Nat. Volatiles & Essent. Oils, 2021; 8(5): 10266-10273

The Effect of The Thickness of Active Layer and The Temperature of The Polymer Solar Cells (PSCS) On the Efficiency

Nagwa Ibrahim[1], **Hanadi M. Abdulsalam**[2],

[1]*Department of Physics, College of Uyun AlJiwa, Qassim University, KSA*

[2]*Department of Maths &Natural Sciences, Prince Mohammad bin Fahd University, KSA*

Abstract

Polymer solar cells (PSCs), which are composed of two photoactive layers, bulk-heterojunction (BHJ) blends of p-type polymer donors and n-type acceptor materials, electronics. Polymer solar cells (PSCs) have been gaining great popularity in recent years due to their potentials to be low cost, lightweight, and flexible.

In this study, the effect of the thickness of the active layer of the solar cells on the efficiency has been studying. It has been shown that increasing the thickness beyond 100nm decreases the efficiency of the (PSCS). The optimal thickness of the active layer is also greatly increased from 25nm to 60nm. In addition, the devices fabricated at 300 °K .The blend consist of Conjugated Polymer Poly (2-methoxy-5-(3′, 7′- dimethyloctyloxy)-1, 4-phenylenevinylene) MDMO-PPV as electron donor and PCBM as electron acceptor, in a 1:4 weight ratio.

The experimental results show that the maximum efficiency is at a thickness of about 40 nm. In addition, the fill factor decreases with an increase of thickness.

Temperature has a negative effect on the open-circuit voltage. The ideality factor, n, at 300K is about 1.6. This gives a value of about 10 V for the rate of decrease of the open-circuit voltage with temperature.

Keywords: Polymer solar cells (PSCs) , open-circuit voltage, MDMO-PPV, PCBM, thickness, active layer

Introduction:

Polymer solar cells (PSCs) have piqued the interest of researchers due to their appealing characteristics, which include excellent ambient stability, mechanical flexibility, and adaptability [1, 2, 3].The disadvantage of PSCS is that the active layer has limited light-harvesting, low charge carrier mobility, formation of unfavorable film morphology, and so forth [4, 5]. Although a number of valid experiments have been developed to control the size of polymer blends, the photovoltaic performance of PSCs is still restricted by the limited categories of n-type polymers. Therefore, the selection of an appropriate n-type polymer is of great importance for realizing highly efficient PSCs. Several notable families of n-type polymers have been identified to date, including cyanated polyphenylenevinylene and high electron mobility polymer poly [N, N′-bis (2-octyldodecyl)-naphthalene-1,4,5,8-bis(dicarboximide)-2,6-diyl].alt-5,5′-(2,29-bisthiophene) (N2200) [6]. Using conjugated polymers, the power conversion efficiency (PCE) of polymer solar cells has progressively improved [7-10]. To fabricate polymer solar cells, mixtures of donor and acceptor materials blended in organic solvents are employed, which have the ability to produce an interpenetrating network of heterojunctions throughout the bulk of the active film [11-12].It is desirable to optimize the thickness of the cell for

---

[1] Corresponding author: nagwaib@qu.edu.sa

maximum photons absorption and maximum fill factor .Electron and hole mobility in organic semiconductors are very small compared to that of inorganic semiconductors. This limit the thickness of the blend, hence it limits the photons absorption.

The electron mobility in poly (3-hexylthiophene) (P3HT): PCBM at 300 °K is about, and that of the hole is even lower, by a factor of about 5000 [13-14].It has been shown that increasing the thickness of the blend beyond 100nm decreasing the efficiency of polymer solar cells (PSCs) [15],The effect of temperature on the parameters of polymer solar cells (PSCs) is as follows: a V_{OC} decreases as temperature increases. The temperature characteristics of I_{SC} are dependent on the active material. Because organic semiconducting materials have electrical properties that differ with temperature compared with inorganic materials, such as increasing mobility with increasing temperature [16, 17]. Polymer solar cells containing MDMO-PPV active materials showed a monotonic increase in ISC as temperature increased until 65 C, at which point they became saturated [18].While the I_{SC} of P3HT: PCBM decreased as the temperature increased [19].

Materials and Methods:

The cell was prepared at polymer Laboratory of the Addis Ababa. Indium Tin Oxide (ITO) was used as a transparent anode. A solution of Poly (3, 4-ethylenedioxythiophene)-poly (styrene sulfonate) with concentration of 5mg/ml, was spin coated on the top of the ITO. The blend consist of Poly (2-methoxy-5-(3′, 7′- dimethyloctyloxy)-1, 4-phenylenevinylene) (MDMO: PPV) as electron donor and PCBM as electron acceptor, in a1:4 weight ratio. The blend was coated on the top of the PEDOT: PSS. The aluminum electrode was evaporated over the blend at a pressure of about 6x10-6 mb. The cell is illuminated with a 0.3 Wm-2. The measurements were taken at 300K. The of each solar cell was 1.5 mm2 .

