis has dispersed within the different composition of Carbon nanotubes to the active layer of the photovoltaic. At first parameters like open circuit voltage and short circuit current are taken for different combination of CNT PV cells. These practically experimented values are collected from different research papers. Using these values series and shunt resistances are calculated from the PV cell equation. I-V curves are simulated using all these parameters. From the curves power conversion efficiency and Fill factor are obtained. Both the Efficiency and Fill factor simulated from I-V curves are more or less matched with practical data given in the research paper. In this paper we have mainly simulated the PV cell parameters and tried to correlate the values with the practical data.**

Keywords— CNT, Power conversion efficiency, Fill factor, Organic PV cell, Exciton

I. INTRODUCTION

The organic PV cells are the potential substitute for the traditional Si solar cells due to its low manufacturing cost, light weight and device flexibility [1]. In spite of the low power conversion efficiency and poor device performance organic PV cells are widely under extensive research. However short life time prohibits the practical implementation of organic PV cells [2]. Recently bulk heterojunction PV cells containing donor acceptor materials attract the attention of the researchers for their improved efficiency and performance. Generally four steps involved in organic PV cells operation i.e. exciton generation, diffusion, separation and carrier collection. Photocurrent can be increased by maximising the optical absorption and carrier transport rate and minimising the exciton and carrier recombination rate [3]. Rolled grapheme sheet i.e. carbon nanotubes have excellent electrical properties and can be integrated in organic PV cells to improve the device performance. CNTs increase the photocurrent by facilitating the exciton separation and charge collection. SWNT with conjugated polymer increase the carrier transport rate as an effect of better density of carriers and coulomb traps [4]. In this paper we have simulated different parameters of the photovoltaic and tried to correlate those with the trial ones

II. CARBON NANOTUBES IN ORGANIC PHOTOVOLTAIC CELL

Organic photovoltaic devices (OPVs) are fabricated from thin films of organic semiconductors, such as polymers and small-molecule compounds, and are typically on the order of 100 nm thick. Because polymer based OPVs can be made using a coating process such as spin coating or inkjet printing, they are an attractive option for inexpensively covering large areas as well as flexible plastic surfaces. A promising low cost alternative to silicon solar cells, there is a large amount of research being dedicated throughout industry and academia towards developing OPVs and increasing their power conversion efficiency. The high electric field at photovoltaic active layer junctions can split up the excitons, while the carbon nanotube (CNTs) can act as a pathway for the electrons also [5].Combining the physical and chemical characteristics of conjugated polymers with the high conductivity along the tube axis of carbon nanotubes (CNTs) provides a great deal of incentive to disperse CNTs into the photoactive layer in order to obtain more efficient OPV devices.

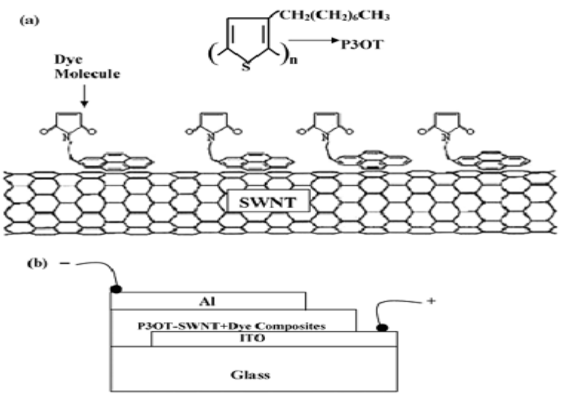

Fig. 1 a. Dye molecule attachment to SWCNTs surface and b. Photovoltaic device architecture [6]

A. CNTs as acceptors in organic PV cells

Semiconducting SWCNTs (s-SWCNTs) display type-II alignment and ultrafast charge transfer with conjugated polymers such as P3HT and it has been suggested that they can act as efficient acceptors at the edge with P3HT [7]. By contrast, recent investigations showed that metallic SWCNTs (m-SWCNTs) in the active layer have detrimental brunt on the photocurrent and speculative studies have predicted that the band alignment of P3HT/m-SWCNTs is unfavourable for charge separation [10]. Nano scale morphology is important in improving cell efficiency. Experiments show that when P3HT: PCBM blend with CNTs adopts an organized morphology in the active layer, the cell's performance is improved. It is found that the absorption spectra, I_{SC} increases while V_{OC} slightly decreases. But Voc remains on the higher side. Moreover, surface resistivity decreases and cause greater shift in the I-V characteristics towards greater fill factor.

