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Deposition of Conducting Oxide Thin Films as Anode for Solar Cell Device

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Authors' contributions

This work was carried out in collaboration between all authors. Author NM designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors AH and ZF managed the analyses of the study and literature searches. All authors read, edit and approved the final manuscript.

Original Research Article

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ABSTRACT

Transparent Conducting Indium Tin Oxide (ITO) and Zinc Oxide (ZnO) thin films were deposited with Pulsed Laser Deposition PLD at 300°C. The ITO films have small grain size of 5-10 nm and a high value transmission (95%) in the wavelength range from 300 to 700 nm with a low resistivity of 2.25×10^{-4} Ω.cm. While Zinc Oxide (ZnO) films have grain size of 15 nm and a transmission of 85% with a resistivity of 2.10×10^{-2} Ω.cm.
A lower resistivity and better spectra selectivity is a measurement of the quality and potential use of transparent ITO and ZnO films for the application as anode electrodes for optoelectronic devices. The optimized ITO film was then used individually as anode in a solar cell based on organic conjugated polymer BEH-co-MEH-PPV. The cell fabricated in this study with an active layer made by solution-processed polymer. It was also found that the surface roughness and work function of oxide films are very important to enhance the stability and efficiency of electrode thin films used for solar cells. The solar cell structure ITO/BEHP-co-MEH-PPV/Al has shown a photovoltaic performance with open circuit voltages (V_{oc}) of the cell being 0.45 V and power conversion efficiency of 6.4% and a fill factor of 40%.

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1. INTRODUCTION

In recent years, there has been an increase in the number of applications of transparent conducting oxides such as ITO and ZnO thin films, due to their unique optical, electrical and mechanical properties which are different to those of bulk material. Indium tin oxide (ITO) is an n-type transparent semiconductor with a wide band gap (E_g = 4 eV). These properties have led them to play an irreplaceable and increasing role in many areas of today's very demanding and rapidly developing technology, especially in the electronic displays and optical industries [1-2].

Interest in transparent films with an oxide layer such as indium tin oxide (ITO) and zinc oxide (ZnO) has increased for a wide range of applications including heat-reflecting mirrors [3], the field of flat panel displays [4] antireflection Coatings [1], organic light-emitting diodes [3], and gas sensors [2], and as transparent electrodes in solar cells [4-5-6].

Another transparent semiconducting material is the zinc oxide thin film ZnO which is nowadays attracting considerable attention for its possible use in transparent electronic devices. ZnO is a very interesting material, due to its high transmittance in the visible region and to its high chemical, thermal and mechanical stability [7]. ZnO is a wide band gap material (3.2 eV), it is transparent in the visible and therefore also less light sensitive than other materials [7-8-9-10].

Franklin et al [6] demonstrated that by using a pulsed laser deposition system in addition to forming high quality ZnO, the optical and electronic properties of ITO can be preserved—even at high temperature—presenting a methodology for preparing highly crystalline ZnO on ITO over a temperature window significantly larger than that of previous literature reports.

In general the desired properties for conducting oxide films used as anodes in optoelectronic devices are as follows [5-6]:

1. Low specific resistivity.
2. Good thermal stability.
3. High uniformity across the flat substrate.
4. Low particle contamination.
5. Good adherence to substrate.
6. Low manufacturing costs.

In this investigation, we deposited transparent conducting ITO and ZnO films individually by a Pulsed Laser Deposition technique. Our aim was to make a comparative study between the two oxides by investigating their morphologies; and their electrical and optical properties, and to use the best transparent conducting ITO or ZnO films with good spectral selectivity as anode in a solar cell based on a conjugated polymer BEHP-co-MEH-PPV.