Results and disruptions :

The effect of temperature on the open- circuit voltage (V_{oc}):

The open - circuit voltage (V_{oc}) can be expressed:

$$V_{oc} = n\frac{KT}{q}\ln\left(\frac{J_{sc}}{J_0} + 1\right) \qquad (1)$$

Where n is ideality factor , K is the Boltzman constant is temperature in Kelvin ,J_{sc} is the short-circuit current , J_0 is the saturated current density , q electron charge .

Since $J_{sc} \gg J_0$

$$V_{oc} \cong n\frac{KT}{q}\ln\left(\frac{J_{sc}}{J_0}\right) \qquad (2)$$

$$\frac{dV_{oc}}{dT} = n\frac{KT}{q}\ln\left(\frac{J_{sc}}{J_0}\right) + n\frac{KT}{q}\frac{d}{dT}(\ln J_{sc} - \ln J_0) \qquad (3)$$

If we assume that J_{sc} is intendent of temperature then (3) become:

$$\frac{dV_{oc}}{dT} = n\frac{KT}{q}\ln\left(\frac{J_{sc}}{J_0}\right) - n\frac{KT}{q}\frac{d}{dT}\ln J_0) \qquad (4)$$

From Eq.(2) and Eq.(4):

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{dT} - \frac{nKT}{q}\frac{d}{dT}\ln J_0$$

he saturation current density can be written as:

$$J_0 = Ce^{-E_g/KT}$$

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{dT} - \frac{nKT}{q}\frac{d}{dT}(-\frac{E_g}{KT})$$

$$\frac{dV_{oc}}{dT} = \frac{V_{oc}}{T} - \frac{n}{q}(\frac{E_g}{T})$$

Due to the relatively large band-gap of organic materials ,we can assume that , at thermal equilibrium ,the Fermi level lies in the middle of the highest occupied molecular orbital (HOMO),and the lowest unoccupied. molecular orbital(LUMO). When the cell is illuminated, the open-circuit voltage (Voc) is given by

q Voc = $F_n - F_p$ (5)

Where F_n and F_p are the electron and the hole quasi-Fermi levels, and q is the elementary charge. The upper limit for the Voc is given by the potential offset of the (HOMO) of the donor (HOMO)D and the (LUMO) of acceptor (LUMO)A ,[1] This indicates that F_n aligns with the (LUMO)A and F_P aligns with the (HOMO)D

For ohmic contact , the open circuit Voc ,is given by ,[20],

q Voc =(HOMO)D –(LUMO)- qΔV (6)

Fixed the (LUMO) of the PCBM at a value of -4.3 eV, and obtained a relationship for Voc from (HOMO)D [20] , obtained from different heterojunction solar cells. The relationship has the form :

q Voc = $(\mathrm{HOMO})_D$- $(\mathrm{LUM0})_A$ $-$0.3q (7)

The absorbed photons generate excitons which dissociate at the blend layer interface. The exciton binding energy is about 0.5 eV,[21]. This requires that the offset between the (LUMO)A and the (LUM0)D to be about 0.5 eV. Then we can write:

(LUMO)A - (LUMO)D = 0.5eV and

(HOMO)A -(HOMO)D = 0.5 eV (8)

The band-gap of the donor is given by:

(HOMO)D - (LUMO)D = E_g (6.5) From Eq. (9)

and Eq. (63) (LUMO)A- (LUMO)D = E_g- q Voc - 0.3q . (10)

When substantiating the value of the (LUMO)A - (LUMO)D off-set in Eq.(10)

$0.5 = E_g$ - q Voc - 0.3

q Voc = $E_g - 0.8$ eV. (11)

$$\frac{dV_{oc}}{dT} = \frac{1}{qT}\left(E_g - 0.8\right) - \frac{n}{qT}E_g \quad (12)$$

The absorption Spectrum of MDMO: PPV/PCBM is shown in Fig. (2). It is seen that the cutoff wavelength is at 600 nm. Using the relation Eq. (13) where E_g is the band gap, h is Planck's constant, c is the speed of light, and λ, is the wavelength. The band-gap , E_g , of

