Temperature effects on electrical and structural properties of MEH-PPV/PEIE OLED Device

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Abstract. This paper explores the performance of configuration ITO/MEH-PPV/PEIE/Al OLED under the variations of temperature. The MEH-PPV and MEH-PPV/PEIE thin film were deposited on ITO substrates using spin coating technique with fixed spin speed of 3000 rpm and baked at low temperature ranging from 90 °C to 180 °C, respectively. The surface roughness values for MEH-PPV and MEH-PPV/PEIE films were analysed using AFM with 5 µm × 5 µm scanning area. The roughness of MEH-PPV thin films were reduced from 2.825 nm to 1.625 nm when temperature increased. Contrary to MEH-PPV/PEIE films where the roughness increased linearly up to 3.397 nm when the temperature increased. The maximum absorption peak spectrum obtained from UV-Visible (UV-Vis) was found at 500 nm to 510 nm when baked temperature were varied. Furthermore, the turn on voltage from J-V characteristics gives no specific pattern across different temperature and agreed with the trend of surface roughness values. The turn-on voltage at T= 150 °C gives the lowest value of 3 V. Overall, the variations of low temperature gives an effects on structural and electrical properties of this OLED configuration.

1. Introduction

Organic material have been investigated recently due to its attractive applications in optoelectronics and microelectronic devices [1]. Poly [2-methoxy-5(2’ –ethylhexyloxy)-1, 4-phenylenevinylene), MEH-PPV is one of these materials that widely used in optoelectronic field such as organic light-emitting diode (OLED), organic photovoltaic (OPV) and also organic field-effect transistor (OFET) [2]. MEH-PPV can be diluted using aromatic and non-aromatic solvent such as chloroform, THF and toluene. The present of alkoxy phenyl group of the polymer chains makes this material easy to dilute. Previous work used solution based method to diluted MEH-PPV films where the good quality of that film and high solubility were obtained [3].

OLED device can be fabricated by using various method such as spin coating technique, vacuum deposition, dipping coating and inkjet printing. However some of the method are quite expensive and certain of them are suitable for small scale device. For example, the vacuum deposition method, the manufacturing cost must be cut down so that the small size OLED can be accepted in the display market [4]. Solution processed is widely used in the making of organic light emitting diode for large scale production [5], which correspond to their simple processing procedure and low manufacturing cost [5,7].
Previous work, Juhari et al. [6] investigated the surface morphology of MEH-PPV thin films. The MEH-PPV thin films were baked at room temperature. The SEM images shown in the report indicates the surface was affected by application of electric field. Later, Azhar et al. [7] investigated electrical properties of MEH-PPV thin films based on annealing temperature effects. However, the structural properties of MEH-PPV thin film is not much discuss and the annealing temperature used quite low (50 °C, 75 °C and 100 °C). Therefore, it is necessary to investigate the effect of temperature on electrical and structural properties of MEH-PPV and MEH-PPV/PEIE thin films.

In this work, the $J-V$ characteristics for device configuration of ITO/MEH-PPV/PEIE/Al were investigated when MEH-PPV/PEIE thin films were baked at temperature ranging from 90 °C to 180 °C. Hence, the performance of the MEH-PPV/PEIE thin films in terms of surface roughness were analyzed using Atomic Force Microscopy (AFM). The performance of surface roughness were obtained using AFM. The results were then analyzed and compared.

2. Experimental

2.1. Fabrication processes

The MEH-PPV used for this experiment with molecular weight of 70,000 ~ 100,000 Mw and polyethylenimine ethoxylated (PEIE) (80 % ethoxylated) used was purchased from Sigma Aldrich. The 5 mg MEH-PPV powder was diluted in 1 ml toluene. Next, PEIE was diluted in ethanol with the concentration of 0.3 wt %. The indium-tin-oxide (ITO) glass substrates were cleaned by using deionized (DI) water, ethanol and acetone in ultrasonic bath for 10 minutes respectively. The ITO glass substrates were dried on hot plate with temperature of 90 °C for 2 minutes. Then, MEH-PPV solution was deposited onto ITO glass substrates via spin coating method with spin speed of 3000 rpm [8]. The ITO/MEH-PPV thin films were baked at different temperature of 90 °C, 120 °C, 150 °C and 180 °C for 15 minutes. After that, PEIE solution was deposited onto ITO glass substrates via spin coating method with spun speed of 4000 rpm. The ITO/MEH-PPV/PEIE thin films were baked at 90 °C for 2 minutes. Finally, the aluminum (Al) as a cathode were deposited. The active area of the device are 0.5 cm$^2$. The configuration of ITO/MEH-PPV/PEIE/Al and the molecular structures of MEH-PPV and PEIE are shown in Figure 1.

![Figure 1. The chemical structure of the (a) MEH-PPV, (b) PEIE and (c) schematic illustration of structure of ITO/MEH-PPV/PEIE/Al device.](image-url)
2.2. Device characterization

AFM was used to analyze the surface roughness with scanning area of 5 μm². The absorption spectrum of MEH-PPV/PEIE thin films were measured using UV-Visible (UV-Vis) spectrophotometer with scanning range from 300 nm to 800 nm. Semiconductor Parametric Analyzer (SPA) was used to measure the J-V characteristic of ITO/MEH-PPV/PEIE/Al. The voltage applied to operate the device was from 0 V to 10 V.

