

Study and Analyze the Effect of Hole Transport Layer on the Power Conversion Efficiency of P3HT:PCBM based Organic Solar Cell

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Abstract: Organic solar cell research has attracted scientific and commercial interest in the last decade due to a rapid increase in power conversion efficiencies (PCEs). The most-prominent reported material system in Bulk Heterojunction (BHJ) is the mixture of poly(3-hexylthiophene) and [6,6]-phenyl-C61-butyric acid methyl ester (P3HT:PCBM). Due to the various research efforts that have been done on the improvement of solar cells, the effect of Hole Transport Layer (HTL) was also noticed as an important factor. This paper gives a effect of different HTL materials like PEDOT:PSS (poly(3,4-ethylenedioxythiophene):poly(4-styrenesulfonate) and MoO₃ (Molybdenum trioxide) on the photovoltaic performance of BHJ solar cell using blends of P3HT and PCBM in 1:1 ratio using common organic solvents. Prior to these processes, fabrication and designing of solar cells, right from the initial steps such as patterning of ITO coated glass, etching, cleaning and subsequent processes were performed.

Keywords: Organic Solar Cell, Bulk Heterojunction (BHJ), Power Conversion Efficiency (PCE), Hole Transport layer (HTL), PEDOT:PSS, MoO₃

1. Introduction

Organic solar cells are developing as a low-cost and lightweight energy source, and today, PCEs in the range of 8-10% have been obtained using conjugated polymers as electron donor materials in combination with fullerene/other acceptors in Bulk heterojunction geometry [1]–[3]. However, in order to enable commercial applications, the efficiencies and life time of organic solar cells still need to improve significantly. Among all of these scientific reports, the most-prominent reported material system in Bulk Heterojunction is the mixture of poly(3-hexylthiophene) and (6,6)-phenyl-C61-butyric acid methyl ester (P3HT:PCBM). The variation in electronic, chemical and structural properties with material and size dependence has attracted researchers in recent years. The device performance is highly dependent on the choice of polymer as electron donor material [4]. Studies have reported that HTL layer is also has a prominent effect on the device performance [5]–[7].

The typical organic solar cell device structure includes a transparent electrode based on indium tin oxide (ITO) and a hole transport layer (HTL) to reduce roughness and/or obtain an efficient hole-extraction from the organic materials with deep highest occupied molecular orbital (HOMO) levels in the active layer [8]. PEDOT:PSS is often used as HTL because of its easy process ability, smooth surface, and having the work function which matches to the HOMO level of many donor-type organic semiconductors. Recent studies revealed that the intrinsic device stability in ambient conditions for devices incorporating PEDOT:PSS is compromised by its hygroscopic nature, which introduces humidity in the devices and degrades the low-work-function metal [9], [10]. Transition metal oxides, such as MoO₃, V₂O₅, NiO, and WO₃, [11]–[14] have been employed as alternatives to PEDOT:PSS, based on the favourable energy level alignment [15] and the increased stability demonstrated in organic solar cells [9]. They can be deposited via various

methods, including thermal or electron beam evaporation, sputtering [13] or pulsed-laser deposition [16]. We propose here a vacuum thermal evaporation process for MoO₃ as HTL for both polymer based solar cells: we investigate the process and compare the photovoltaic results with the ones obtained on analogous organic solar cells processed on PEDOT:PSS and evaporated MoO₃. Thus to understand the effect of various HTL materials a systematic fabrication and characterization analysis was performed.

Layered structure for the fabricated device is shown below. Figure 1.1, here we have ITO coated glass substrate onto which we deposited various layers to form a solar cell as shown. Active material is a blend of Active material which is a combination of Polymer (Donar) and Fullerene (Aceptor) material. In our device, Polymer is P3HT and the fullerene is PCBM. Here we use PEDOT:PSS and MoO₃ as HTL layer in different samples and study their effect on the device efficiency of organic photovoltaic.

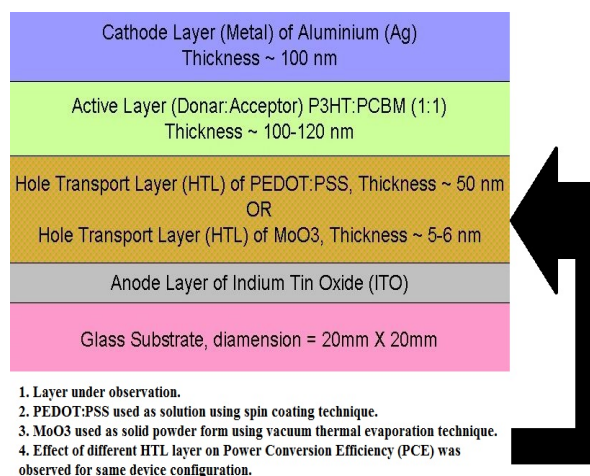


Figure 1.1: Layered structure of an OPV device.