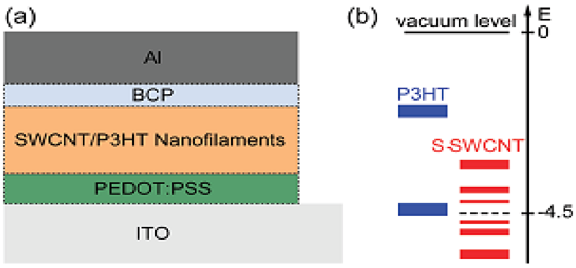

Fig. 2 a) Schematic of the solar cell (b) Band alignment diagram for P3HT/s-SWCNTs interfaces [8]

The PCE of an OPV cell composed of poly (3-octylthiophene) and SWCNTs has been shown to be 0.04% [6]. Interestingly, in spite of the low PCE, the open-circuit voltage of the OPV cell is high (0.75 V) compared to conventional fullerene-based OPV cells. High open-circuit voltage was also noted in another paper [5], but the overall efficiency was still low. There have been many attempts to increase the PCE. To improve the miscibility between conjugated the polymer and the CNTs surface modification techniques were utilized as a means to attach a thiophene group on the surface layer. Nevertheless, the PCE of the OPV cells with CNT acceptors is low compared to that of fullerene-based OPV cells.

B. CNTs as charge transport layer in organic PV cells

CNTs can be used as a charge-transport layer in an OPV device. Because CNTs have a remarkably high level of electronic mobility and a work function similar to that of the electrode, CNTs are good candidates for use in the charge-transport layer. Indeed, many studies have reported the large enhancement of PCE by insertion of CNTs as transporting layer. Due to the high work function of CNTs, CNTs are mainly effective in hole transportation [9].The high mobility of CNTs improves the PCE by increasing the carrier transport capabilities. Because the work function can be altered by a post-treatment procedure, it is expected that the charge carrier transport also can be tuned. Indeed, the work function of MWCNTs can be changed to 4.4 eV and 5.2 eV by n-doping and p-doping, respectively. According to a charge for the transportation results in an electron-only device and a hole-only device, the n-doping and p-doping of MWCNTs were found to have enhanced only the electron transport and the hole transport, respectively. This indicates that the end-use tailor-fit tuning of CNTs is possible in electronic applications. In Fig. 3 excitons can be generated in both the polymer and the fullerene. These excitons can then be dissociated at the polymer/fullerene, the fullerene/nanotube and the polymer and nanotube interfaces. Moreover, the electrons captured by the polymer can be transferred to the fullerenes and electrons that captured by the fullerenes can be transferred to the SWNTs, both processes being energetically favored. This schematic indicates faster electron transport than that in the ordinary PV device, where only hopping through the fullerenes is allowed [10]. Certainly incorporation of CNTs in the active layer on the acceptor side ensures better charge transport and thus increases the photocurrent.

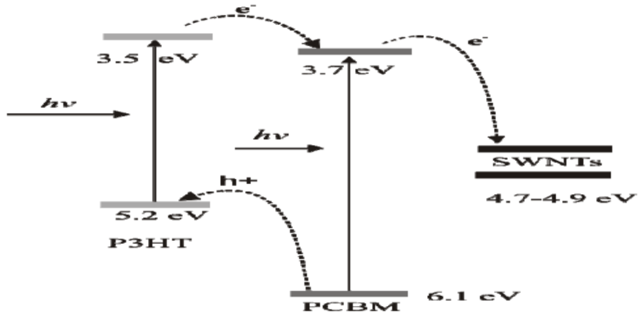

Fig. 3 Energy band diagram for P3HT: PCBM-SWCNT organic Photovoltaic [10]

