Fabrication of P3HT: PCBM bulk heterojunction organic solar cell

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Abstract. The fabrication of organic solar cells (OSCs) employing solution processing has proven to be a convenient method to guarantee the fabrication of OSCs at low cost and large-scale production. This manuscript demonstrates the successful fabrication of TFOSC with device structure: poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT: PSS)/poly (3-hexylthiophene) (P3HT): [6, 6]-phenyl-C61-butyric acid methyl ester (PCBM)/lithium fluoride (LiF)/aluminium (Al) under ambient conditions. An overall power conversion efficiency of 3.25% and charge carrier mobility of $1.22 \times 10^{-2} \text{cm}^2\text{v}^{-1}\text{s}^{-1}$ was obtained and PEDOT: PSS was beneficial in improving the charge transport processes in the preparation of organic solar cells.

1. Introduction

The increase in the world population, energy consumption per capita and more industrial usage has necessitated a search for alternative sources of energy. The discovery of petroleum in the 19th century marked a giant evolution in human history (Steele and Heinzel, 2001). It is agreed generally that the increasing use of fossil fuels, which represent the main part of the world energy production (Grossiord, Kroon, Andriessen, and Blom, 2012), is responsible for greenhouse gas emissions and the increasing ecosystem and climate instabilities (Tong and Soboyejo, 2012) which has resulted in an increase of natural disasters occurring repeatedly in different parts of the world. However, solar energy has emerged as a form of alternative energy source to traditional sources such as coal and fossil fuels. Solar energy is reliable is abundant and free. Also, the total energy from the sun reaching the earth per year is estimated to be about 6700 times the annual world primary energy consumption.

Organic solar cells (OSCs) are promising new devices for the conversion of light into electricity. The technology currently demonstrates moderate power conversion efficiencies (PCEs) and operational stabilities that do not qualify OSCs for rapid, large-scale commercialization. Nonetheless, academic curiosity and the potential of the technology has motivated intense research into this field. It’s still relatively new, but it involves photoactive organic layers, comprised of chains and bucky-balls of p-type and n-type semiconducting polymers (Yuan, Ouyang, Cimrová, Leclerc, Najari, and Zou, 2017; Chabinyc and Yueh-lin, 2006) and oligomer (Murphy, Jean, and Fréchet, 2007) materials. NREL, (2019) established that the power conversion efficiency has continually shown increase, with laboratory solar cell efficiency reaching 10% in 2012 (Tong, Asare, Rwenyagila, Anye, Oyewole, Fashina, and Soboyejo,
2015) and recently increased to ~15.6% (NREL, 2019) and ~12% in well-optimized OSC systems with non-fullerene acceptor materials (Chen and Zhang, 2017), while more efforts are being explored to improve semiconducting polymeric materials (Vyprachticky, Demirtas, Dzhabarov, and Cimrova, 2017).

Presently, crystalline silicon solar cells are the majorly used solar cells but the cost of fabrication of such solar cells is expensive and there has not been any obvious improvement in the power conversion efficiency. The high cost of production of the solar cells has encouraged research into other alternatives of fabrication and types of solar cells (OSC) at a low cost. In this study, we are reporting the photovoltaic parameters obtained using P3HT: PCBM based bulk heterojunction organic solar cell. Also, the charge transport property of the device was investigated.

2. Materials and Methods.

The OSC was fabricated using the solution-processing method. First, the ITO substrate was covered with polystyrene sulfonate (PEDOT: PSS) after it has been sonicated for 10 minutes. A thin layer of PEDOT: PSS (40nm thick) was deposited on the substrate by spin coating at 3500rpm for 60s and annealed at 100°C for 30 minutes under ambient condition. The active layer was prepared by dissolving P3HT and PCBM at a ratio of 1:1 in chloroform at a concentration of 20 mg/ml. The active layer solution was spin coated at 1200rpm for 40s on the dried PEDOT: PSS. The sample was then transferred to the furnace for annealing at 100°C for 10 minutes in nitrogen atmosphere (Oseni and Mola, 2017). Finally, 0.4 nm and 60 nm thick lithium fluoride (LiF) electron transport layer and aluminum (Al) back contact were deposited thermally under vacuum respectively using Edward Auto 306 deposition unit at a pressure of 1e-6 mbar. After few minutes of post deposition annealing in the nitrogen furnace for 10 minutes, the devices were characterized in ambient environment using Keithley HP2420 source meter under AM 1.5 solar simulator (Model SS50AAA) operating at a light intensity of 100mW/cm². The effective area of the solar cells was estimated to be 0.05 cm². The thin film absorption characteristics of the device was studied using the ultraviolet-Visible (UV-Vis) spectrometer (T80-PG-Instrument limited).

3. Results and discussion
The optical absorption spectra taken for the fabricated OSC was obtained using the ultraviolet-Visible (UV-Vis) spectrometer (T80-PG-Instrument limited). Figure 2 shows the absorption spectra with two distinct intensity peaks. The first peak is observed between 350-400 nm which can be attributed to the presence of the PEDOT: PSS and PCBM. Also, the second intensity peak which is more pronounced and observed between 450-600 nm indicates the presence of the active layer blend (P3HT: PCBM). These peaks indicate the ability of the device to absorb solar radiation within visible range (400-700 nm).

