

FABRICATION OF MEH-PPV:PCBM BASED ORGANIC SOLAR CELLS

Thet Thet Naing¹, Nyein Wint Lwin², Than Zaw Oo³

Abstract

For the fabrication of MEH-PPV:PCBM solar cells, the bulk heterojunction blend solutions of MEH-PPV:PCBM (1:2 wt%) were prepared in chloroform, dichlorobenzene, toluene and xylene. A thin layer of poly (3,4-ethylenedioxythiophene):poly(styrenesulfonate) or (PEDOT:PSS) was spin-coated on pre-cleaned ITO glass plates. Then the PEDOT: PSS coated substrate was annealed at 100°C for 15 min. Subsequently, MEH-PPV:PCBM photoactive layer was spun-coat at 1000 rpm for 60 s on the top of PEDOT:PSS layer. After annealing at 130°C for 8 min, the devices were completed by deposition of cathode aluminum through a mask by thermal evaporation at a pressure of 10^{-6} Torr. The I-V curves of the devices were recorded under illumination of light intensity (100 mWcm^{-2}). The photovoltaic efficiency of organic solar cells were evaluated from the J-V characteristics of the device. It was measured using a computer-controlled digital source meter (Keithley 2420) with a Newport solar simulator (A.M. 1.5, 100 mWcm^{-2}). Light intensity was calibrated with a National Renewable Laboratory (NREL)-calibrated monocrystalline Silicon solar cell.

Keywords: MEH-PPV:PCBM solar cells.

Introduction

Photovoltaic (PV) cells convert solar energy into electrical energy. Solar cells are usually divided into three main generations. The first generation solar cells are mainly based on silicon (Si) wafers. The silicon-based photovoltaics have outstanding advantages in both efficiency and lifetime with power conversion efficiencies (PCE) in excess of 25% [K.Wu *et al.*, (2010)]. Second generation solar cells are thin-film solar cells which include amorphous silicon (a-Si), and cadmium telluride (CdTe), and copper indium gallium selenide (CIGS). Their typical performance is 10-15% [X. Wang *et al.*, (2010)]. Third generation solar cells are organic heterojunction solar cells, dye sensitized solar cells (DSSC) and organic/inorganic hybrid solar cells. Organic solar cells have received attention due to their low-cost, easy processability, low weight, and mechanical flexibility. Their power conversion efficiencies have increased considerably from 0.001% in 1975 to 1% in 1986 and more recently to 8.13% in 2010 [C. Tang *et al.*, (2007)].

The choice of solvent for polymeric blends is one of the major factors which have influence on the performance of the polymer solar cell. To provide effective donor- acceptor charge transfer and transport in bulk heterojunction solar cells, the photoactive layer has to demonstrate the right morphology, which means appropriate domain size, crystallinity and vertical distribution of both components [B. Chung *et al.*, (2007)]. The choice of solvent, annealing temperature and time are the most critical factors determining the final morphology. The effect of morphology can be described by the formation of an effective network between donor and acceptor which creates effective routes for separated charge transport. The properties of the solvents, such as boiling point, solubility and surface tension have a considerable impact on the final morphology of the photoactive layer, thereby determining the device performance. It

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is thus crucial to explore a suitable solvent for the particular polymeric material that yields the preferable morphology of photoactive layer [J. Kim *et al.*, (2007)].

Several attempts have been implemented in order to achieve the higher device efficiency. The choice of solvent for polymeric blends is a major factor which influences on the performance of the polymer solar cells. To provide effective donor-acceptor charge transfer and transport in bulk heterojunction solar cells, the photoactive layer has to demonstrate the right morphology, which means appropriate domain size, crystallinity and vertical distribution of both components. The properties of the solvents, such as boiling point, solubility and surface tension have a considerable impact on the final morphology of the photoactive layer, thereby determining the device performance. It is thus crucial to explore a suitable solvent for the particular polymeric material that yields the preferable morphology for photoactive layer.

Experimental Details

This section details about device fabrication and efficiency measurement.