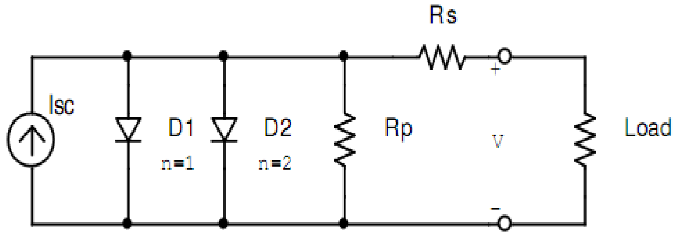

Fig. 4 Equivalent circuit of a photovoltaic cell

III. CURRENT-VOLTAGE ANALYSIS: ORGANIC PV CELLS

Different parameters like-Diode ideality factor, series resistance ,shunt resistance ,fill factors ,short circuit current density, open circuit voltage, recombination largely effects the power conversion efficiency of the photovoltaic cell. All these parameters can be extracted from the I-V curves of the photovoltaic cell. Considering all these effect equivalent circuit of a PV cell is shown in Fig.4. Summarizing the effects solar cell equation found to be-

$$I = I_{sc} - I_{01}\left(e^{\frac{q(V+IR_S)}{kt}} - 1\right) - I_{02}\left(e^{\frac{q(V+IR_S)}{2kt}} - 1\right)\frac{V+IR_S}{R_P} \qquad (1)$$

It is possible to combine the first diode (D_1) and the second diode (D_2) and rewrite the equation (1) in the following form.

$$I = I_{sc} - I_0\left(e^{\frac{q(V+IR_S)}{nkt}} - 1\right) - \frac{V+IR_S}{R_P} \qquad (2)$$

Considering as I=0 we have only the effects of the shunt resistance, R_p where $V=V_{oc}$ and considering V=0 we have only the effects of the series resistance R_s where $I=I_{sc}$. I_{sc} is short circuit current V_{oc} is open circuit voltage of the of the PV cell.

A. Parameters extraction for different photovoltaic cells

Open circuit voltage and short circuit current of P3HT: PCBM-Boron doped MWCNT and P3OT: N-(1-pyrenyl) maleimide- SWCNT organic PV cell have been taken from the specified papers [7, 8]. Series and shunt resistances are calculated from equation (2)

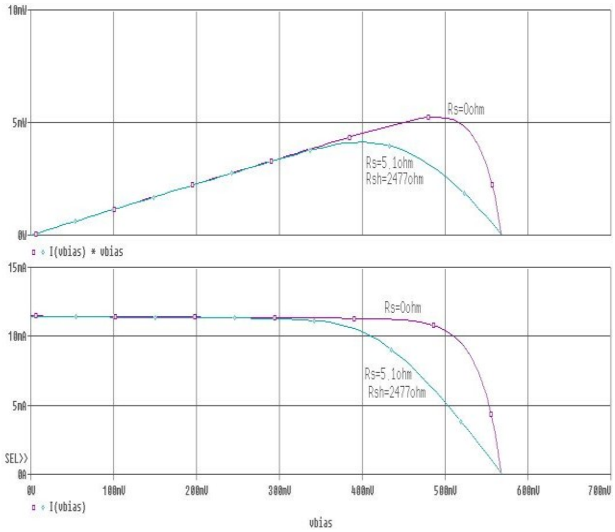

Fig. 5 Power (Current) as a function of Voltage curve for P3HT: MWCNT-PCBM concentrations