The photovoltaic parameters of the fabricated OSC was studied using the Keithley HP2420 source meter under AM 1.5 solar simulator (Model SS50AAA) operating at a light intensity of 100 mW/cm². A current density (Jsc), open circuit voltage (Voc), fill factor (FF) and power conversion efficiency (PCE) of 13.37 mA/cm², 0.57 V, 42.60 and 3.25 % was obtained respectively from the current density – voltage curve in Figure 3. The open circuit voltage of the device is similar to the values reported in literatures (Hoppe and Sariciftci, 2006; Steim et al., 2010). The high Jsc obtained can be attributed to improved charge carrier transport value determined in figure 5 which leads to a PCE of 3.25 %.

![Figure 2: UV-Vis spectra of the fabricated OSC.](image-url)
The charge transport property of the device was studied using the measured space charge limited current (SCLC). The experimental SCLC data taken from the device dark current density -voltage curve (Figure 4) was compared with the Mott-Gurney's law given by the equation (1):

\[ J = \frac{9}{8} \varepsilon \varepsilon_0 \mu_0 \exp \left( 0.89 \gamma \frac{V}{L} \right) \frac{V^2}{L^2} \]

Where \( \varepsilon \) the relative dielectric permittivity of the material, \( \varepsilon_0 \) is the permittivity of free space; \( \mu_0 \) is the zero-field mobility; \( L \) is the thickness of the active layer, and \( V \) is the voltage dropped across the sample which is corrected for built-in potential \( V_0 \). The space charge transport mobility determined in Figure 5 are compared with current density equation 1. The dark boxes in Figure 5 are the experimental data while the solid line is the computer fit according to equation 1. The zero-field mobility derived from the fit is \( \mu \), \( 1.22 \times 10^{-2} \text{ cm}^2\text{V}^{-1}\text{s}^{-1} \) is comparable to the values reported in literature (Coropceanu, Cornil, da S. Filho, Olivier, Silbey, and Bredas, 2007).
4. Conclusion

High current density is obtained from P3HT: PCBM bulk heterojunction organic solar cell fabricated using solution process method in ambient laboratory condition. The observed high current density can be attributed to the high PCE of 3.25% obtained. Also, the optical property of the device was found to be
suitable for light transmission and as well as absorption of short wavelength emission within the visible region of the electromagnetic spectrum. The observed results are attributed mainly to less trap states in the active layer and smooth interfacial contacts between the active layer and PEDOT: PSS. Also, the power conversion can be improved by the introduction of nanoparticles and solvent additives which will improve the morphology and photovoltaics properties of the OSCs.

5. References

[1] Chabinyc, M. L. and Yueh-lin, L. (2006). Semiconducting polymers for thin-film electronics, *Journal of Macromolecular Science, Part C: Polymer Reviews*, 46(1), 1–5.

[2] Chen, W. and Zhang, Q. (2017). Recent progress in non-fullerene small molecule acceptors in organic solar cells (OSCs), *Journal of Materials Chemistry C*, 5, 1275–1302.

[3] Coropceanu, V., Cornil, J., da S. Filho, D. A., Olivier, Y., Silbey, R. and Bredas, J-L. (2007). Charge Transport in Organic Semiconductors, *Chemical Reviews*, 107, 926-952.

[4] Grossiord, N., Kroon, M. J., Andriessen, R. and Blom, P. W. M. (2012). Degradation mechanisms in organic photovoltaic devices, *Organic Electronics*, 13, 432–456.

[5] Hoppe, H. and Sariciftci, N.S. (2008). Polymer Solar Cells. *Advances in Polymer Science*, 214, 1.

[6] Murphy, R. A., Jean, M. J. and Fréchet, M. J. (2007). “Organic semiconducting oligomers for use in thin film transistors,” *Chemical Reviews*, 107(4), 1066–1096.

[7] Tong, T. M., Asare, J., Rwenyagila, E. R., Anye, V., Oyewole, O. K., Fashina, A. A and Soboyejo, W. O. (2015). A study of factors that influence the adoption of solar powered lanterns in a rural village in Kenya, *Perspectives on Global Development and Technology*, 14(4), 448–491.

[8] Tong T. M. and Soboyejo, W. O. (2012). Adhesion and Interfacial Fracture: from Organic Light Emitting Devices and Photovoltaic Cells to Solar Lanterns for Developing Regions, Dissertation, Princeton University, NY.

[9] Vyprachticky, D., Demirtas, I., Dzhabarov, V. and Cimrova, V. (2017). “New copolymers with thieno[3,2-b] thiophene or dithieno[3,2-b:2′,3′-d] thiophene units possessing electronwithdrawing 4-cyanophenyl groups: synthesis and photophysical, electrochemical, and electroluminescent properties,” *Journal of Polymer Science Part A: Polymer Chemistry*, 55(16) 2629–2638.

[10] Yuan, J., Ouyang, J., Cimrová, V., Leclerc, M., Najari, A and Zou, Y. (2017). “Development of quinoxaline based polymers for photovoltaic applications,” *Journal of Materials Chemistry C*, 5, 1858–1879.