Device Fabrication and Efficiency Measurement

The fabrication steps for organic photovoltaic device are depicted in Fig.(1). The devices were fabricated on indium tin oxide (ITO) coated glass substrates which are used as the transparent electrodes. The indium tin oxide (ITO) glasses were cleaned by sequential ultrasonication in acetone, distilled water and isopropyl alcohol (IPA) for 15 min consecutively and dried by nitrogen blow. Since ITO was coated throughout the glass substrate, etching had to be carried out to remove the ITO at the sides, leaving the only ITO in the center region as shown in Fig. 2(a). ITO surfaces were then treated by UV light in order to remove the organic contamination on the ITO surface. Fabricated OPV devices are shown in Fig.(2)(b). The ultrasonic cleaner and UV chamber used in our ITO cleaning processes are shown in Fig.(2)(c) and (d) respectively. For the fabrication of MEH-PPV:PCBM solar cells, the bulk heterojunction blend solutions of MEH-PPV:PCBM (1:2 wt%) were prepared in chloroform, dichlorobenzene, toluene and xylene. A thin layer of poly (3, 4- ethylenedioxythiophene):poly (styrenesulfonate) or (PEDOT:PSS) (Sigma Aldrich) was spin-coated at 3000 rpm for 60 s on pre-cleaned ITO glass plates. Then the PEDOT:PSS coated substrate was annealed at 100 °C for 15 min. Subsequently, MEH-PPV:PCBM photoactive layer was spin-coat at 1000 rpm for 60 s on the top of PEDOT:PSS layer. The active layer thicknesses were in the range of 80 nm-100 nm as determined by a surface profiler (Tencor Alpha-Step IQ). After annealing at 130 °C for 8 min, the devices were completed by deposition of cathode aluminum (Al) (~ 100 nm) through a mask by thermal evaporation at a pressure of 10^{-6} Torr. The device active area was around 0.07 cm². Fig.(4)(a) shows thermal evaporator (NTE 1000) for the deposition metal (Al) cathode. The I-V curves of the devices were recorded under illumination of light intensity (100 mW/cm²). The photovoltaic efficiency of organic solar cells were evaluated from the J-V characteristics of the device. It was measured using a computer-controlled digital source meter (Keithley 2420) with a Newport solar simulator (A.M. 1.5, 100 mW/cm²). Light intensity was calibrated with a National Renewable Laboratory (NREL)-calibrated monocrystalline Silicon solar cell. Fig.(3)(b) shows the experimental setup for the efficiency measurement of OPV devices.

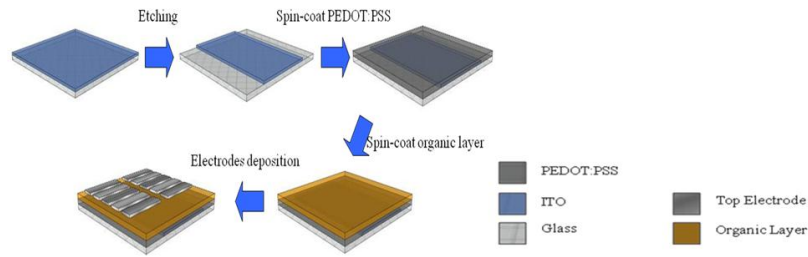


Figure 1 Fabrication steps for organic photovoltaic device

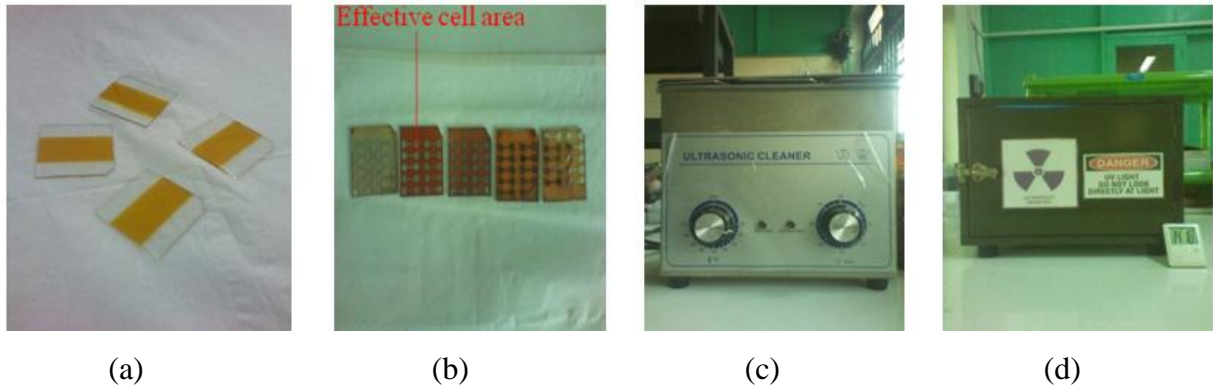


Figure 2 Illustrations of (a) etched ITO pattern on glass substrate, (b) fabricated OPV devices, (c) ultrasonic cleaner and (d) UV chamber