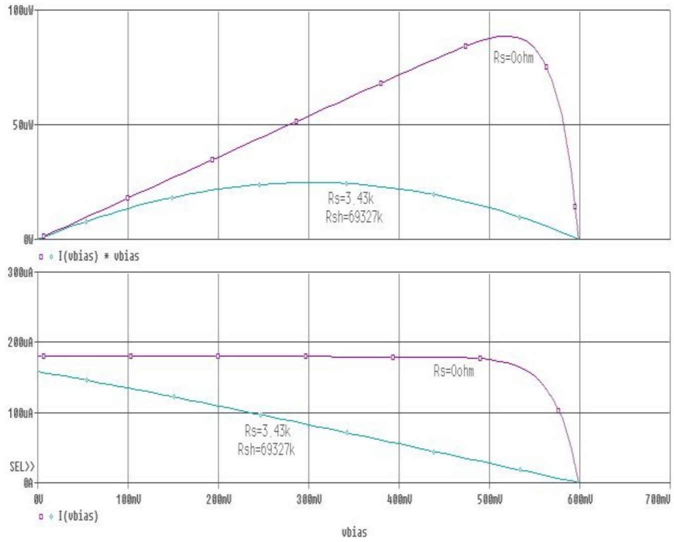

Fig. 6 Power (Current) as a function of Voltage curve for P3OT: SWCNT- N-(1pyrenyl) maleimide

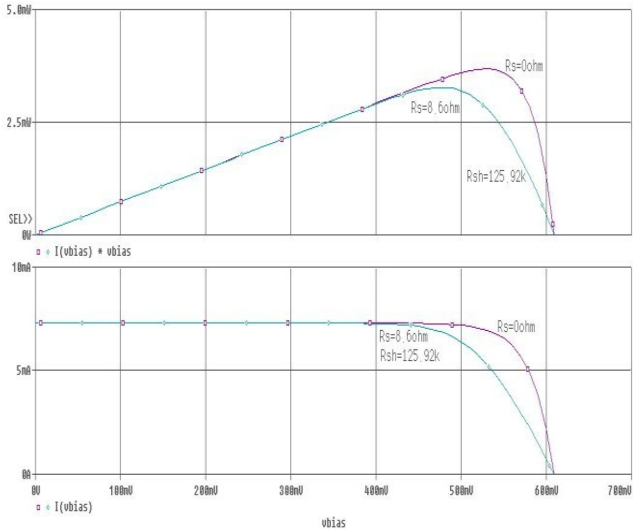

Fig. 7 Power (Current) as a function of Voltage curve for P3HT-SWCNT, MWCNT-PCBM concentrations

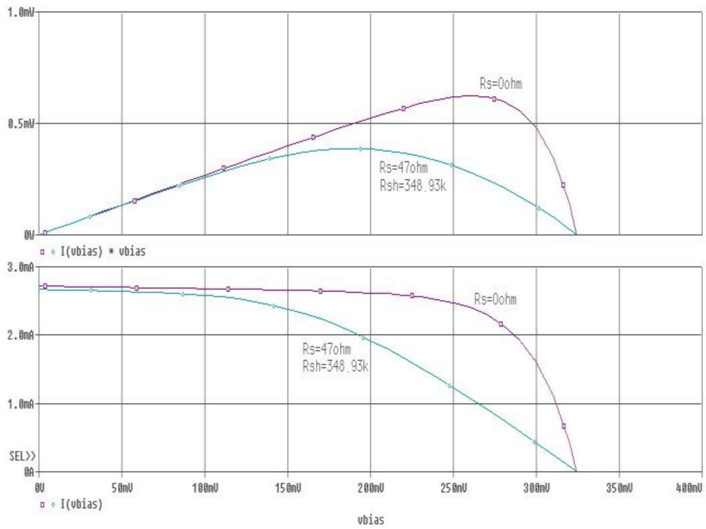

Fig. 8 Power (Current) as a function of Voltage curve for P3HT-SWCNT-C_{60} concentrations

Using these parameters i.e. V_{OC}, I_{SC}, R_S and R_P simulated curve and ideal curve (Rs=0) are shown in Fig. 5 and Fig. 6. PCE and FF are extracted from the curves. From our analysis we see that simulated efficiency is 4.12% and the fill factor is .63 whereas trial PCE is 4.1% and trial FF is .613.Parameters V_{OC} and I_{SC} of P3HT: PCBM- SWCNT, MWCNT and P3HT: C_{60}-SWCNT organic PV cells have been taken [9, 10].Using these parameters simulated curve and ideal curve (R_S=0) are shown in Fig. 7 and Fig. 8 respectively. Simulated conversion efficiency for the PV cells is 3.27% and .51% respectively. Alternatively trial PCE for the PV cells is 2.7% and .57% respectively. FF are .73 and .48 respectively conversely trial FF are .62 and .512 correspondingly. All the results are enlisted in table I. We can conclude that the simulated values correlate with the trial values.