3. Result and Discussion

3.1. Absorption spectrum of OLED device

Figure 2 shows the absorption peak wavelength of ITO/MEH-PPV/PEIE with different temperature varied from 90°C to 180°C. The maximum absorption peak for 90 °C to 150 °C shared the same peak wavelength at 506 nm. While for 180 °C, the maximum absorption peak dropped and become blue shifted. As the temperatures increase, the intensity increases due to the formation of inter-chain excited states [7]. The inset graph is the absorption peak wavelength of ITO/MEH-PPV at 90 °C. The results are then compared where the absorption peak wavelength of ITO/MEH-PPV acts as a constant. During the process of spin coating process, the polymer chains are fixed, which make the π-electron delocalization increases in the system as the annealing temperature increased [9,10].

![Figure 2. Absorption peak wavelength of ITO/MEH-PPV/PEIE with different temperature. The inset is absorption peak wavelength of ITO/MEH-PPV at 90 °C.](image)

3.2. Surface morphology of ITO/MEH-PPV and ITO/MEH-PPV/PEIE

Figure 3 shows the AFM images of MEH-PPV thin films at different temperature with constant baked time of 15 minutes. As observed in Figure 3, the surface morphology of MEH-PPV with temperature of 180 °C appeared to be smooth compared to other temperature. Multiple white peaks were observed in Figure 3(a), (b), (c) and (d). However, lesser peaks can be observed in Figure 3(d).
Figure 3. The AFM images of MEH-PPV thin films with scanning area of 5 μm² for temperature of (a) 90 °C (Ra = 2.825 nm), (b) 120 °C (Ra = 1.967 nm), (c) 150 °C (Ra = 1.966 nm), (d) 180 °C (Ra = 1.625 nm).

Based on previous report, Juhari et al [11] reported surface morphology of MEH-PPV would affect the performance of the device. Figure 4 shows the AFM images of ITO/MEH-PPV/PEIE at different temperature with constant bake time of 15 minutes for MEH-PPV. The surface roughness increases as the temperature increased.

According to Zhang et al [12], films prepared below 150 °C has non-uniform particles and more dense which produced rougher surface. Figure 4(c) showed device annealed at 150 °C has small peak and micro round hollows are found on the surface. This may due to bubble present in the MEH-PPV solution that burst when heat was applied. Despite of the surface roughness, the image formed shows that the particles are uniformly coated onto the device. Surface roughness at 180 °C showed the highest value with 3.397 nm.

Figure 3 and Figure 4 showed different values for the surface roughness as the temperature increase. The configuration used in Figure 3 was ITO/MEH-PPV while in Figure 4 was ITO/MEH-PPV/PEIE. The surface roughness in Figure 4 are high may be due to the present of PEIE on top of the MEH-PPV thin films. The surface roughness shown are not smooth compared to the one in Figure 3. During the experiment, after deposition of PEIE thin films, the PEIE layer spread over the glass with uneven thickness. It may also due to the glass substrate are not cool enough before the deposition of PEIE layer. Hence, the Ra values increases as the temperature increase.
**Figure 4.** The AFM images of ITO/MEH-PPV/PEIE with temperature of (a) 90 °C (Ra = 2.834 nm), (b) 120 °C (Ra = 2.604 nm), (c) 150 °C (Ra = 2.974 nm), (d) 180 °C (Ra = 3.397 nm).

**Table 1.** Ra values for ITO/MEH-PPV and ITO/MEH-PPV/PEIE.

| Configuration          | ITO/MEH-PPV | ITO/MEH-PPV/PEIE |
|------------------------|-------------|------------------|
| Temperature (°C)       | Ra (nm)     | Ra (nm)          |
| 90                     | 2.825       | 2.834            |
| 120                    | 1.967       | 2.604            |
| 150                    | 1.966       | 2.974            |
| 180                    | 1.625       | 3.397            |

3.3. **J-V characteristic of OLED**

Figure 5 shows the J-V characteristic of the ITO/MEH-PPV/PEIE/AL by varying the temperature. Based on Figure 5, it has been observed that the turn on voltage decrease with the increasing of temperature. By extrapolate the J-V graph, we estimated the turn on voltage for each temperature. Between 90 °C and 150 °C, the turn on voltage for 150 °C is 6 V while 90 °C is 7.2 V. For 120 °C and 180 °C, the turn on voltage is higher than 90 °C and 150 °C. But between 120 °C and 180 °C, turn on voltage for 180 °C is 7.8 V while 120 °C is 9.2 V. It can be seen devices with temperature of 90 °C, 150 °C and 180 °C, the current density significantly increased. But for temperature of 120 °C, the current density is nearly in straight line. This is due to low current density compared to others. Temperature of 150 °C has the highest current density, which indicate that it has the most enhancement of electron conductivity [7]. By increasing the temperature, it does improve the performance of OLED in terms of producing low turn on voltage. This can be supported with previous research by Sepeai et al [13] and Lee and Park [14] which have reported the possibility of improving the performance of OLED by thermal annealing.
4. Conclusion
In conclusion, the fabrication of ITO/MEH-PPV/PEIE/Al device was successfully fabricated by varying the temperature for ITO/MEH-PPV and ITO/MEH-PPV/PEIE thin films. Temperature of 90°C, 120 °C and 150 °C obtained the highest maximum peak absorption at 506 nm. The AFM images for ITO/MEH-PPV/PEIE thin films showed the surface roughness increased as the temperature increase. The highest value of surface roughness is 3.397 nm at 180 °C. OLED device with MEH-PPV thin films baked at 150 °C, shows obvious performance improvement compared to other temperature. The obtained results from the experiment could be used on OLED fabrication.

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