Characteristics of MEH-PPV thin films on ITO electrode for organic light emitting diodes

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Abstract: *Indium tin oxide thin films were deposited by rf magnetron sputtering on glass substrate at a substrate temperature of 200°C. The effect of sputtering pressure on the structural, optical, electrical and morphological properties of ITO film was studied. All ITO films have shown preferred orientation along [400] direction. The average optical transmission in the visible region is increased and rms roughness is decreased with increasing pressure. The current-voltage characteristics of ITO/MEH-PPV/Al structure have shown a typical Schottky diode like behavior.*

Keywords: sputtering; Indium tin oxide; photo luminescence; current.

1. Introduction

Due to the unique properties of high electrical conductivity (≈10^4 S/cm) and high optical transmittance (~90%) in the visible wavelength range, indium tin oxide (ITO) film has been widely used as transparent conductor in the optoelectronic devices such as organic light emitting diodes (OLED) [1], liquid crystal displays (LCD) [2] and plasma display panels [3]. ITO is an n-type degenerate semiconductor with a free carrier concentration in the range 10^{19}-10^{21} cm^{-3}. Various deposition techniques such as sputtering, evaporation, chemical vapor deposition and sol–gel method have been used for the deposition of ITO thin films [4-6]. Among these methods, RF-magnetron sputtering is widely used as a reliable tool for the deposition of high quality ITO films [7,8].

Properties of the ITO film depend on the deposition conditions. Various deposition parameters like substrate temperature, rf power, oxygen-to-argon ratio, deposition pressure and substrate-to-target distance can influence the properties of the deposited films [9-11]. In this paper, we report the influence of sputtering pressure on the structural, electrical, optical and morphological properties of the ITO thin films by keeping all other parameters constant. The UV-Vis absorption and photo luminescence (PL) characteristics of poly [2-methoxy-5-(2'-ethyl-hexyloxy)-1,4-phenylene vinylene (MEH-PPV) films were studied. The current-voltage characteristics of OLED structure were studied.

2. Experimental

ITO films were deposited by rf (13.56 MHz) magnetron sputtering from an ITO target containing 90 wt.% of In_2O_3 and 10 wt.% of SnO_2 using EDWARDS E306A sputtering system. Glass slides were used as the substrates. Prior to deposition, the chamber was evacuated to a background pressure of 2.0×10^{-5} mbar, and the working pressure during the film deposition was varied from 0.7×10^{-1} mbar to 1.1×10^{-1} mbar by using ultra pure Ar gas. The rf power and the deposition time were 50 W and 30 min, respectively. The distance between the substrate and the target was about 4 cm. The substrate temperature was kept constant at 200°C. The structural characterization of the films was carried out using a Philips X-Pert PRO MRD X-ray diffractometer with CuKα radiation (λ = 0.15418 nm). The optical transmission was measured in the wavelength range of 300 –1100 nm using a UV-VIS-NIR- spectrophotometer (Perkin-Elmer Lambda 45). The sheet resistance was measured by Veeco FPP-5000 four point probe. Atomic force microscopy (AFM) (Veeco Nanoscope-IV) in tapping mode was used to evaluate the surface morphology of the films.

The ITO film has been used as an anode layer and MEH-PPV as the emitting layer of OLED structure. The layer of MEH-PPV was spin coated from a toluene solution at a concentration of 4 mg/mL with three different spin speeds. The UV-Vis absorption and photo luminescence (PL) spectra of these MEH-PPV films were recorded. Aluminum cathode dots were deposited on top of the emitting layer by thermal evaporation using shadow mask. The dc Current-Voltage characteristics of the OLED test structures were obtained using Keithley 485 pico-ammeter and Advantest R6144 programmable dc voltage generator.

3. Results and discussion

3.1 Structural properties: X-ray diffraction patterns of ITO thin films prepared at different sputtering pressures are shown in Fig.1.(a). All ITO films have shown preferred orientation along [400] direction. The relative intensity of (400) peak is decreased with increasing pressure as shown in Fig.1.(b). Orientation of the film depends on mobility of sputtered particles on the substrate [12]. If the sputtered particles have enough energy, then the film would be oriented along thermodynamically favorable [400] direction. At high sputtering pressure, the energy of sputtered particles arriving at the substrate decreases due to frequent collisions with Ar ions. As the sputtering pressure is decreased, the energy of sputtered particles will increase and they will move more actively to thermodynamically

favorable (400) oriented grains. As a result, the degree of (400) orientation is high at low
sputtering pressures and decreases with increasing pressure. Resistivity of the film was found to increase with increasing deposition pressure.

3.2 Surface morphology: Fig.2 shows the surface morphology of ITO thin films deposited at different sputtering pressures. Rough surface morphology was observed for the films deposited at low sputtering pressures. The root mean square (rms) roughness of the film deposited at 0.07 mbar pressure was 12.2 nm and was decreased to 3.7 nm when the deposition pressure was increased to 0.11 mbar.