TABLE I. PARAMETERS EXTRACTED FOR DIFFERENT PV CELLS

Donor Acceptor	**Transport layer**	**Trial FF**	**Trial PCE (%)**	**Simulated FF**	**Simulated PCE (%)**
P3HT-PCBM	Boron - MWCNT	.613	4.1	.63	4.12
P3OT- N(1-pyrenyl)maleimid	SWCNT	.35	.036	.26	.024
P3HT- PCBM	SWCNT, MWCNT	.62	2.7	.73	3.27
P3HT- C_{60}	SWCNT	.512	.57	.48	.51

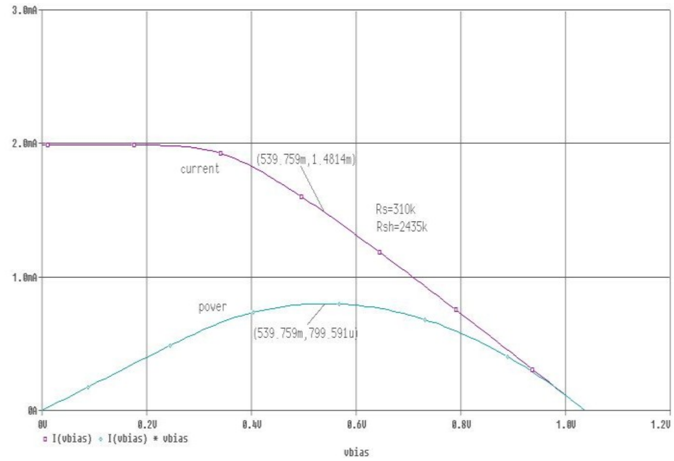

Fig. 9 Power (Current) as a function of Voltage curve for P3HT: SWCNT

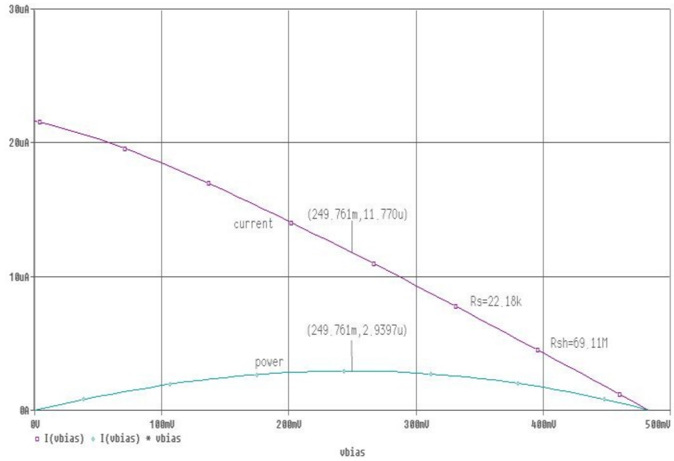

Fig. 10 Power (Current) as a function of Voltage curve for MO-PPV: SWCNT

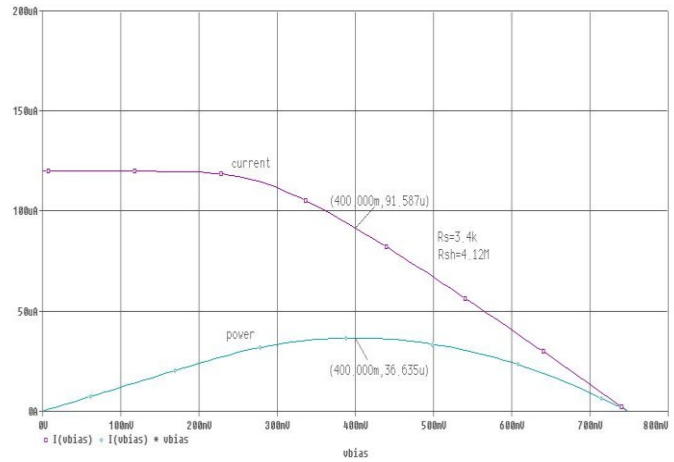

Fig. 11 Power (Current) as a function of Voltage curve for P3OT: SWCNT

B. Parameters extraction for different PV cells :CNT as acceptors

Different practically obtained parameters like open circuit voltage, short circuit current of P3HT: SWCNT and MO-PPV: SWCNT organic PV cells under illumination of AM 1.5 have been taken from specified paper [11, 12].Then R_S and R_P are calculated form PV cell equation. Using these parameters V_{OC}, I_{SC}, R_S and R_P, simulated curve is shown in Fig. 9 and Fig. 10 respectively. From the table II it is observed P3HT: SWCNT provides maximum efficiency of .72% correlates with trial PCE .67%. Simulated FF is .386 whereas the trial FF for the PV cell is about .38. Simulated PCE and FF for MO-PPV-SWCNT PV cell is .0029% and .2674 respectively. On the other hand trial PCE and FF is .0042% and .26 respectively. Same parameters for P3OT: SWCNT organic PV is being taken [13]. Using these parameters simulated curve is shown in Fig. 11. Simulated PCE is .0366% and FF is .40. These values correlate with the trial PCE .04% and trial FF .40. All the results are listed in table II. It can be said that the simulated and trial parameters are more or less coordinated with each other.

TABLE II. PARAMETERS EXTRACTED FOR PV CELLS (SWCNT AS ACCEPTORS)

Donor	**Acceptor**	**Trial FF**	**Trial PCE (%)**	**Simulated FF**	**Simulated PCE (%)**
P3HT	SWCNT	.38	.67	.386	.72
MO-PPV	SWCNT	.26	.0042	.2674	.0029
P3OT	SWCNT	.40	.04	.40	.0366

IV. SHORTCOMINGS OF CNTS PERFORMANCE