2. Experimental

After the initial steps such as patterning of ITO coated glass, etching, cleaning and subsequent processes, the deposition of PEDOT:PSS was carried in first sample by using spin coating technique at the speed of 1200 rpm to form a thin layer of around 50 nm. This sample was dried in a vacuum oven for around 20 minutes. In the second sample the MoO₃ was deposited using vacuum thermal evaporator at the deposition rate of 0.1 Å/sec to form a very thin film of around 5-6 nm. After the deposition of HTL layer the polymer (P3HT:PCBM) was deposited by spin coating technique using a common solvent (chlorobenzene) in both the samples. This layer was also deposited at the speed of 1200 rpm and known as the active layer of thickness around 100-120 nm. Now the last layer also known as cathode was deposited using vacuum thermal evaporation technique at the deposition rate of 10 Å/sec to form a layer of thickness around 100 nm. The pressure of the vacuum chamber should be maintained around 5×10^{-7} torr to ensure good quality deposition. Otherwise without reaching low enough pressure, hot vaporized metal particles react with remaining oxygen molecules and form metal oxide.

3. Results and Discussions

Current - Voltage characteristics

Solar cells are operated between open circuit and short circuit conditions. This is in the fourth quadrant of the current - voltage characteristics, which is shown in Figure 1.2. The current - voltage curve provides a basis for the characterization of the properties of a solar cell. Such a cell is described by several parameters [17]–[19].

Open-Circuit Voltage (V_{oc}): The maximum possible voltage across a photovoltaic cell or the voltage across the cell in sunlight when no current is flowing.

Short-Circuit Current (I_{sc}): This is the current that flows through an illuminated solar cell when there is no external resistance (i.e., when the electrodes are simply connected or short-circuited). The short-circuit current is the maximum current that a device is able to produce.

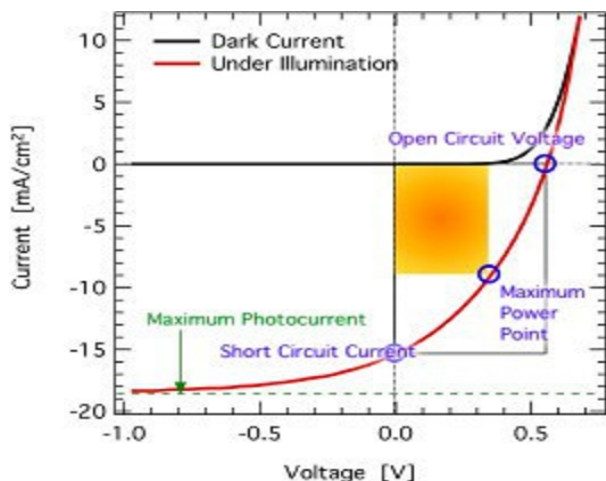


Figure 1.2: Current - Voltage characteristics

Fill Factor (FF): The ratio of a photovoltaic cell's actual maximum power output to its theoretical power output if both current and voltage were at their maxima, I_{sc} and V_{oc}, respectively. This is a key quantity used to measure cell performance. It is a measure of the 'squareness' of the I–V curve. The formula for FF in terms of the above quantities is:

$$FF = \frac{V_{mpp} \cdot I_{mpp}}{V_{oc} \cdot I_{sc}} \quad (1)$$

Where,

V_{mpp} = Voltage at Maximum Power Point

I_{mpp} = Current at Maximum Power Point

Power Conversion Efficiency (PCE or η): The ratio of power output to power input. In other words, PCE measures the amount of power produced by a solar cell relative to the power available in the incident solar radiation (P_{in}). P_{in} here is the sum over all wavelengths and is generally fixed at 100 W/cm² when solar simulators are used (in lab). This is the most general way to define efficiency. The Formula for PCE, in terms of quantities defined above is:

$$\eta = \frac{V_{mpp} \cdot I_{mpp}}{P_{in}} = \frac{V_{oc} \cdot I_{sc} \cdot FF}{P_{in}} \quad (2)$$

Figure 1.3, shows the J-V characteristics graph of a P3HT:PCBM device (light and dark characteristics) using PEDOT:PSS as HTL and device parameters are shown in Table 1.1. It was found that the J_{sc} (current density) was found to be 4.91 mA/cm², where V_{oc} was 0.514V, fill factor (FF) and power conversion efficiency (PCE) of a device has reached upto 43.3% and 1.09% respectively. The current density voltage measurements have been used to discuss the performance characteristics of a polymer cell.

