Journal of Ovonic Research Vol. 16, No. 4, July - August 2020, p. 229 - 233

ELECTRICAL CHARACTERISTICS AND EFFICIENCY OF ORGANIC SOLAR CELLS WITH (P3HT: ICBA) ACTIVE LAYER AT AMBIENT AIR

N. ADAWI, J. GHABBOUN*
Department of Physics, Bethlehem University, Bethlehem, Palestine

A combination of narrow band donor polymer and one of the fullerene derivatives provide a possible solution for the production of efficient organic solar cells. The organic active layer is made from a combination of Poly(3-hexylthiophene-2,5-diyl) with 1’,1’’,4’,4’’-tetrahydro-di[1,4] methanonaphthaleno [5,6] fullerene-C60 (P3HT:ICBA). High holes mobility in conjunction with good solubility and partial air stability make regio-regular P3HT electron donor, a reference material of choice for both fundamental and applied research in organic solar cells. Polymers fullerene ICBA organic solar cells are effective acceptors because of their high electron affinity and ability to transport charge effectively. Spin coating was used to deposit the P3HT:ICBA layer from a solution on a ITO substrate. Aluminum electrodes were vapor deposited under vacuum at different stages with a thermal evaporator and a Keithley set-up was used for Current-Voltage (IV) measurements at ambient. The success of this research is measured by effectively building and tests the cells under ambient air conditions, while the efficiency is better appreciated through using a controlled atmosphere with inert gas. Samples were prepared with different P3HT:ICBA blend ratios. While the maximum efficiency known for the best organic cells is more than 10%, the maximum achieved efficiency in this research is 0.89% for 1:1 (P3HT:ICBA) blend ratio. IV curves were made for the cells with illumination of 100 mW/cm^2 at 25 ºC.

(Received May 8, 2020; Accepted August 20, 2020)

Keywords: Organic solar cell, P3HT, ICBA, Efficiency, Electrical characteristics, Ambient

1. Introduction

Inorganic solar cells have reached power conversion efficiency around 39% [1], while commercially available solar panels have a significantly lower efficiency between 15–20%. Another way to fabricate solar cells is to use organic materials, like conjugated polymers, fullerenes and other organic materials. Solar cells made from thin polymer films are particularly attractive because of their ease of fabrication, mechanical flexibility, and potential for low cost fabrication of large areas. Additionally, their material properties can be redesigned by modifying their chemical construction that lead to better customization than traditional solar cells allow. Although huge progress has been made, the efficiency of organic solar cells still not commercially obtainable [2]. The most efficient organic solar cells have an efficiency of 5-11%. To improve the efficiency of organic solar cells it is important to understand the limits of their performance under ambient conditions.

Organic solar cell (OSCs) is one type of solar cells based on photovoltaic phenomena. The semiconductor in these cells is the organic semiconductor and this is the naming reason.

Organic electronics have significant potential where organic semiconductor materials can be deposited on flexible substrates using low-cost processing techniques, such as roll-to-roll solution printing, screen printing, ink jet printing and other low temperature deposition techniques [3,4]. Moreover, manufacturing technology for flexible electronics is already established in the OLED industry where the fundamental issues, including molecular design, thin-film deposition or device encapsulation, have already been confronted [5]. This development could boost fabrication of organic photovoltaic in the laboratory and in industrial environment.

* Corresponding author: jamalg@bethlehem.edu

The OSCs has many advantages over inorganic solar cell, but until now organic solar cells are not used in a commercial way because the efficiency is still low comparing with the inorganic solar cell. Production of OSC's is cheap with low environmental impact during manufacturing, a few grams of materials are needed per m^2, color can be any color or semi- transparency, it is non-toxic, good low-light is enough for a decent performance, they have low weight, flexible and can be easily integrated with application [6,7].

OSCs can be divided into three types, the first type contains a single layer (one organic layer) where work on it, started in 1964 with efficiency <0.1%, second type Bi-layer "Heterojunction" (two organic layers) started in 1986 with efficiency ≈5 and third type Bulk Heterojunction (mixed single layer) (BHJ) started in 1990 with efficiency ≈11% [8-13].

In this work, samples of organic solar cells of the third type BHJ, with different blend ratios of P3HT: ICBA as active mixed layer, were prepared and electrically characterized at ambient air[14].

2. Experimental

The BHJ cells consist of layers as shown in Fig. 1. These are mainly; an ITO (Indium Tin Oxide) coated glass substrate, with aluminum electrodes directly deposited on it, followed by a PEDOT:PSS layer, covered by the organic active layer, over which lies an aluminum cathode.