2. EXPERIMENTAL DETAILS

For the deposition of (ZnO) and (ITO) films, a KrF excimer Laser was used as the Pulsed Laser Deposition source (PLD). A laser repetition rate of 10 Hz was used, with a target to substrate distance of 5.5 cm and a laser pulse energy density of 2.7 J/cm^2. The thin film growth chamber exhibits a base pressure of 10^{-6} Torr. Glass was used as the substrate material in this study. Film growth was performed at a temperature of 300ºC in an oxygen pressure of 10 mTorr for 20 minutes. The schematic diagram of the PLD system used in the preparation of conducting oxide thin films is illustrated in Fig. 1.

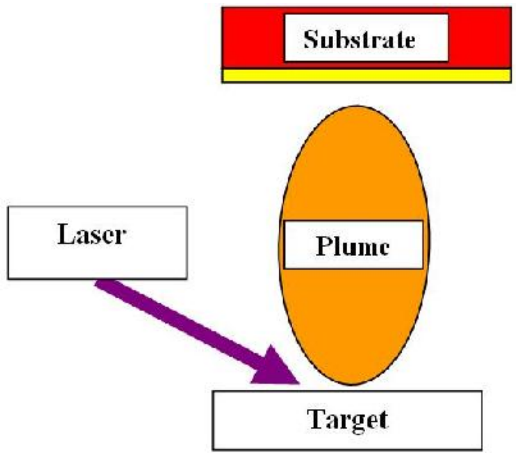


Fig. 1. A schematic diagram of the Pulsed Laser Deposition process.

Indium Tin Oxide target was fabricated using high purity In_2O_3 (99.995%) with SnO_2 (99.998%) as received from the supplier (Sigma-Aldrich). The target was pressed and sintered at room temperature for 24 hours in air. Target was fabricated with In_2O_3 (90%): SnO_2 (10%). Fig. 2 shows the ITO target used in the deposition process. Zinc oxide target was fabricated using high purity ZnO (99.98%) as received from (Sigma-Aldrich).

Fig. 2. Shows the ITO target used in the pulsed laser deposition process.

The surface morphology and roughness were observed using Atomic Force Microscopy (AFM) in tapping mode. The optical transmission measurements were performed with an UV/Visible Spectrophotometer. The sheet resistance of the deposited films was measured using a four-point probe method at room temperature. The used Solar cell structure was ITO/BEHP-co-MEH-PPV/Al where the optimized ITO was the anode and aluminum Al the cathode respectively. The performance of the solar cell was examined and presented in reference [11]. The conjugated copolymer powder (BEHP-co-MEH-PPV) was purchased from (Sigma-Aldrich) and used as received. The spin coated polymer films were dried at room temperature, and protected from light to avoid photo degradation process. The aluminum cathode was then deposited through a mask by thermal evaporation at a base pressure of 10^{-6} Torr. Further experimental details, processing conditions and research results were presented in a recent publication [11].

3. RESULTS AND DISCUSSION

3.1 Optical Properties

Fig. 3 represents the transmission spectra for the conducting transparent indium tin oxide (ITO) and zinc oxide (ZnO) films. The ITO film showed high transmission higher than 90% in the visible range, while ZnO film has transmission higher than 85%.