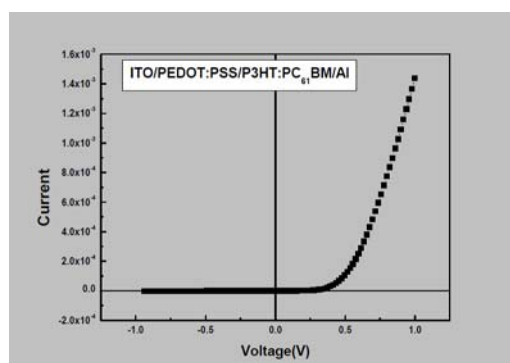


Figure 1.3 (a)

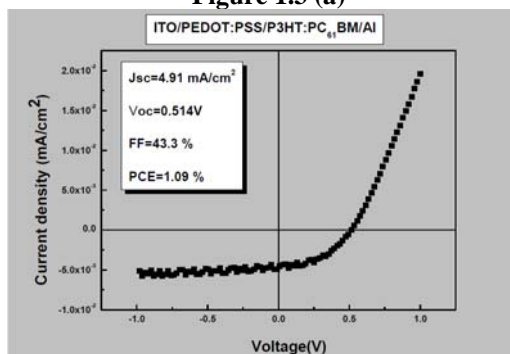


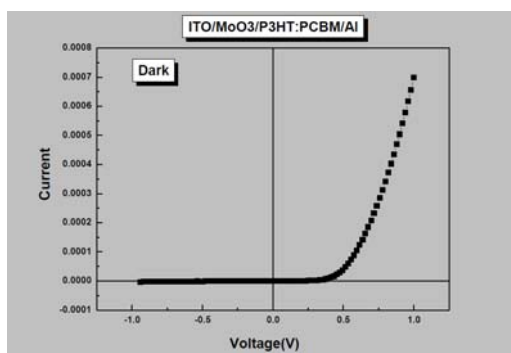
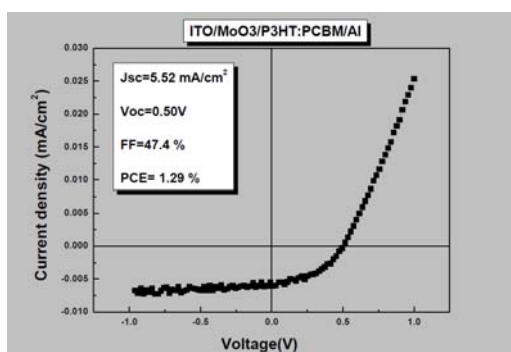
Figure 1.3 (b)

Figure 1.3: (a) and (b): J-V characteristics of P3HT based organic solar cell with PEDOT:PSS as HTL.

Table 1.1: J-V characteristics graph of a P3HT:PCBM device using PEDOT:PSS as HTL

Rotation speed	Voc (volts)	Jsc (mA/cm ²)	Fill Factor (FF)	Power Conversion Efficiency (PCE)
1200 rpm	0.514	4.91	43.3 %	1.09 %

Figure 1.4, shows the J-V characteristics graph of a P3HT:PCBM device (light and dark characteristics) using MoO₃ as HTL and device parameters are shown in Table 1.2. The solar cell showed a fill factor (FF) of 47.4%. The Voc and Jsc values were 0.50 and 5.52 respectively. The power conversion efficiency (PCE) value obtained is 1.29%.

**Figure 1.4 (a)****Figure 1.4 (b)****Figure 1.4: (a) and (b):** J-V characteristics of P3HT based organic solar cell with MoO₃ as HTL.**Table 1.2:** J-V characteristics graph of a P3HT:PCBM device using MoO₃ as HTL

Rotation speed	Voc (volts)	Jsc (mA/cm ²)	Fill Factor (FF)	Power Conversion Efficiency (PCE)
1200 rpm	0.50	5.52	47.4 %	1.29 %

4. Conclusion

We have fabricated several OPV device based on P3HT and finding average PCE in the range of 1.0% to 1.30% in the device geometry of ITO/HTL/P3HT:PCBM/Al in ambient condition. We also examine the effect of different HTL (Hole transport layer) and found that replacement PEDOT:PSS with MoO₃ resulted better PCE. We demonstrated various techniques to fabricate PEDOT:PSS and MoO₃ thin films as a hole transport layer using spin coating and thermally evaporated organic solar cells respectively. Since the extinction coefficient of PEDOT:PSS is much larger than any other materials except P3HT:PCBM and electrodes, the photon absorption of the active layer is highest when PEDOT:PSS is not used. Further PEDOT:PSS is hygroscopic, acidic, corrosive and its properties changes

with change of manufacturer. Hence we conclude that the replacement of PEDOT:PSS with alternative materials such as MoO₃ results in better PCE.

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