

Study the Important Parameters Affecting Performances of P3HT:PCBM Organic Solar Cells

ABSTRACT

Aims: Organic solar cells were realized and characterized. The I(V) characteristics as function of concentration of the blend of the active layer and the type of substrate are given.

Study design: Theoretical study of the performances of organic solar cells is given. The cells were realized and characterized.

Place and Duration of Study: Laboratory of Advanced Technologies of Genie Electrics (LATAGE) Faculty of Electrical and Computer Engineering Mouloud MAMMERI University (UMMTO), BP 17 RP 15000, Tizi-Ouzou, Algeria.

Methodology: we discuss general mechanisms leading to generation and transport of charge carriers and parameters which govern the behavior of organic solar cells. The absorption spectra of P3HT:PCBM is measured. Solar cells were realized and characterized.

The current density characteristic results for the cells were compared for two substrates (ITO and FTO) and the concentration effect of the blend is studied.

Results: The current density characteristic depends on various parameters, the type of the substrates, the concentration of the blend and temperature.

Conclusion: Our study shows that the performances of the organic solar cells depend on different parameters. In order to improve the performances of the cells, transparent electrodes with high transmittance and high conductivity must be used.

Keywords: organic solar cells, performances, P3HT:PCBM, transparent electrodes, temperature, AFM, concentration.

1. INTRODUCTION

Polymer solar cells have attracted much attention during the last years due to their lower fabrication cost and possibility of using flexible substrates [3]. However, their efficiency is usually less than 5%. The active layer morphology related to blending preparation and annealing, is one of the most important factors affecting solar cell efficiency [1], [2], [3]. Organic solar cells undergo many degradation pathways during their lifetime. Efficiency loss is due to light, oxygen and water [1]. The exposure to oxygen leads to an enhanced charge carrier concentration and a decreased charge carrier mobility. A lower mobility leads to a higher extraction time for the charge carriers and therefore to an enhanced bimolecular recombination probability which results in the decreased FF. The open circuit voltage is slightly increased because the Langvin recombination rate is lower when the mobility decreased. The higher charge carrier densities reduce the internal field and therefore increase the open circuit voltage [1]. Thermal annealing improves cell efficiency.

2. PARAMETERS AFFECTING CHARACTERISTICS OF ORGANIC SOLAR CELLS

2. 1. Charge transport in polymer fullerene films

A polymer: fullerene bulk hetero-junction solar cell can be regarded as an insulator sandwiched between two electrodes. The light entering the transparent electrode is considered to be uniformly absorbed by the active layer, which results in a uniform generation of electron-hole pairs throughout the specimen. In photovoltaic cells the recombination probability of the free charge carriers depends on the mean carrier drift length mean carrier drift length.

$$w_{e,h} = \mu_{e,h} \tau_{e,h} E \quad (1)$$

Where: $w_{e,h}$: the mean carrier drift length of electrons (e) and holes (h)

μ : charge carrier mobility

τ : charge carrier lifetime before trapping or recombination

E: the electric field.

If the mean carrier drift lengths of electrons and holes are smaller than the device thickness L ($w_{e,h} < L$), the both charge carriers are accumulated in the layer. At steady state, the distance which they travel increases linearly with applied voltage (V) and the photocurrent J_{ph} follows Ohm's law:

$$J_{ph} = q G (\mu_e \tau_e + \mu_h \tau_h) \frac{V}{L} \quad (2)$$

Where q: the electric charge

G: the generation rate of electron-hole pairs.

The photocurrent density J_{ph} as a function of the applied voltage V is given by the equation (3):

$$J_{ph} = q G L (1 + b) \frac{-b + \left(b^2 + \frac{4(1-b)V\mu_h\tau_h}{L^2} \right)^{1/2}}{2(1-b)} \quad (3)$$