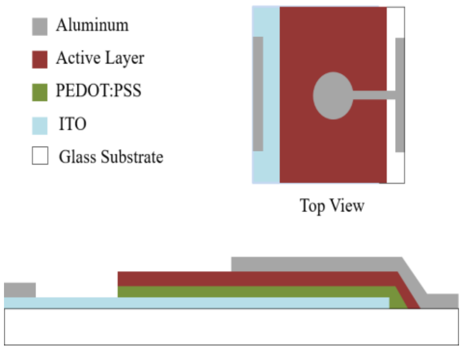

Fig. 1. BHJ cell architecture.

3. Fabrication

The substrate was masked except for the last 5 mm of the substrate. Zn powder was spread over the unmasked part and rubbed with a cotton swab dipped in HCl to wipe out the ITO. Then the substrate was washed with water and the mask was rapidly removed. ITO glass substrate was washed and cleaned by sonication (ultrasonic): first in de-ionized water in 3 times, 15 minutes each. Then it was rinsed in acetone bath for 15 minutes and in isopropyl bath for 15 minutes. Finally, the sample was dried at 110 ºC in oven for two minutes.

Depositing of Al electrodes was done using Vacuum Thermal Evaporation (VTE). After the deposition the substrate was washed for 15 min in iso-propanol path, then dried in oven for two minutes and finally put in UV-ozone for 15 min.

This mixture of PEDOT:PSS was filtered using a 0.45 μm filter before deposition on the substrate by spin coating at 4000 rpm for 60 sec, to take off all impurities with dimensions >0.45 μm [14]. The thickness of this layer is around 40 μm. After that electrodes are rapidly cleaned using a cotton swab dipped in de-ionized water. This layer was dried (annealed) at 150 °C for 5 min.

Active layer preparation, 34mg of P3HT solved in 2ml of dichlorobenzene and 34mg of ICBA in 2ml dichlorobenzene, then each mixture was immersed in water bath at 70 ºC with stirrer for 30 min, after that we mixed the active layer blend with different ratio.(1:1 - 1:2 - 1:3 - 2:1 -

3:1) each blend mixed with stirrer for 5 min then cooled down and kept overnight in hotplate at 30 ºC [13].

A total of 5 cells were made using different active layer components mixing ratios. Thickness of the active layer at 500 rpm for 60 sec is estimated to be around 100 nm [14]. To compare the efficiency dependence on blend ratio.

The blend material was filtered using 0.45µm filter before spin coating. After that rapidly immersed in water. Electrodes were swabbed dipped in dichlorobenzene, then the film was annealed at 110 °C for 2 min [15-17]. Finally the upper electrode deposited using mask in (VTE).

Finally, the active layer thickness, deposited according to [18] with a best value of around 100nm. This thickness is expected as it is comparable to the range of the polymers short excitation diffusion length.

3.1. I-V Measurement and Efficiency (η)

IV test measures the open-circuit-voltage (V_{OC}) and the short current (J_{SC}). To calculate the Filling Factor (FF) and efficiency (η) based on an input power measured by Li-185. In our case the Cryogenic Four-Probe Station was used with two probes from which connection is established between the cells and Keithley 2601(SMU) to measure the IV characteristics in both light and dark conditions. The measurement done at STC (100 mW/cm^2 of irradiance at a temperature of 25ºC and Air Mass AM 1.5)

3. Results and discussion

Table 1 summarizes IV characteristics and efficiency dependence on blend ratio. The input power for all setups was 100 mW/cm^2 and the active area is around 0.25 cm^2 for all cells. The table shows the parameters that affect the efficiency of the cells. Measurements obtained from Keithley 2601 and later on processed using Origin Lab 2019 software using fitting "Nonlinear Implicit Curve Fit "with Solar Cell IV function.

Table 1. IV measurements for OSCs with different P3HT:ICBA blend ratio.

Blend ratio	J_{SC} (mA/cm^2)	V_{OC} (V)	J_{max} (mA/cm^2)	V_{max} (V)	FF	η
1:1	1.3965185	0.84808	1.302320	0.68	0.74772	0.89%
2:1	1.4114571	0.09001	0.693439	0.04405	0.24043	0.03%
3:1	0.2128938	0.44837	0.158484	0.3655	0.60684	0.06%
1:2	0.0087491	0.43389	0.004868	0.22868	0.29329	0.0011%
1:3	1.3470955	0.09001	0.664241	0.04405	0.24131	0.03%

Figs. 2 and 3 show the IV and Power-Voltage (PV) curves for our cells. Some of these curves are similar to a typical solar cell as for the 1:1 and 3:1 blends. Other blends like 2:1 and 1:3 do not show this typical behavior in their IV curves. This could be due to some parameters such as irradiation current (I_{ph}), saturation current of the diode (I_s), diode ideality factor (N), thermal voltage (V_t), series resistor (R_s) and parallel resistor (R_{sh}). These blends of 2:1 and 1:3 blends have high short circuit current I_{SC} but they have very low open circuit voltage V_{OC} that depends on the mentioned parameters. IV for 1:2 blend has very low I_{SC} and V_{OC} and does not behave like a solar cell.