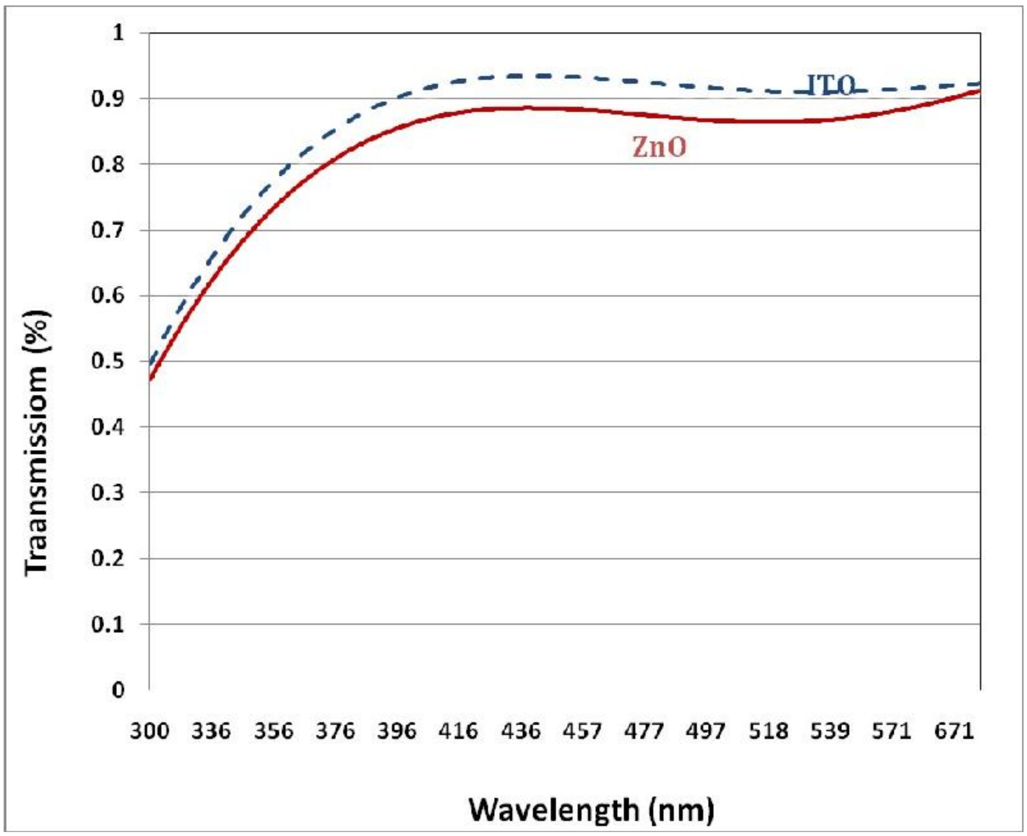


Fig. 3. The transmission spectra of the ITO and ZnO films deposited by PLD.

The absorption spectrum (EA) of the ITO films in the band gap edge region has been obtained from the optical transmission and reflection measurements at room temperature, the Energy gap was found to be (Eg = 3.57 eV) for the film deposited at 300ºC as shown in Fig. 4.

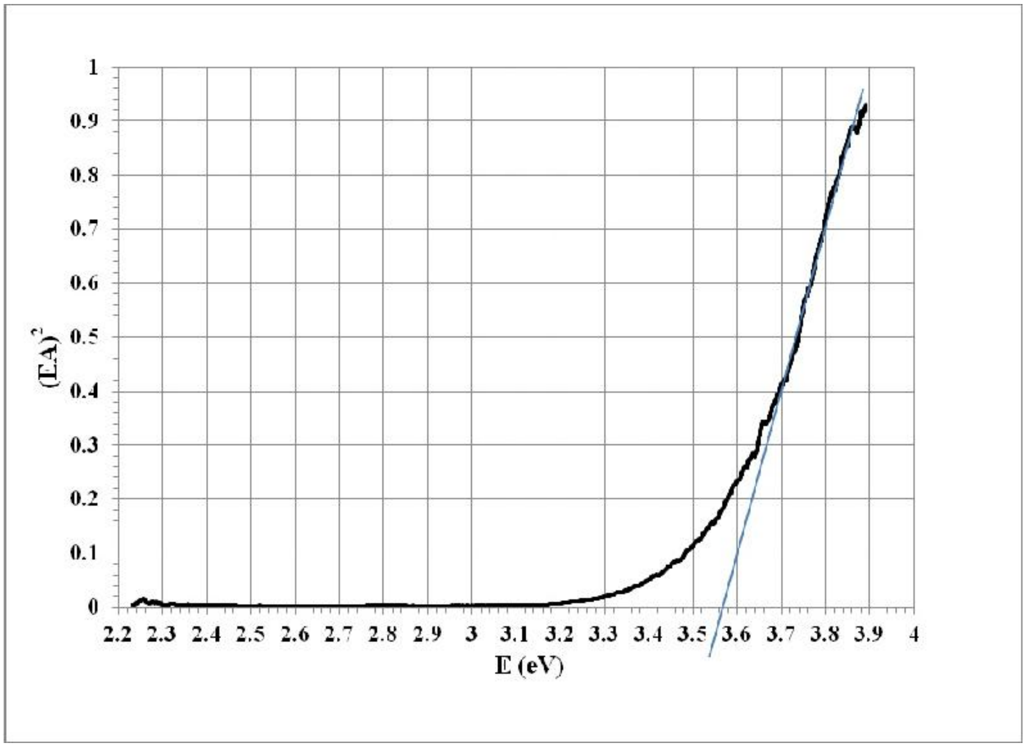
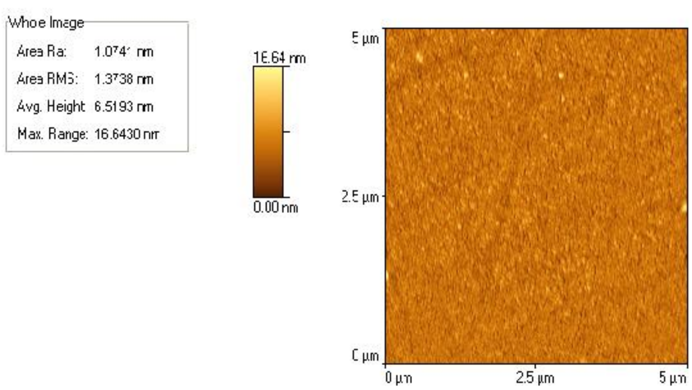