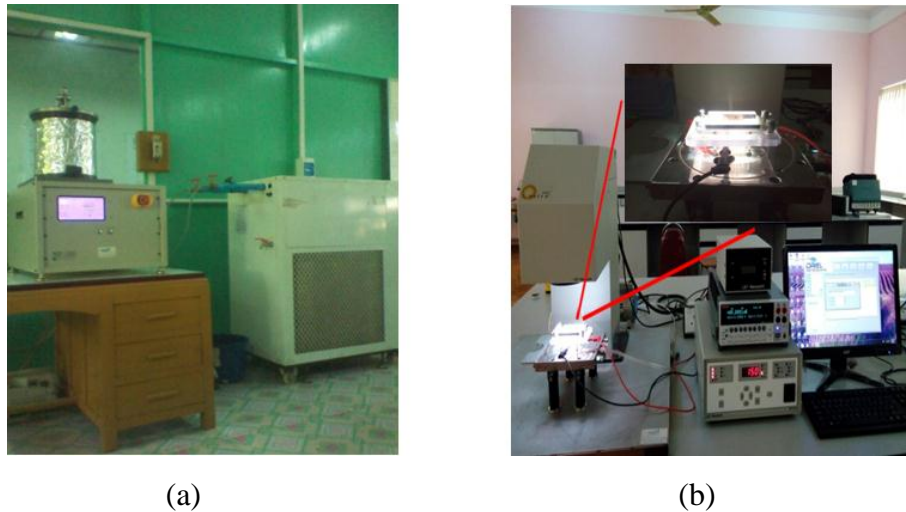


Figure 3(a) Thermal evaporator (NTE 1000) for the deposition metal (Al) cathode and (b) Experimental setup for the measurement of device efficiency (Newport Solar simulator and Keithley source meter)

Results and Discussion

This section discusses the photovoltaic performance of MEH-PPV:PCBM based organic solar cells.

Photovoltaic Performance of MEH-PPV:PCBM Devices: Correlating the Properties and Performance

The device performances of MEH-PPV:PCBM solar cells using four different solvents (chloroform, dichlorobenzene, toluene and xylene) were evaluated under A.M 1.5 solar

irradiation of intensity 100 mW/cm^2 . The current-voltage (J-V) characteristics of these devices are shown in Fig. (4)(a). Dichlorobenzene based device showed the highest J_{sc} of 0.66 mA/cm^2 and FF of 26.40. Its power conversion efficiency (PCE) is as high as 0.112%. The power conversion efficiencies of chloroform and toluene based devices are 0.0067% and 0.0080% two orders lower than that of dichlorobenzene. The PCE of xylene based device is as low as 0.0003%. In order to understand more about the system, it is crucial to correlate the optical, electrical and morphological properties of the photoactive layer with each and every device parameters (V_{oc} , J_{sc} and FF) which determine the device efficiency. The open circuit voltages (V_{oc}) of the devices are 0.82 V, 0.63 V, 0.70 V and 0.43 V for toluene, dichlorobenzene, chloroform and xylene respectively. It is well accepted that the V_{oc} in organic solar cell is determined by the energy level difference between highest occupied molecular orbital (HOMO) of p-type donor material and lowest unoccupied molecular orbital (LUMO) of n-type acceptor material. Higher V_{oc} of 0.82 V is produced in the device with toluene while lower V_{oc} of 0.43 V in the device with xylene. In Fig. 4(b), we can see that there is a change in optical band gap energy of the active layer with toluene and xylene.