Where b is the drift length ratio defined here as

$$b = \mu_h \tau_h / \mu_e \tau_e$$

For equal electron and hole $\mu\tau$ products ($b=1$), it can be seen that equation (2) equal to equation (1) and at higher voltages the photocurrent saturates at $q G L$. according to equation (2), for very different charge transport properties of electrons and holes ($1 \gg b \rightarrow 0$), the J_{ph} approaches one half power on V:

$$J_{ph} = q G (\mu_h \tau_h)^{1/2} V^{1/2} \quad (4)$$

2.2. Current density in a structure ITO/PEDOT:PSS/P3HT:PCBM/LiF/AI

The current density J_D depends quadratically on voltage. This behavior is characteristic for a space-charge limited current (SCLC) given by:

$$J_D = \frac{9}{8} \epsilon_0 \epsilon_r \mu_e \frac{V^2}{L^3} \quad (5)$$

Where $\epsilon_0 \epsilon_r$ is the permittivity of PCBM. For PCBM the relative dielectric constant $\epsilon_r=3.9$.

$$\mu_e = 2.10^{-7} \text{ m}^2/\text{Vs}.$$

$\epsilon_0=8.854.10^{-14} \text{ F/cm}$ is the constant dielectric of free space.

2.3. Temperature effect on the electrical transport of organic solar cells

Thermal annealing improves cell efficiency. During thermal annealing, growth and perfection of polymer crystallization occurred, which increases the charge transport capability. However, a prolonged annealing process will increase the crystallization of P3HT and force the aggregation of PCBM [2], [4]. The ordered structure facilitates the charge transport [6], [10]. Figure (1) shows the AFM (Atomic Force Microscopy) image of P3HT: PCBM deposited with spin coater. After annealing at 130 °C during 30 min the structure was ordered.

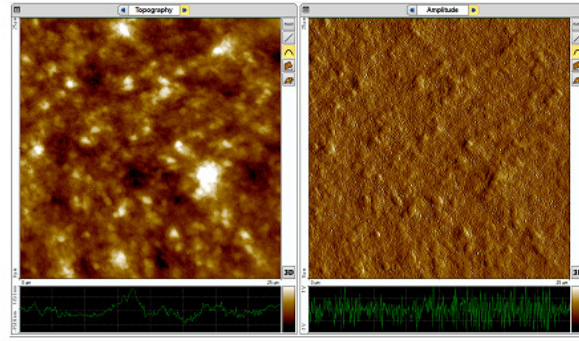
The open circuit voltage of the organic solar cells depends on temperature as in Eq. (6)

$$V_{oc} = \frac{k_B T}{q} \ln \left(\frac{J_{ph}}{J_0} + 1 \right) = \frac{E_g}{q} - \frac{n k_B T}{q} \ln \left(\frac{N_v N_c \mu k_B T}{J_{sc} L N_A} \right) \quad (6)$$

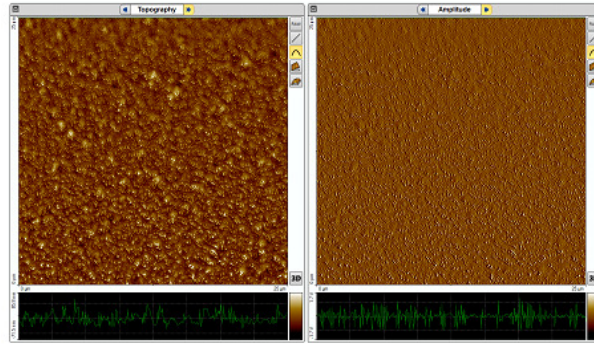
For $T=0^\circ\text{K}$, $V_{oc}=E_g/q$.

Where $E_g = \text{LUMO}_{\text{acceptor}} - \text{HOMO}_{\text{donor}}$

78 K_B is a Boltzmann constant, q is the elementary charge, L is the thickness of the active layer, μ is the
 79 mobility of carriers, N_c and N_v are the state density of electron and hole respectively and n is the ideality
 80 factor of the diode.



a- P3HT:PCBM without annealing



b- P3HT:PCBM annealed at 130°C during 30 min

Fig.1. AFM topography of P3HT:PCBM

a- without annealing, b-annealed at 130°C

2.4. Effect of solvent annealing

Solar cells employ the slow-solvent-vapor treatment blend films as the active layer exhibit the enhanced power conversion efficiency that of as-cast and fast thermal annealing blend films [5].

2.5. Series and shunt resistances

The increase in both series and shunt resistances can be caused by the reduction in the mobile charge density and mobility associated with the creation of traps produced by the interaction of oxygen and water with the polymer.

Several factors contribute to increase the series resistances when the device is left in ambient conditions such as reduction of mobility, metal corrosion at the contact or changes in the contact barrier and charge space regions [7].