Fig. 4. Energy band gap versus $(EA)^2$ for the ITO thin film (E_g= 3.57 eV).

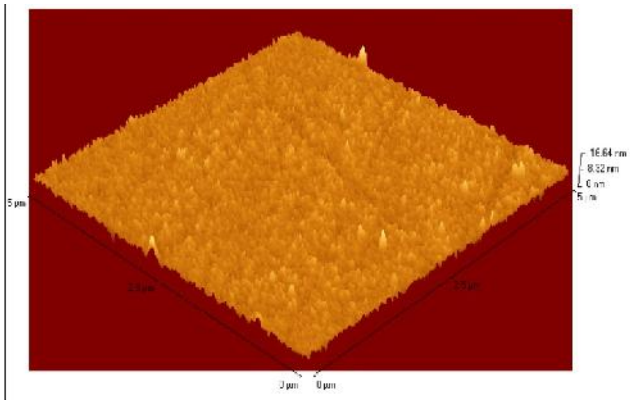
3.3 Atomic Force Microscopy

Atomic Force Microscopy (AFM) was used to find surface roughness and grain sizes of the deposited oxide films used as anodes in the fabricated solar cells.

Fig. 5 shows the AFM surface morphology of a dense ITO film with small grain size of 5-10 nm and a surface roughness with an average of 6-7 nm. While the average roughness for the ZnO film was 5 nm with fine grain sizes as shown in Fig. 6.

