Variation of MEH-PPV layers with/without PEDOT:PSS layer in organic solar cells

R Suryana¹,², L K Tyas¹ and F Nurosyid¹,²
¹Physics Department of Graduate Program, Universitas Sebelas Maret, Indonesia
²Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Indonesia
Email: rsuryana@staff.uns.ac.id

Abstract. Organic solar cell in structures of Glass/FTO/TiO₂/MEH-PPV and Glass/FTO/TiO₂/PEDOT:PSS/MEH-PPV were fabricated using spin coating method. The MEH-PPV layer was varied at 1 layer, 2 layer, 3 layer and 4 layer. All samples without/with PEDOT:PSS for each MEH-PPV layer were characterized using the UV-Vis spectroscopy to evaluate the absorbance, the cross-section SEM to determine the thickness of MEH-PPV layer and the I-V meter to calculate the performance of organic solar cell. The thickness for each MEH-PPV layer was 0.88 µm (1 layer), 1.14 µm (2 layer), 2.35 µm (3 layer) and 5.81 µm (4 layer). The absorbance of samples without/with PEDOT:PSS increase with increasing the thickness of MEH-PPV. Adding PEDOT:PSS can improve the performance of samples. It is considered that PEDOT:PSS can enhance hole collection, exciton diffusion and photocarrier transport.

1. Introduction

Organic solar cells have great potential to be developed as a renewable energy source and environmentally friendly. However, the power efficiency is still low and cannot be accepted commercially. Therefore, it is needed a comprehensive study to improve the efficiency of organic solar cells [1]. Poly[2-methoxy-5-(2-ethylhexyloxy)-1.4-phenylenevinylene] (MEH-PPV) is still attractive polymers for organic solar cells which has the absorption of light at a wavelength of 450-550 nm [2]. In addition, MEH-PPV has properties which compatible with organic solar cell applications such as absorption of the highest energy of sunlight at a wavelength of 500 nm [3], as electron donor (p-type semiconductor) material [4], has orbital energy at 5.3 eV for highest occupied molecular orbital (HOMO) and lower unoccupied molecular orbital (LUMO) at 3.2 eV [5].

Due to its stability and easily controlled size and shape, the TiO₂ nanoparticle semiconductor material is added as an acceptor in a MEH-PPV-based hybrid solar cell [6]. TiO₂ as an acceptor (n-type semiconductor) has a valence band 7.6 eV and conduction band 3.7 eV [7].

One of important materials in an organic solar cell is poly (3,4-ethylenedioxythiophene) polystyrene sulfonate (PEDOT:PSS) which can improve the roughness of active layer [8]. In addition, PEDOT:PSS can improve the conversion performance by enhancement of hole collection, exciton diffusion and photocarrier transport [9]. In this work, we present the influence of PEDOT:PSS on the performance of hybrid solar cell based on MEH-PPV/TiO₂ nanoparticle with variation of MEH-PPV layer.
2. Experimental

TiO$_2$ nanoparticle (21 nm, anatase phase) Sigma Aldrich, poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEH-PPV) Sigma Aldrich, and poly[3,4-ethylenedioxythiophene polystyrene sulfonate] (PEDOT:PSS) Sigma Aldrich was used as main material in hybrid solar cell while ethanol and chlorobenzene was used as solvent. Aluminum layer was coated on MEH-PPV layer using evaporator as metal contact.

The FTO was cut in size of 2 cm × 1.5 cm. The FTO surface was patterned using zinc powder and HCl. The width of conductive part was 2 mm while the width of non-conductive (glass) part was 4 mm, 3 mm and 4 mm as shown in Fig. 1. Conductive part was covered by the scotch tape that is resistant to acid. Zinc powder was coated onto entire the FTO surface then HCl solution was dropped onto non-covered part and waiting for 3 min. The remaining of zinc powder and HCl solution was cleaned using the cotton bud and was rinsed into aquades with ultra-sonic cleaner for 3 min. The non-conductive (glass) was checked using a multimeter to confirm that the FTO surface has been removed.

0.5 g TiO$_2$ was dissolved in 2 ml ethanol then stirred for 30 min at 300 rpm using a vortex stirrer. 0.05 g MEH-PPV was dissolved in 5 ml chlorobenzene then distilled at 300 rpm for 18-24 h until seen homogeneous solution.

The hybrid solar cell structure was conducted in two types i.e. FTO/TiO$_2$/MEH-PPV/Al and FTO/TiO$_2$/PEDOT:PSS/MEH-PPV/Al. Later, it was named type I and type II, respectively. The FTO surface was coated by TiO$_2$, PEDOT:PSS, and MEH-PPV using the spin coating method. For type I, the TiO$_2$ solution was dropped on center of the FTO conductive glass and was spun by spin coater at 1000 rpm for 30 s. Then it was annealed at 450°C for 30 min. While MEH-PPV solution was coated on the TiO$_2$ layer at 1000 rpm for 60 s then annealed at 80°C until dried. MEH-PPV layer was varied i.e. 1 layer, 2 layer, 3 layer, and 4 layer. For type II, PEDOT:PSS was coated on the TiO$_2$ layer at 800 rpm for 30 s before coating the MEH-PPV. Then, it was annealed at 110°C for 15 min.