The short circuit current (J_{sc}) of dichlorobenzene based device is 0.66 mA/cm^2 which is higher than those of chloroform, toluene, xylene based devices (0.10 , 0.07 and 0.04 mA/cm^2). The photocurrent generation (J_{sc}) in organic solar cells is related to the number charge carriers and carrier mobility. The number of carrier generated is in turn related to the absorption (electron excitation) properties of photoactive materials. The absorption spectra (Fig. 4(b)) shows that the dichlorobenzene and chloroform offers the higher absorption properties as compared to those of others. It suggests that higher absorption with dichlorobenzene and chloroform would generate the higher current. However, only dichlorobenzene device generates higher current. As mentioned earlier, the current generation is also related to the carrier mobility. It seems that the mobility of the chloroform based photoactive layer would be poor, resulting in the lower current in the devices. Another possibility of lower J_{sc} in chloroform, toluene and xylene based devices is that the ionization of excitons is insufficient in the devices with chloroform, toluene and xylene due to the less exciton ionization interfaces [N. Shaheen *et al.*, (2001)].

The fill factor (FF) in the devices is very sensitive to the surface morphology/roughness of the active layer and series resistance of the device. The FF of the device is 26.40 for dichlorobenzene, 14.10 for toluene, 13.46 for xylene and 9.84 for chloroform. The series resistance of the devices is calculated from the slope of the J-V curves at the open-circuit point (Fig. 5(a)). The R_s is $0.87 \text{ }\Omega\text{cm}^2$, $32.32 \text{ }\Omega\text{cm}^2$, $58.99 \text{ }\Omega\text{cm}^2$ and $467.28 \text{ }\Omega\text{cm}^2$ for the device with dichlorobenzene, toluene, xylene and chloroform respectively. It is obvious that the highest FF in the dichlorobenzene device would be due to the lowest R_s and the lowest FF in chloroform device would be due to the highest R_s . Since the FF of the devices is also related to the surface roughness/morphology of the films, the roughness profiles of the photoactive layers with various solvents are generated and depicted in Fig. (5)(b). The lowest surface roughness (R_a) achieved in the active layer with dichlorobenzene leads to higher FF in the device with dichlorobenzene.

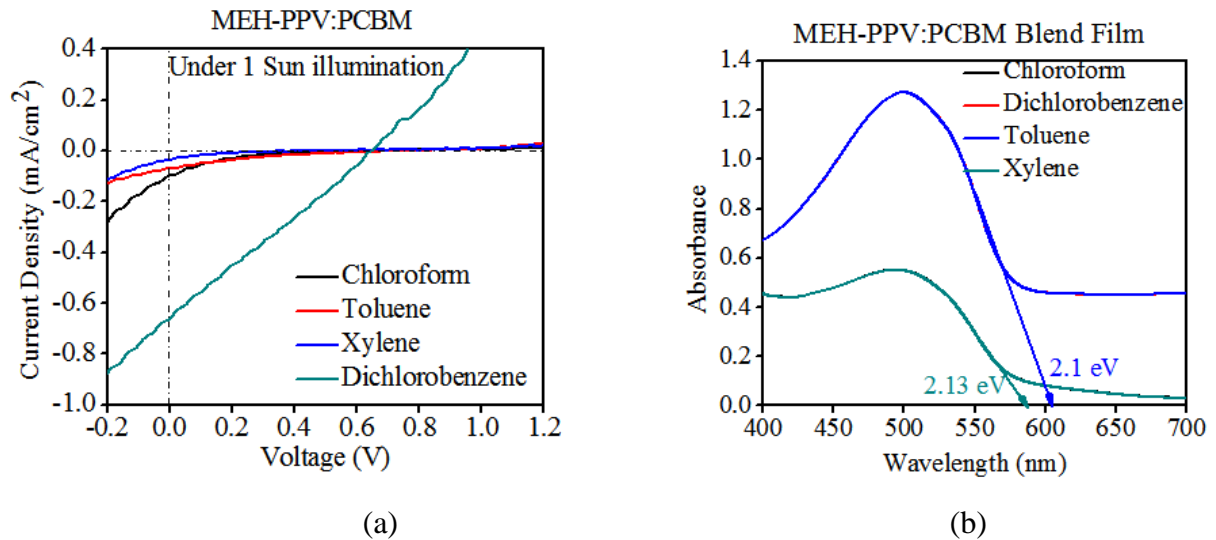


Figure 5 (a) J-V characteristics of MEH-PPV:PCBM devices using four different solvents. and (b) Absorption spectra of MEH-PPV:PCBM blend films using four different solvents