3.3 Optical properties: Fig.3 shows the optical transmittance spectra of ITO thin films deposited at different pressures. The film deposited at 0.07-mbar pressure showed an average optical transmission of 75% in the visible region. For all other films the average optical transmission was greater than 85% in the visible region. Sharp fall in the transmission spectrum was observed in the near-IR region for the film deposited at 0.07 mbar pressure. All other films have not shown any significant change in the transmission spectra in the near-IR region. The change in the optical transmittance spectra in near-IR region can be explained by classical Drude theory. According to this theory, the transmittance decreases and reflectance increases in the near-IR region with increasing electron concentration. So the film deposited at 0.07 mbar pressure has higher electron concentration compared to all other films. The optical band gap energy of the films was calculated from the transmittance data. The optical band gap energy of the film deposited at 0.07 mbar pressure was 3.3 eV. The band gap energy value increased to 3.73 eV when the sputtering pressure is increased to 0.08 mbar and no significant change is observed with further increase in deposition pressure.

3.4 Characterization of MEH-PPV film: Figure 4(a) shows the optical absorption spectra of MEH-PPV films deposited at different spin speeds. The absorption peak shifts towards lower wavelength region with increasing spin speed. The blue shift of the absorption spectra indicates that the conjugation length of MEH–PPV was reduced.

Figure 4(b) shows the photo luminescence (PL) spectra of MEH-PPV films deposited with different spin speeds. The PL spectrum has also shown blue shift with increasing spin speed. The PL spectrum has peaks at 579 nm, 570 nm and 558 nm for the films deposited at 1000 rpm, 2000 rpm and 3000 rpm respectively. The energy difference between the absorption peak and PL peak is called Stokes shift. The stokes shift for the film deposited at a spin speed of 1000 rpm is 0.41 eV and decreases to 0.37 eV as the spin speed is increased to 3000 rpm. This decrease in stokes shift indicates that luminous efficiency of the film increases with increasing spin speed.

3.5 Current-voltage characteristics of OLED: Fig.5. shows the current-voltage characteristics of OLED structure made on ITO anode prepared at 0.11 mbar pressure. The ITO film deposited at 0.11 mbar pressure was used as the anode because it is relatively smoother and highly transparent. The MEH-PPV film was deposited with a spin speed of 3000 rpm since the film deposited at this spin speed has shown small stokes shift. The I-V characteristics show a typical Schottky diode like behavior. The barrier height and ideality factor for the diode are 0.78 eV and 9.4 respectively.

4. Conclusions

Indium tin oxide thin films were deposited by rf magnetron sputtering on glass substrate at a substrate temperature of 200^{o}C. The effect of sputtering pressure on the structural, optical, electrical and morphological properties of ITO film was studied. All ITO films have shown preferred orientation along [400] direction. The average optical transmission in the visible region is increased and rms roughness is decreased with increasing pressure. Stokes shift of MEH-PPV film is found to decrease with increasing spin speed. The current-voltage characteristics of ITO/MEH-PPV/Al structure have shown a typical Schottky diode like behavior.

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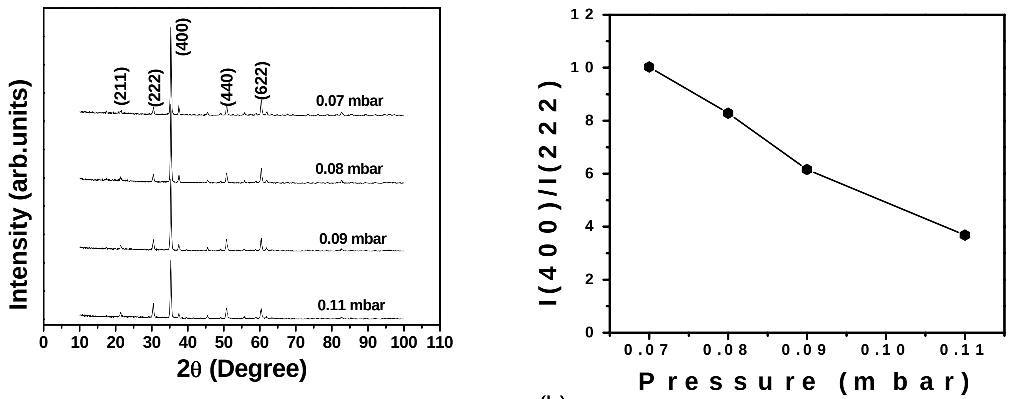
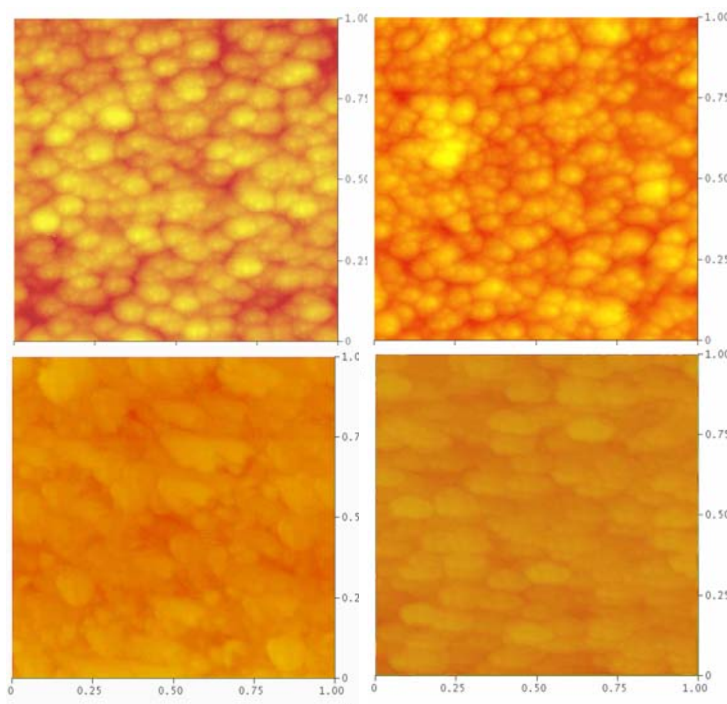