The J-V characteristics of an organic solar cell can be simulated with the equation (7)

$$J = J_0 \left\{ \exp \left(\frac{V - J R_s A}{n K_B T / e} \right) - 1 \right\} + \frac{V - J R_s A}{R_p A} - J_{ph} \quad (7)$$

Where, J_0 is reverse saturation current density, V is the applied voltage, n is the ideality factor, R_s is the series resistances, R_p is the shunt resistance, J_{ph} is the photocurrent, A is the active area, K_B is the Boltzmann constant, T is the temperature, and e is the elementary charge.

2.6. Influence of the buffer layer

The BHJ (bulk heterojunction solar cells) appears to be a very promising device structure to be exploited in the mass production of organic solar cells. away from the development and optimization of novel active materials, like novel acceptors or low band-gap polymer donors, the correct optimization and choice of the HTL (*Hole transport layer* : MoO_3 , WO_3 , NiO , V_2O_5 , PEDOT:PSS , ...) together with the ETL (*Electron transport layer* : ZnO , SnO_2 , TiOx , ...) play a fundamental role in order to get the best performance from a device. An improved J_{sc} was observed for the G - PEDOT: PSS devices due to the improved charge collection compared to PEDOT: PSS devices [8].

3. EXPERIMENTAL RESULTS

3.1. Temperature effect in the absorption spectra of P3HT: PCBM layer

Fig.2 shows the absorption spectra of P3HT: PCBM layers for different temperature

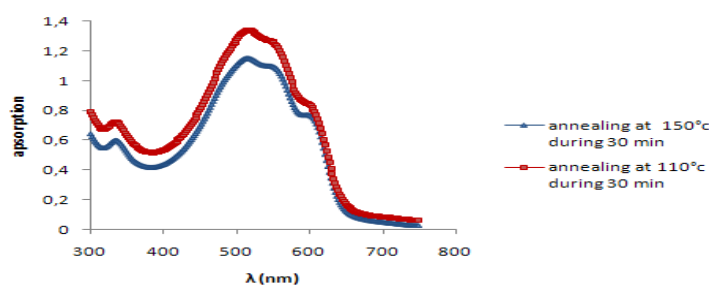


Fig.2 Absorption spectra of P3HT: PCBM layers of different temperatures.

3.2. Concentration effect on the performances of organic cells

Fig.3 shows the current density (J) voltage (V) characteristics of the organic solar cells made with the different concentrations. The higher performances are obtained when the concentration of the blend is 70 mg/ml, efficiency = 3.2, V_{OC} =0. 52 V, J_{sc} =12, 74 mA/cm², FF= 48.56.

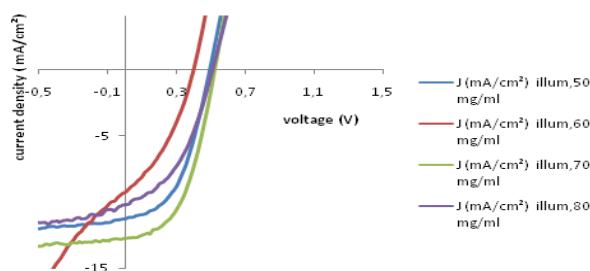


Fig. 3 Characteristic J (V) as a function of the concentration of the P3HT: PCBM blend.

3.3. Effect of the substrates type ITO and FTO

The type of substrates is another parameter which affects the performances of the solar cells, flexible organic solar cells as a function of post-annealing temperatures were studied [9]. In this work we use two different transparent electrodes deposited on glass : ITO and FTO. The FF of cells with ITO is better than

with FTO substrates because the transmittance and the conductivity of ITO are higher than of FTO. Fig. 4 shows $J(V)$ characteristics of organic solar cells with different substrates.

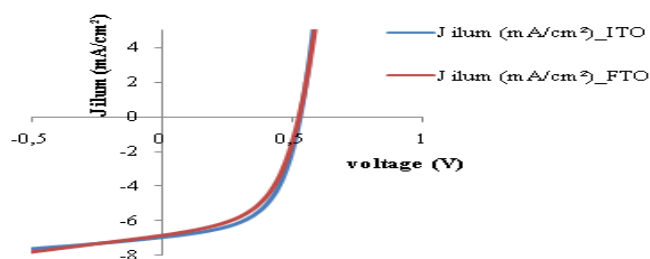


Fig.4. Characteristics $J(V)$ of organic solar cells with different substrate.