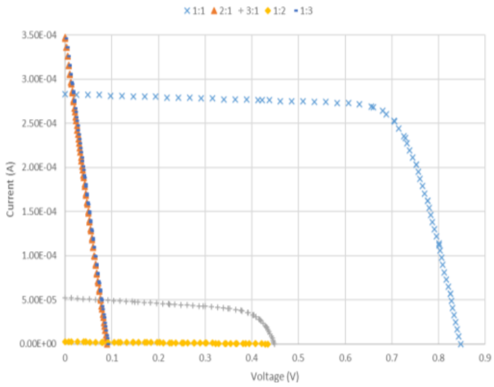

Fig. 2. Current-Voltage (IV) curves of solar cell for different blend ratiosP3HT:ICBA.

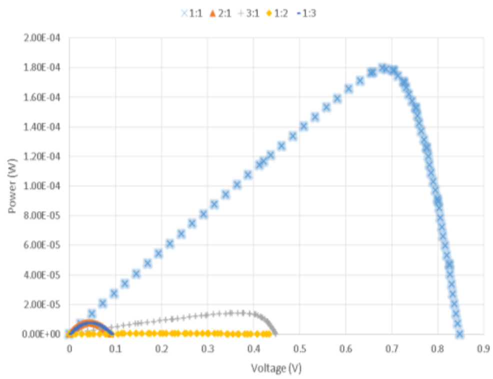

Fig. 3. Power-Voltage (PV) curves of solar cell for different blend ratiosP3HT:ICBA.

The highest efficiency η from our data in table 4 was achieved at 1:1 blend ratio with 0.89%. This efficiency is considered very low since experiment was done at ambient and not in gloves box with controlled atmosphere, followed by 3:1, 2:1 and 1:3 blend ratios and finally 1:2 is the lowest. For the IV curves, the 2:1 has the highest current most of the time but it falls earlier (decreases) compared to other blends. From the 1:1 IV curve, the maximum power achieved at around 0.68 V.

4. Conclusions

Different OSCs have been built and tested. Different parameters such as efficiency, Saturation current, ideality factor and open circuit voltage affecting the efficiency of the OSC are investigated with different blend ratios of P3HT:ICBA. The conclusion is summarized in the following, referring to the parameters involved in building the solar cell.

Study of the effect of the active layer ratio between the acceptor and the donor on efficiency revealed that the best ratio was achieved for the 1:1 blend with a percentage of around 0.89% of conversion efficiency. Our data could have measurements errors or a result of the process of coating that could have affected the actual ratio due to the difference in viscosity.

The relatively modest efficiency is due to the rapid oxidation of the active layer that could produce higher density traps once exposed to air after vacuum evaporation.

Acknowledgements

This research was funded by an Internal research Grant at Bethlehem University.

References

[1] M. A. Green et al., Progress in Photovoltaics: Research and Applications **14**(5), 455 (2006).
[2] G. Li, et al., Nature Materials **4**(11), 864 (2005).
[3] F. C. Krebs, Solar Energy Materials and Solar Cells **93**(4), 393 (2009).
[4] C. A. Bishop, Vacuum deposition onto webs, films and foils, Third edition ed. 2015, Amsterdam: Elsevier / William Andrew Publishing. xix, 582 pages.
[5] H. Klauk, Organic electronics : materials, manufacturing and applications. 2006, Weinheim: Wiley-VCH. xvii, 428 p.
[6] A. Mohammad Bagher, International Journal of Renewable and Sustainable Energy **3**(3), 53 (2014).
[7] J. Al-Zanganawee et al., Journal of Ovonic Research 14(4), 287 (2018).
[8] A. Facchetti, Materials Today **16**(4), 123 (2013).
[9] M. C. Scharber, N. S. Sariciftci, Prog. Polym. Sci. **38**(12), 1929 (2013).
[10] M. A. Green et al., Progress in Photovoltaics: Research and Applications **26**(1), 3 (2018).
[11] J. Nelson, Materials Today **14**(10), 462 (2011).
[12] S. Mori et al., Organic photovoltaic module development with inverted device structure. MRS Proceedings, 2015. 1737.
[13] P. D. Topham, A. J. Parnell, R. C. Hiorns, Journal of Polymer Science Part B: Polymer Physics **49**(16), 1131 (2011).
[14] B. Kadem, A. Hassan, Energy Procedia **74**, 439 (2015).
[15] G. Zhao, Y. He, Y. Li, Adv. Mater. **22**(39), 4355 (2010).
[16] A. Ng et al., ACS Appl Mater Interfaces **5**(10), 4247 (2013).
[17] I. Singh et al., Journal of Nanophotonics **5**, 8 (2011).
[18] Q. Wan et al., Advanced Functional Materials **26**(36), 6635 (2016).