(a) (b)

Figure 1. (a) XRD patterns of ITO thin films deposited at different sputtering pressures, (b) variation of the relative intensity of (400) peak.

(a) (b)



(c) (d)

Figure 2. AFM images of ITO thin films deposited at:
(a) 0.07 mbar, (b) 0.08 mbar, (c) 0.09 mbar and (d) 0.11 mbar.

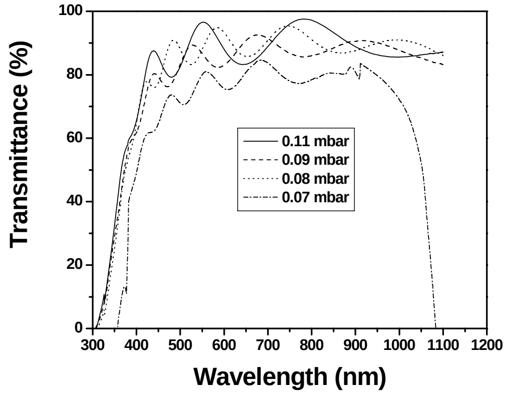


Figure 3. Optical transmittance spectra of ITO thin films prepared at different sputtering pressures.

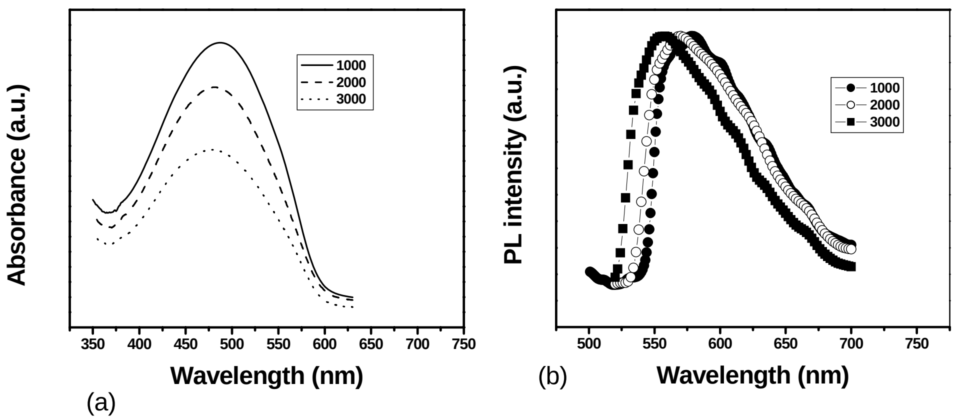


Figure 4. (a) Absorption and (b) PL spectra of MEH-PPV thin films deposited with different spin speeds.

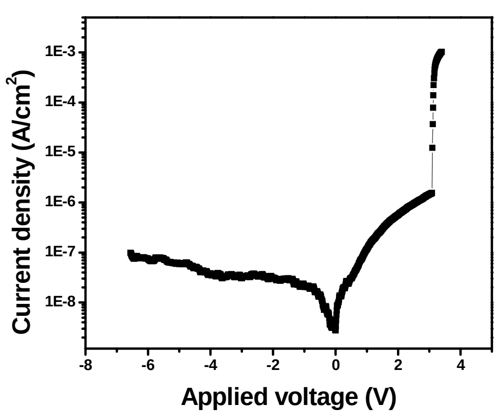


Figure 5. Current-voltage characteristics of OLED