4. CONCLUSION

Various parameters contribute to the stability of the performances of organic solar cells. The materials used in their elaboration such as the active layer and the electrode contact. The current density depends in temperature, the mobility of carrier charges, and substrate type. Thermal annealing reduce interface defect, and increases cristallinity which improves the mobility of carriers then improves photocurrent. Several factors contribute to increase the series resistances when the device is left in ambient conditions such as reduction of mobility, metal corrosion at the contact or changes in the contact barrier and charge space regions.

In general, there are six main important processes which might limit the power conversion efficiency of organic photovoltaic devices:

1. Light absorption in the film.
2. Free charge carrier generation.
3. Charge transport to the opposite electrodes and extraction by the electrodes.
4. Carrier recombination.
5. Architecture dimension, and design of the device.
6. Temperature effect (annealing temperature of the active layer and the final device).

In order to improve the performances of organic solar cells we must use polymer with a small gap, adequate HTL and ETL, and transparent electrodes with high transmittance and high conductivity.

REFERENCES

- [1]. Julia Schfferhans, Andreas Baumann, Alexander Wagenpohl, Carsten Deibel, Vladimir Dyakonov. Oxygen doping of P3HT: PCBM blends: Influence in trap states, charge carrier mobility and solar cell performance. *Organic Electronics*. 2010; 11:1693-1700.
- [2]. Yu-CchingHuang, Yu-ChiaLiao, Shao-SianLi, Ming-Chun-WeiCheen, Wei-Fang Su. Study of the effect of annealing process on the performance of P3HT: PCBM phphotovoltaic devices using scanning-probe microscopy. *Solar Energy Materials & Solar Cells*. 2009; 93: 888-892.
- [3]. P.G. Karagiannidis, D. Georgiou, C. Pitsalidis, A. Laskarakis, S. Logothetidis. Evolution of vertical phase separation in P3HT: PCBM thin films induced by thermal annealing. *Materials Chemistry and Physics*. 2011; 129: 1207-1213.
- [4]. P.G. Karagiannidis, S. Kassavetis, C. Pitsalidis, S. Logothetidis. Thermal annealing effect on the nanomechanical properties and structure of P3HT: PCBM thin films. *Thin Solid Films*. 2011; 519: 4105-4109.
- [5]. Tzung-Fang Guo, Ten-Chin Wen, Georgi l'vovich Pakhomov, Xing-Guo Chin, Siou-Hong Liou, Pei-Hong Yeh, Cheng-Hsein Yang. Effects of film treatment on the performance of poly(3-

- hexylthiophene)/soluble fullerene-based organic solar cells. Thin Solid Films. 2008; 516: 3138-3142.
- [6]. Anusit Keawaprajak, Phimwipha piyakulawat, Annop Klamchuen, Phansa Klaraska, Udom Asawapiron. Influence of crystallizable solvent on the morphology and performance of P3HT:PCBM bulk-heterojunction solar cells. Solar Energy Materials & Solar Cells .2010; 94: 531-536.
- [7]. V. S. Balderrama, M. Estrada, A. Cerdeira, B. S. Soro-Cruz, L. F. Marsal, J. Pallares, J. C. Nolasco, B. Iniguez, E. Palomars, J. Albero. Influence of P3HT :PCBM blend preparation on the active layer morphology and cell degradation. Microelectronics Reliability .2011; 51: 597-601.
- [8]. Sung-Ho Jin, B. Vijaya Kumar Naidu, Han-Soo, Sung-min Park, Sung Chul Kim, Jae Wook Lee, Yeong-Soon Gal. Optimization of process parameters for high-efficiency polymer photovoltaic devices based on P3HT:PCBM system. Solar Energy Materials & Solar Cells. 2007; 91 :1187-1193.
- [9]. Seungju Kim, Sangouk Ryu. Efficiency of flexible organic solar cells as a function of post-annealing temperatures. Current Applied Physics. 2010; 10 : 181-184.
- [10]. Biswajit Ray n, Pradeep R. Nair, Muhammad .Alam. Annealing dependent performance of organic bulk-heterojunction solar cells: A theoretical perspective. Solar Energy Materials & Solar Cells. 2011; 95: 3287–3294.