MDMO: PPV/PCBM is found to be 2.1eV (substituting λ =600 nm in Eq.(13)).with Substituting n=1.6 Eq. (14) [22] ,,and Fig.(1), Fig.(2)

$$E_g = \frac{hC}{\lambda} \quad (13)$$

$$V_{oc} = \frac{KTn}{q}\ln I \quad (14)$$

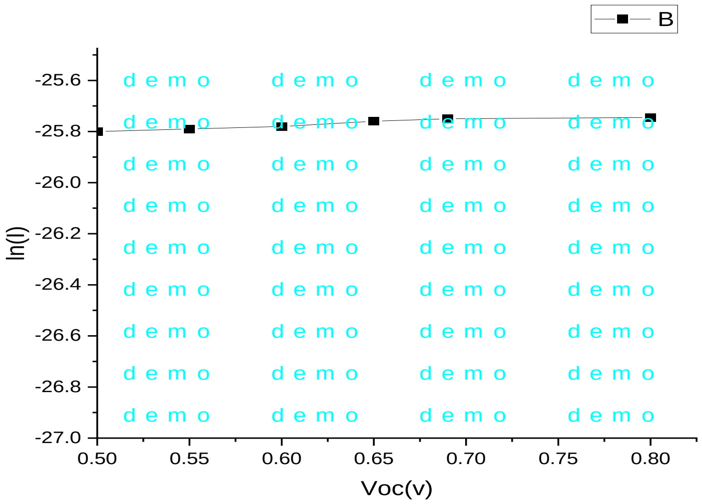

Figure (1):open-circuit voltage versus ln(I)

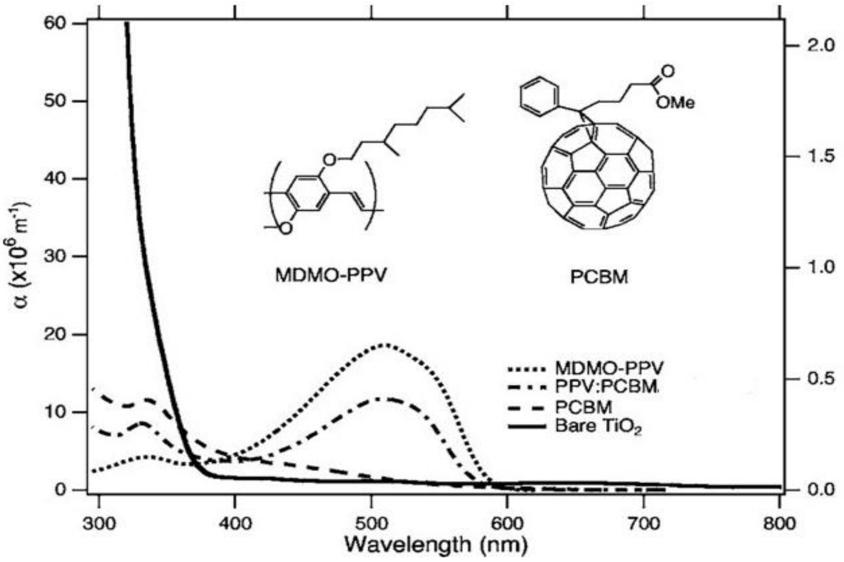

Figure (1):The absorption Spectrum of MDMO: PPV/PCBM

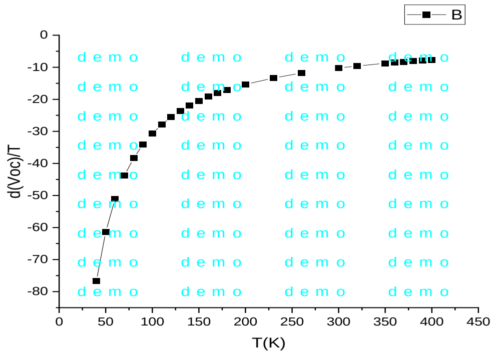

Figure (3) :Rate of open –circuit voltage(Voc)with increasing of temperature

Effect of the thickness:

The effect of thickness on fill factor was studied by taking measurements from three solar cells with thicknesses: 25 nm ,40 nm and 60 nm. Fig.4 shows the variation of the fill factor with thickness . The fill factor decreases as the thickness increases. Charge recombination seems to increase as the thickness increases, while photons absorption increases as the thickness increases. The thickness needs to be optimized for maximum efficiency .

Fig.5 shows the short–circuit current density and the open circuit voltage for blend thicknesses of 25 nm , 40 nm and 60 nm. The VOC seems to be approximately independent of the blend thickness. The short –circuit current is maximum at 40 nm thickness.