![Figure 1](image.png)

Figure 1. The pattern of the FTO surface after the dry etching

Finally, aluminum was coated on the top of MEH-PPV layer using evaporator. A shadow mask in column size of 10 cm × 3 mm was put onto the sample at perpendicular to Fig. 1 pattern. Thus, an active area was obtained in size of 4 mm$^2$. When the pressure was reached at about 7×10$^{-6}$ Torr, the DC current was increased slowly until aluminum evaporate at range of 16–20 A. The sample was placed on the PCB holder, then the active area was contacted using the silver paste to measure I-V characteristic.

Absorbance of the sample at wavelength of 200 – 800 nm with/without PEDOT:PSS was measured by ultraviolet visible (UV-Vis) spectroscopy. The thickness of each MEH-PPV layer was determined.
by scanning electronic microscopy (SEM). The performance of the sample was analyzed by I-V measurement using the 2062A system source Keithley with irradiation using Xenon lamp at 1000 W/m².

3. Results and Discussion

Absorbance of FTO/TiO₂/MEH-PPV (type I) and FTO/TiO₂/PEDOT:PSS/MEH-PPV (type II) samples are shown in Fig. 2 (a) and (b), respectively. Absorbance patterns are almost similar between type I (without PEDOT:PSS) and type II (with PEDOT:PSS). Absorbance increases with increasing the MEH-PPV layer. There are three peaks which can be observed by UV-Vis spectroscopy i.e. about 200 nm, 325 nm and 400 nm. These peaks correlate to TiO₂ at 200 nm [10] and MEH-PPV+TiO₂ at 325 and 400 nm [11] while PEDOT:PSS curve increase from 400 nm to 1200 nm [12]. We cannot observe PEDOT:PSS absorption especially in peak of about 400 nm in Fig. 2 (b). However, the adding PEDOT:PSS can increase absorption in type II.

Fig. 3 shows the cross-section SEM images of MEH-PPV layer on FTO substrate. The thickness of MEH-PPV increase with increasing the amount of layer i.e. 0.88 μm (1 layer), 1.14 μm (2 layer), 2.35 μm (3 layer) and 5.81 μm (4 layer). Based on Fig. 2, type I and type II without Al layer absorb ultraviolet (UV) or visible (Vis) light, the values of the absorbance bands depend on the MEH-PPV thickness according to Beer’s law [13]. The smaller thickness for 1 layer which also has the lowest absorbance.

Effect of PEDOT:PSS layer on the performance of organic solar cell with variation of MEH-PPV layer were determined through I-V characterization. I-V curves for each MEH-PPV layer under irradiation of Xenon light are shown in Fig. 4(a) without PEDOT:PSS and 4(b) with PEDOT:PSS. The procedure to obtain the efficiency of organic solar cell is similar to dye-sensitized solar cell (DSSC) case which has been demonstrated in the previous work [14].
Figure 3. Cross-section SEM images of MEH-PPV layer on FTO with two orange lines indicate thickness for each layer on (a) 1 layer, (b) 2 layer, (c) 3 layer and (d) 4 layers

Figure 4. I-V characteristics for each MEH-PPV layer on the organic solar cell without PEDOT:PSS (a) and with PEDOT:PSS (b) under Xenon irradiation

Table 1 summarize the I-V measurement consisting the open circuit voltage ($V_{oc}$), the current short circuit ($I_{sc}$), the voltage maximum ($V_{m}$), the current maximum ($I_{m}$) to calculate the fill factor (FF) and the efficiency ($\eta$). In the case both without and with PEDOT:PSS, the performance on samples for MEH-PPV 1 layer and 2 layer are almost similar. For MEH-PPV 3 layer, the performance decrease while for MEH-PPV 4 layer, the performance increase. Main processes involved in the organic solar cell consists of photon absorption by the MEH-PPV to generate the exciton, exciton diffusion toward the donor/acceptor interface, exciton dissociation at the donor/acceptor through an ultrafast electron transfer [15]. Then electron/hole will be transported toward correct electrodes. Therefore, many excitons are generated when MEH-PPV layer increase and diffused toward the donor/acceptor interface to produce the electron and hole. It is considered that the performance of sample increase with increasing the MEH-PPV layer. However, until this work is reported, we have not understood why the performance on the organic solar cell with MEH-PPV at 3 layer decrease.
The performance of organic solar cell with adding the PEDOT:PSS are higher than the samples without adding the PEDOT:PSS. This is an evidence that PEDOT:PSS can improve the conversion performance by enhancement of hole collection, exciton diffusion and photocarrier transport [9].