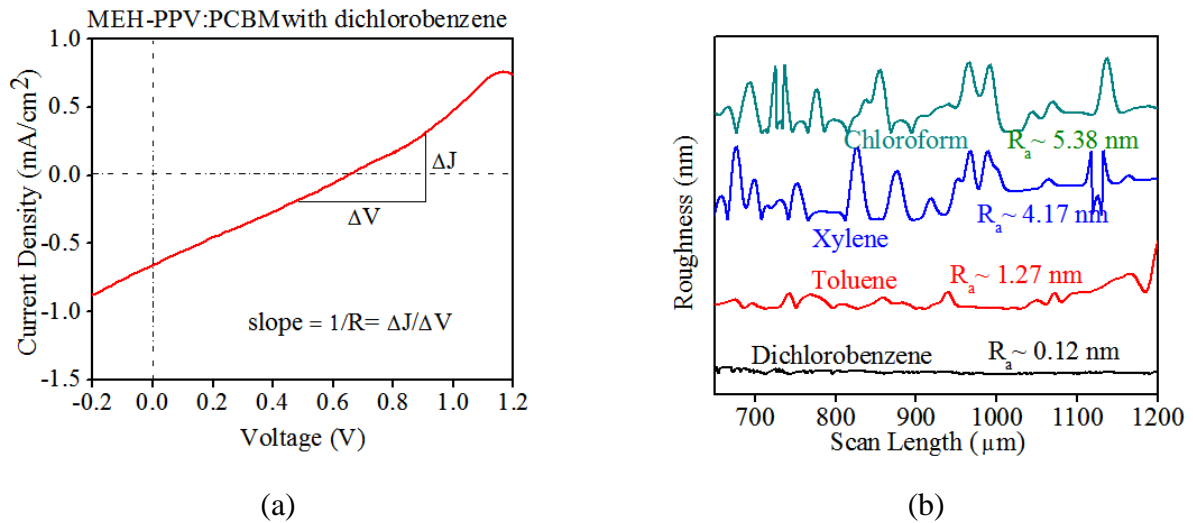


Figure 5 (a) Estimation of series resistance (R_s) from the J-V curve and (b) Roughness profiles for the MEH-PPV:PCBM films with different solvents

Conclusion

The optical properties of MEH-PPV:PCBM devices were investigated. The solvents used were chloroform, dichlorobenzene, toluene and xylene. The solvent "dichlorobenzene" provides the highest absorption intensity and lowest band gap energy of 2.1 eV. Achieving the high optical absorption and low band gap energy is requisite for photoactive layers in solar cells. The fabrication of organic solar cells using MEH-PPV:PCBM polymer blend film as photoactive layer. The device using "dichlorobenzene" produced the efficiency as high as 0.112% (open circuit voltage 0.63 V, short circuit current density 0.67 mAcm⁻² and fill factor 26.40).

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References

- Chung B, D. Yanfei, L.Ping and C. Qiying, (2007) *Appl. Phys. Lett.* Vol. **55**, pp-1741.
- Kim J and G. Weihao, (2007) "An Overview on MEH-PPV:PCBM", *J.Sci.* Vol **45**, pp- 222.
- Shaheen N, C.Markus and J. Christoph, (2001) "Polymer- Fullerene Bulk Heterojunction Solar Cells", *Appl. Phys. Lett.* Vol. **78**, pp-98.
- Tang C, B.Minnaert and M. Burgelman, (2007) "Modelling MEH-PPV:PCBM (1:4) Bulk Heterojunction Solar Cells", *Appl. Phys. Lett.* Vol. **91**, pp-143.
- Wu K and J. deBoisblanc, (2010) "Synthesis and Charactreization of MEH-PPV:PCBM Organic Solar Cells", Master Thesis.
- Wang X, D.Lui and L.Jiuyan, (2010) "Orgnic Photovoltaic Materials and Thin Film Solar Cells", *Front. Chem. Lett.* Vol. **5**, pp-45.