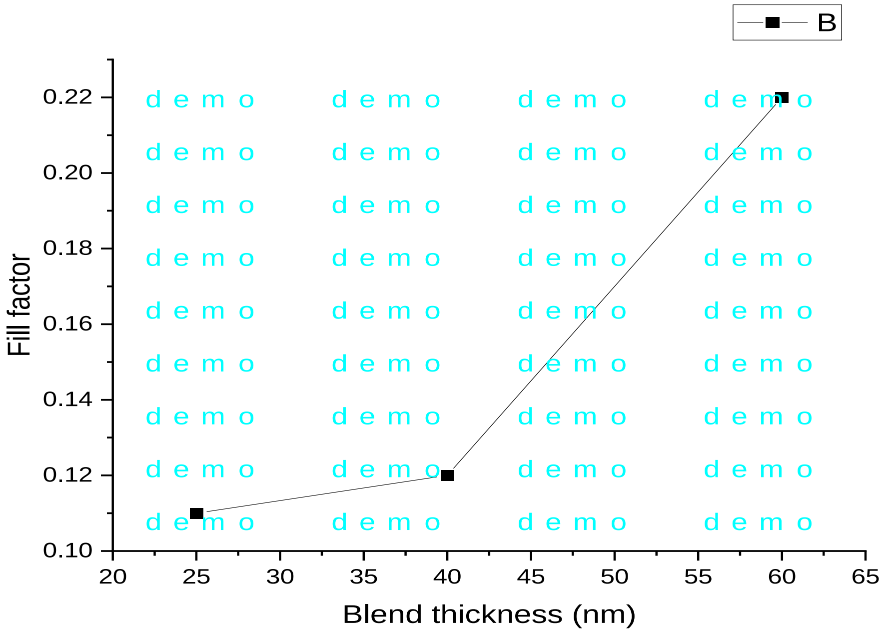

Figure (4):Variation of fill factor with thickness

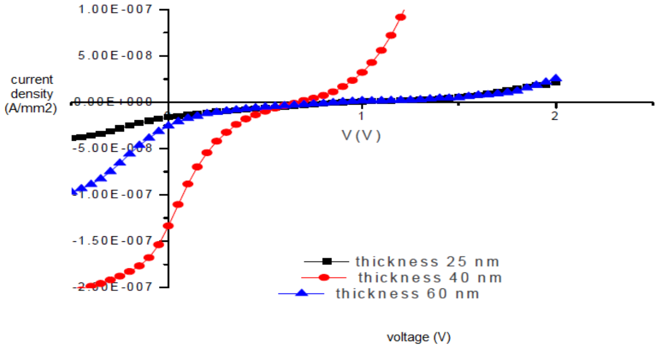

Figure (5): Current-voltage characteristics for three cells with thicknesses : 25 nm , 40 nm and 60 nm.

Conclusion:

A model for Polymer solar cells (PSCs) has been proposed. The model has been compared with measurements from MDMO: PPV /PCBM solar cells.The electron acceptor is preferably to have the lowest unoccupied orbital which makes (LUMO)A-(LUMO)D offset of about 0.5 e V . Higher values of the offset result in the reduction of the VOC. Lower values of the offset may not be sufficient to break the excitons into free-charge carriers.The thickness of the cell has to be optimized for maximum efficiency. As the

thickness increases, the photons absorption increases, but the fill factor decreases.

Low cost fabrication and simple and process of Polymer solar cells (PSCs) makes them grainy elected for the generation of electricity. To enhance the performance of organic, many requests by the researchers in the field. This can be done upon strict research studies performed through materials analysis to the devices fabrication and characterization, thereby inquiring about beneficial strategies to improve the performance of these devices .

ACKNOWLEDGEMENT:

Author would like to thank, Department of physics, College of Uyun AlJiwa, Deanship of scientific research Qassim University.

REFERENCES:

1- Kang, H. et al. From fullerene-polymer to all-polymer solar cells: the importance of molecular packing, orientation, and morphology control. Acc. Chem. Res. 49, 2424–2434 (2016).

2- Chen, S. et al. Highly flexible and efficient all-polymer solar cells with high-viscosity processing polymer additive toward potential of stretchable devices. Angew. Chem. Int. Ed. 57, 13277–13282 (2018).

3- Kim, T. et al. Flexible, highly efficient all-polymer solar cells. Nat. Commun. 6, 8547 (2015).

4- Baobing Fan,Wenkai Zhong,Xiao-Fang Jiang,Qingwu Yin,Lei Ying,Fei Huang,Yong Cao, Improved Performance of Ternary Polymer Solar Cells Based on A Nonfullerene Electron Cascade Acceptor (2016)

5- Lei, T. et al. High-performance air-stable organic field-effect transistors: Isoindigo-based conjugated polymers. J. Am. Chem. Soc. 133, 6099–6101 (2011).