Table 1. Summary of the efficiency of organic solar cell without/with PEDOT:PSS for each MEH-PPV layer

| MEH-PPV | Voc (Volt) | Isc (Ampere) | Pm (Watt) | Vm (Volt) | Im (Ampere) | FF | η (%x10^-2) |
|---------|------------|-------------|-----------|-----------|-------------|----|-------------|
| 1 layer | 0.009914 | 8.64x10^-8 | 8.57x10^-9 | 0.009914 | 8.64x10^-7 | 0.234 | 0.0214 |
| 2 layer | 0.009872 | 2.9x10^-8 | 9.50x10^-9 | 0.054932 | 1.73x10^-7 | 0.322 | 0.0238 |
| 3 layer | 0.009898 | 6.89x10^-9 | 2.44x10^-9 | 0.039805 | 6.12x10^-8 | 0.265 | 0.0061 |
| 4 layer | 0.009872 | 1.38x10^-7 | 6.52x10^-8 | 0.114997 | 5.67x10^-7 | 0.138 | 0.1630 |

| GLASS/ FTO/ TiO2/ PEDOT/PSS/ MEH-PPV | Voc (Volt) | Isc (Ampere) | Pm (Watt) | Vm (Volt) | Im (Ampere) | FF | η (%x10^-2) |
|-------------------------------------|------------|-------------|-----------|-----------|-------------|----|-------------|
| 1 layer | 0.009933 | 3.67x10^-7 | 3.65x10^-8 | 0.009933 | 3.67x10^-7 | 0.221 | 0.0912 |
| 2 layer | 0.018084 | 8.57x10^-8 | 2.58x10^-8 | 0.055066 | 4.68x10^-7 | 0.162 | 0.0644 |
| 3 layer | 0.009919 | 7.26x10^-9 | 3.64x10^-9 | 0.009919 | 3.67x10^-8 | 0.219 | 0.0091 |
| 4 layer | 0.009991 | 5.23x10^-7 | 9.50x10^-8 | 0.114994 | 8.26x10^-7 | 0.393 | 0.2375 |

4. Conclusion
The highest efficiency of FTO/TiO2/PEDOT:PSS/MEH-PPV/Al with MEH-PPV 4 layer is 0.2375 x 10^-2%. The performance of organic solar cell increase with adding the PEDOT:PSS layer. It is considered that PEDOT:PSS can improve the conversion performance by enhancement of hole collection, exciton diffusion and photocarrier transport.

Acknowledgments
Authors wish to thank PNBP Universitas Sebelas Maret 2015 for financial support through Hibah Mandatory

References
[1] Supriyanto A, Kusminarto, Triyana K, Roto, Salleh M M and Umar A A 2010 J. Mater. Sci. Eng. 04 40
[2] Omer B M 2012 J. Nano Electron. Phys. 4 04006
[3] Kim M S 2009 Understanding Organic Photovoltaic Cells: Electrode, Nanostructure, Reliability, and Performance (Dissertation: The University of Michigan, US)
[4] Aernouts T 2006 Organic Bulk Heterojunction Solar Cells From Single Cell Towards Fully Flexible Photovoltaic Module (Dissertation: Katholieke University Leuven Belgia)
[5] Oku T, Nagaoka S, Suzuki A, Kikuchi K, Hayashi Y, Sakuragi H and Soga T 2008 J. Ceram. Process. Res. 9(6) 549
[6] Kim S S, Jo J, Chun C, Hong J C and Kim D Y 2007 J. Photochem. Photobiol. A Chem. 188(2-3) 364
[7] Tiwana P, Docampo P, Johnston M, Snaith H and Herz L 2011 ACS Nano 5 5158
[8] Iftimie S, Radu A, Radu M, Besleaga C, Pana I, Craciun S, Girtan M, Ion L and Antohe S 2011 Dig. J. Nanomater. Biostruct. 6(4) 1631
[9] Brincoveanu O A, Ioanid A, Iftimie S and Antohe S 2016 Romanian Reports in Phys. 68(3) 1097
[10] Zhou K, Zhu Y, Yang X, Jiang X and Li C 2011 New J. Chem. 35 353
[11] Habellhames F, Lamiri L, Zerguine W and Nessark B 2013 Mater. Sci. Semicond. Process. 16(3) 727
[12] Luo J, Billep D, Blaudeck T, Sheremet E, Rodriguez R D, Zahn D R T, Toader M, Hietschold M, Otto T and Gessner T 2014 J. Appl. Phys. 115 054908
[13] Seoudi R, El-Bahy G S, El Sayed Z A 2006 Opt. Mater. 29 304
[14] Suryana R, Khoiruddin, Supriyanto A 2013 Material Science Forum 737 15
[15] Chen C, Wu F, Geng H, Shen W and Wang M 2011 Nanoscale Res. Lett. 6 350