We conclude to the decision that the SWCNT in organic PV cell provides poor efficiency due to the inefficient charge transport through the active layer as excitons recombines before they are completely separated. Series resistance also dominates results in poor conversion efficiency. They have low quantum efficiencies (<1%) and low power conversion efficiencies (<0.1%). A major problem with them is that the electric field resulting from the difference between the two conductive electrodes is seldom sufficient to break up the photo generated excitons. Often the electrons recombine with the holes rather than reach the electrode. To deal with this problem, the multilayer CNT organic photovoltaic cells were developed. The diffusion length of excitons in organic electronic materials is typically on the order of 10 nm. In order for most excitons to diffuse to the interface of layers and break up into carriers, the layer thickness should also be in the same range as the diffusion length. However, typically a polymer layer needs a thickness of at least 100 nm to absorb enough light. At such a large thickness, only a small fraction of the excitons can reach the hetero junction interface [13]. To address this problem, a new type of heterojunction photovoltaic cells is designed, which is the dispersed hetero junction photovoltaic cells.

V. CONCLUSIONS

In this paper we have presented the analysis of organic PV cell based on parameters. We achieved a significant correlation between the experimental and simulated parameters of the organic photovoltaic. The presented analysis shows simulated results can find many possible theoretical ways to facilitate the future development of the organic solar cell technology. Organic solar cells are inexpensive than their inorganic counterparts but are undesired because of their lower power conversion efficiencies. Further analysis of the parameters of the organic photovoltaic can lead the way to increase the efficiency. Research can also be done through different compositions of the CNTs in the active layer to improve the device performance. Further study on this work based active layer morphology with CNTs creates an opportunity to search for new acceptor and donor materials for better performance.

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