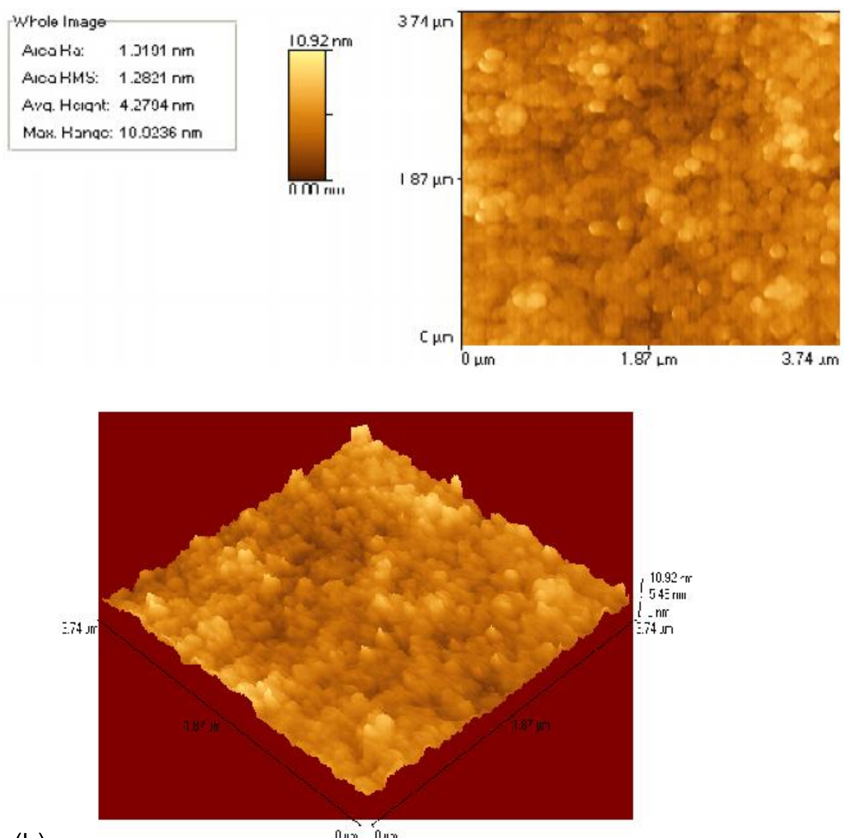


(a)



(b)

Fig. 5. AFM images of the ITO films: (a) The surface morphology and (b) The surface roughness.



(a)

(b)

Fig. 6. AFM images of the ZnO films: (a) The surface morphology and (b) The surface roughness.

3.4 Resistivity

The sheet resistance R_s of the ITO and ZnO films was measured using a four-point probe method at room temperature. By assuming that the thickness of the films was uniform, the resistivity ρ of the films was calculated from the simple equation $\rho = R_s d$, where d is the oxide film thickness. A low resistivity of (2.25×10^{-4} Ω·cm) was measured for the 150 nm thick ITO films at ambient temperature. While for 150 nm ZnO film the resistivity was (2.10×10^{-2} Ω·cm). Table 1 shows the typical properties and results obtained for the 150 nm thick ITO and ZnO films.

The low resistivity of ITO may be attributed to the presence of oxygen vacancies and substitutional tin, created during the growth of the film.

Table 1. Typical properties obtained for the ITO and ZnO oxide films

Property	**Results** (ITO)	**Results** (ZnO)
Transmittance (%)	94-95	85
Optical Band gap (eV)	4.8	3.3
Sheet resistance (Ω / □)	3.37	3.15
Resistivity (Ω.cm)	2.25×10^{-4}	2.10×10^{-2}
Surface roughness	5 nm	6-7 nm
Grain sizes	5-10 nm	10-15 nm
Thickness	150 nm	150 nm

The surface roughness and work function of conducting oxide films deposited on glass substrates are very important to enhance the stability and efficiency of electronic devices. So surface morphology of substrate is directly transferred to the deposited oxides and uneven interface is not desirable for the efficiency and stability of electronic devices based on such oxide films.

3.5 The Solar Cell Characteristics

The proposed organic solar cell ITO/BEHP-co-MEH-PPV/Al fabricated onto glass substrate is illustrated in Fig. 7.

Fig. 8 represents the photovoltaic characteristics of the BEHP-co-MEH-PPV polymer. With the copolymer as a p-type material spin coated onto ITO coated substrate, this has resulted into further increase in a power conversion efficiency of 6.4% and a fill factor of 40%. The solar cell structure ITO/BEHP-co-MEH-PPV/Al has shown a photovoltaic performance with open circuit voltages (V_{oc}) of the cell being 0.45 V and a short circuit current I_{sc} of 3.53 mA/cm^2 [11].