6-.Samantha Brixi, Owen A. Melville, Brendan Mirka,Yinghui He,Arthur D. Hendsbee, Han Meng,Yuning Li &Benoît H. Lessar . Air and temperature sensitivity of n-type polymer materials to meet and exceed the standard of N2200. (2020)

7 Sayed Izaz Uddin , Muhammad Tahir, , Fakhra Aziz , Mahidur R. Sarker, Fida Muhammad , Dil Nawaz Khan and Sawal Hamid Md Ali. - Thickness Optimization and Photovoltaic Properties of Bulk Heterojunction Solar Cells Based on PFB–PCBM Layer. 2020

8- Yu, G.; Gao, J.; Hummelen, J.C.; Wudl, F.; Heeger, A.J. Polymer photovoltaic cells: Enhanced efficiencies via a network of internal donor-acceptor heterojunctions. Science 1995, 270, 1789

9-. Padinger, F.; Rittberger, R.S.; Sariciftci, N.S. Effects of postproduction treatment on plastic solar cells. Adv. Funct. Mater. 2003, 13, 85–88.

10- Charles, U.A.; Ibrahim, M.A.; Teridi, M.A.M. Electrodeposition of organic–inorganic tri-halide perovskites solar cell. J. Power Sources 2018, 378, 717–731.

11. Günes, S.; Neugebauer, H.; Sariciftci, N.S. Conjugated polymer-based organic solar cells. Chem. Rev. 2007, 107, 1324–1338.

12. Yun, T.W.; Sulaiman, K. Fabrication and morphological characterization of hybrid polymeric solar cells based on P3HT and inorganic nanocrystal blends. Sains Malaysiana 2011, 40, 43–47.

13- Kumar, Sunil; Kumar, Manoj; Rathi, Sonika; Singh, Amarjeet .Study of dielectric phenomenon for P3HT: PCBM blend (2017)

14- V. D. Mihailetchi,H. X. Xie,B. de Boer,L. J. A. Koster,P. W. M. Blom Charge Transport and Photocurrent Generation in Poly(3-hexylthiophene): Methanofullerene Bulk-Heterojunction Solar Cells (2006)

15-A. C. Arango,L. R. Johnson,V. N. Bliznyuk,Z. Schlesinger,S. A. CarterEfficient Titanium Oxide/Conjugated Polymer Photovoltaics for Solar Energy Conversion (2000)

16- Bloom, P.W.M.; Vissenberg, M.C.J.M. Charge transport in poly(p-phenylene vinylene) light-emitting diodes. Mater. Sci. Eng. R 2000, 27, 53–94.

17- Noh, S.-U.; Kim, J.-Y.; Lee, C.; Lee, M.-J.; Jung, B.-J.; Hwang, D.-H.; Lee, S.-H.; Kim, H. Correlation between the Temperature Dependences of Short-Circuit Current and Carrier Mobility in P3HT:PCBM Blend Solar Cells. Proc.; SPIE: San Diego, CA, USA, 2006; Volume 6334, p. 63340S.

18- Katz, E.A.; Faiman, D.; Tuladhar, S.M.; Kroon, J.M.; Wienk, M.M.; Fromherz, T.; Padinger, F.; Brabec, C.J.; Sariciftci, N.S. Temperature dependence for the photovoltaic device parameters of polymer-fullerene solar cells under operating conditions. J. Appl. Phys. 2001, 90, 5343–5350.

19- Chivase, D.; Chiguvare, Z.; Knipper, M.; Parisi, J.; Dyakonov, V.; Hummelen, J.C. Temperature dependent characteristics of poly(3 hexylthiophene)-fullerene based heterojunction organic solar cells. J. Appl. Phys. 2003, 93, 3376–3383.

20- Fahmi Fariq Muhammad, Design Approaches to Improve Organic Solar Cells, Journal of Technology Innovations in Renewable Energy, 2014, 3, 63-71

21- Safakath Karuthedath, Julien Gorenflot, Yuliar Firdaus, Neha Chaturvedi, intrinsic efficiency limits in low-bandgap non-fullerene acceptor organic solar cells, nature materials ,2020.

22-- Sanjay Kumar Behura a , Pramila Mahala b , Abhijit Ray , A MODEL ON THE EFFECT OF INJECTION LEVELS OVER THE OPEN-CIRCUIT VOLTAGE OF SCHOTTKY BARRIER SOLAR CELLS, journal of Electron Devices, Vol. 10, 2011, pp. 471-482,2011