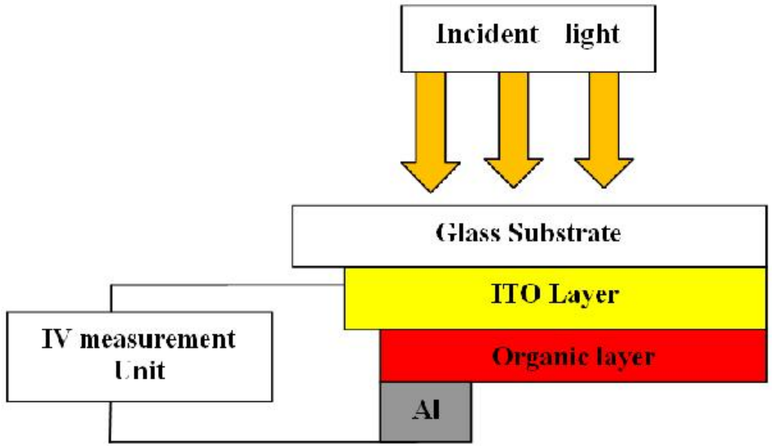


Fig. 7. A cross-sectional view of the ITO/BEHP-co-MEH-PPV/Al solar cell.

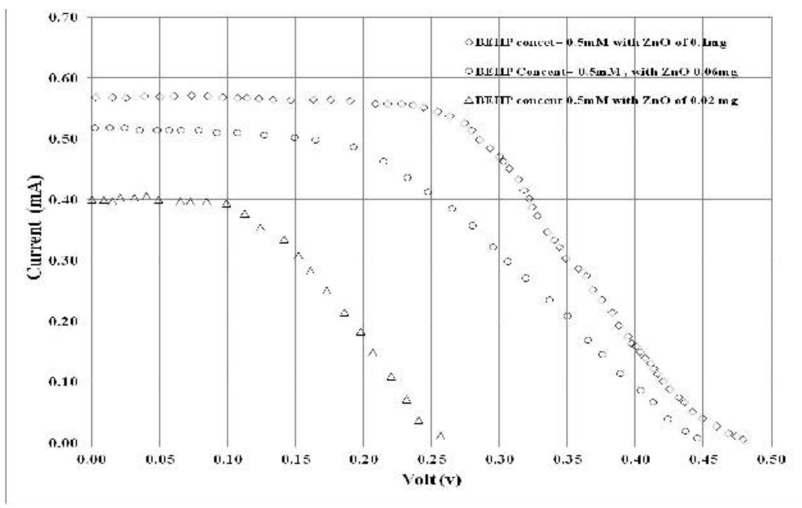


Fig. 8. The photovoltaic characteristics of the solar cell made onto ITO coated substrate.

4. CONCLUSION

In summary, this paper presents the deposition of conducting and transparent thin films to be used as an anode of a solar cell. For the ITO film, AFM of deposited film showed smooth surface and small grain sizes. Average roughness R_a of the ITO deposited film was 5 nm for film thickness of (150 nm). The deposited film was dense, and had good adhesion to glass substrate.

Optical spectra measured by a spectrophotometer showed high transmission of the deposited ITO films (95-96%) with an average roughness surface of 5 nm. While for the ZnO films, the transmission was above 85% in the visible range with average surface roughness of 6-7 nm.

Super-smooth and dense films are particularly desirable for solar cell device. The adhesion quality of deposited films onto substrates is directly dependent on the cleanliness of the substrate. These properties would enhance their chemical stability, especially when used in long term operation of a solar cell.

Optical spectral property, morphology and the ITO resistivity are much better than ZnO film properties when prepared by Pulsed Laser Deposition under the same deposition conditions. High transparency, good conductivity and super smooth properties of both ITO and ZnO oxide thin films are particularly desirable in optoelectronic devices particularly when used as an anode in a solar cell.

We have demonstrated that the power conversion efficiency of organic solar cell can be improved by manipulating the composition of the polymeric active layer spin coated onto ITO coated substrate.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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