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Comparison of Zinc Oxide thin films deposited on the glass and polyethylene terephthalate substrates by thermal evaporation technique for applications in solar cells

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Zinc Oxide (ZnO) thin films have been deposited onto glass and polyethylene terephthalate (PET) substrates at room temperature by thermal evaporation technique in a vacuum of about 3 x 10^{-5} torr. The effects of deposition on the structural, optical, and electrical properties of ZnO films were investigated. The topography of the ZnO thin films were examined by atomic force microscopy (AFM). The surface conductivity of the materials was analyzed using a four-probe meter. The optical transmission method using ultraviolet-visible spectrophotometer determines the refractive index n, reflectance R and energy gap of the ZnO on glass and ZnO on PET thin films.

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1. Introduction

Zinc oxide (ZnO) is an important wide band gap II–VI semiconductor material and a natural n-type electrical conductivity. The ZnO thin films are used in various applications such as transparent conductive film and window materials in solar cell applications due to its high optical transmittance in the visible light region [1]. Recently, ZnO materials have attracted much more interest in the application of optoelectronic devices such as light-emitting diodes (LED), laser diodes, piezoelectric transducer, transistors, bulk acoustic wave devices (SAW), acoustic–optical devices and phosphors [2].

There are different methods to prepare zinc oxide, such as radio-frequency (rf) magnetron sputtering [3], chemical vapour deposition [4], sol–gel method [5], atomic layer deposition [6], Spray pyrolysis (SP) [7], pulsed laser deposition [8] and thermal evaporation [9] etc. Of the various methods, the vacuum evaporation technique is known to be suitable for preparation of ZnO films for wide range of applications.

The replacement to flexible polymer substrates is gaining a great interest [10-12] because it can give advantages such as lighter weight, higher shock resistance and scalable roll-to-roll preparation procedures.

In this paper, ZnO thin films on glass (soda -lime glass) and polyethylene terephthalate (PET) substrates deposited at room temperature by thermal evaporation technique were reported, and the optical and electrical properties of the deposited films were studied.

2. Experimental detail

Glass (soda -lime glass) and PET substrates were deposited with zinc oxide (ZnO) using the thermal evaporation technique in a vacuum ~ 3 × 10^{-5}torr. The PET and glass substrates were washed by alcohol and then ultrasonically cleaned in alcohol for 10 minutes. After that, deionised water was used to rinse the substrate. Lastly, nitrogen gas was used to dry the substrate. The evaporator system, Edwards Auto 306 utilizes a common diffusion and rotary pump to evacuate the high vacuum chamber that was made of an enclosed bell jar. Wafers were loaded on top of the vacuum chamber while tungsten boat was used to hold the molten ZnO for evaporation. Source of ZnO (99.99 % pure) in the form of powder was loaded onto tungsten crucible in the vacuum. Prior to deposition, the ZnO and tungsten boat were clean in alcohol to remove any contamination and dried with nitrogen gas. The vacuum chamber was evacuated to 3 × 10^{-5} torr before the source was heated. The tungsten boat was heated with 3.0A direct current for 10 seconds to melt the ZnO. The current was increased slowly to 8 A until all ZnO was evaporated. The substrate was removed after waiting for a few minute to cool down the chamber. The thickness of ZnO thin film deposited on PET and glass substrates is of the order of 100 nm, which was determined by using optical reflectometer (Model: Filmetrics F20). The surface morphology of each ZnO thin films was performed by atomic force microscopy (AFM) (Model: ULTRA Objective). The optical properties of ZnO deposited on glass and PET substrates were characterized by, UV Spectrophotometer (Model: U-2000 HITACHI). The sheet resistance and the resistivity of the ZnO deposited on glass and PET were measured with a four-point probe (Model: Changmin Tech CMT–SR2000N).

3. Results and discussions

3.1 Surface morphologies

AFM topographic images were done in non contact mode over 5 μm × 5 μm areas for both samples. Fig. 1a and b shows non contact mode images of glass and PET metalized with ZnO. From Table 1, the root mean square of surface roughness (RMS) for ZnO on glass and on PET substrates is 4.77 nm and 13.07 nm respectively.

Table 1. Shows the Parameters AFM for ZnO thin films deposited on glass and PET substrate.

	ZnO on glass	ZnO on PET
Max. Height different	42.74 nm	111.11 nm
Mean	12.34 nm	39.57 nm
Root mean square	4.77 nm	13.07 nm
Average deviation	3.75 nm	9.05 nm
Skewness	0.7	0.46
Kurtosis	0.82	1.41

The skewness for ZnO on glass and PET substrate are 0.7 and 0.46 respectively. Skewness is a measure of symmetry, or more precisely, the lack of symmetry. The ZnO on glass in Fig. 1a have higher skewness compared to PET substrate because the overall distributions have several high peaks on the majority flat surface. However, ZnO on PET in Fig. 1b shows the peaks are scattered over the substrate tends to be equally distributed.

Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak. ZnO on PET has higher kurtosis value, 1.41 than on glass substrate 0.82. Fig. 1b shows a very sharp peak out of majority flat area. Fig. 1a shows that majority surface area is the same heights show low kurtosis value. Obviously, ZnO on glass shows smoother surface than on PET substrate. It is important to note that surface smoothness is a highly desired parameter for the coatings that are used for optical applications in order to reduce the reflection loss due to roughness induced surface scattering.

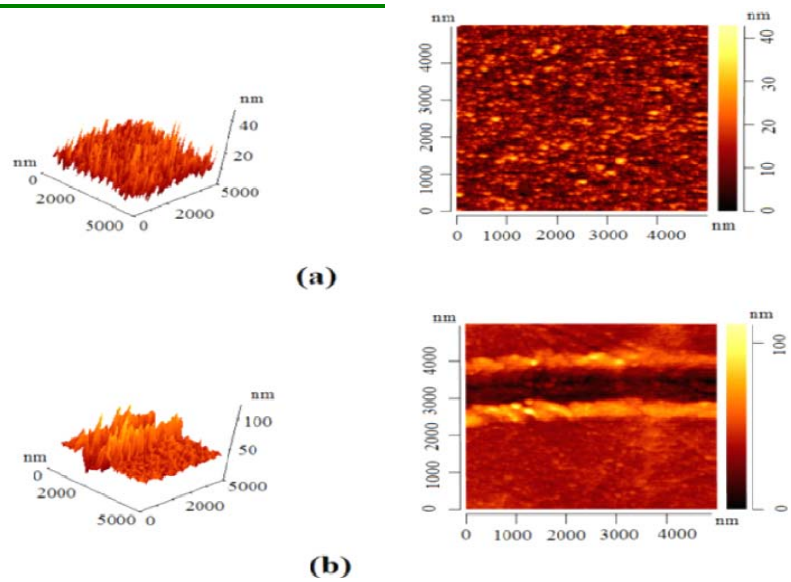

Fig. 1. AFM analysis of ZnO thin films deposited on (a) glass substrate and (b) PET substrate.

3.2 Optical characterization

The optical transmittance spectra of ZnO thin films deposited onto glass and PET substrates are shown in Fig. 2, which indicate that the films are highly transparent in the visible region 400 to 800 nm. The average transmission of the films deposited on glass is about 86%, and PET is about 76%.

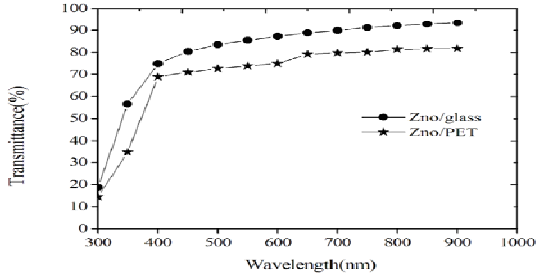

Fig. 2. the transmittance as a function of the wavelength for ZnO thin films deposited on glass and PET substrate.

The optical band gap was calculated using the Tauc relationship which is given by [13]:

$$(\alpha h\nu) = A(h\nu - E_g)^{\frac{1}{2}} \quad (3.1)$$

Where (hυ) is photon energy, (Eg) is the optical band gap of the material, A is a constant.
When $(\alpha h\upsilon)^2$ is plotted as a function of (h υ), the linear portion of the curve is extrapolated to $(\alpha h\upsilon)^2 = 0$, the band gap of the ZnO on glass and PET substrates were found from Fig. 3 and 4. The energy band gap of ZnO film on PET is found to be 3.35 eV. The presence of PET film does not affect the transmission spectrum of ZnO because it is taken as reference material for the transmission spectrum of ZnO film. Energy gap increased to 3.45 eV for the ZnO thin films deposited on glass. All these values 3.35 eV and 3.45 eV for the deposited films on PET and glass substrate well-agree with that reported previously [14, 15].

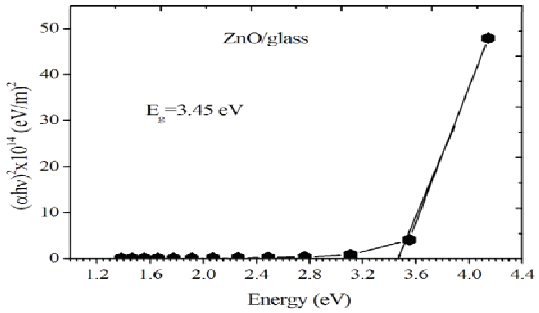

Fig. 3. A plot of $(\alpha h\upsilon)^2$ of as a function of photon energy for ZnO thin films deposited on glass substrate.

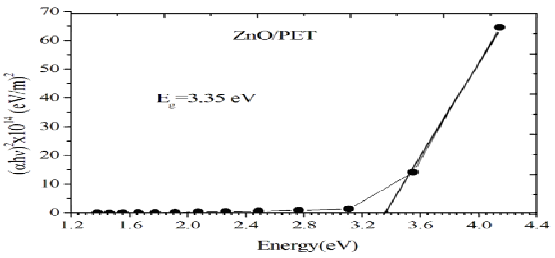

Fig. 4. A plot of $(\alpha h\upsilon)^2$ of as a function of photon energy for ZnO thin films deposited on PET substrate.

Reflectance R of thin films was calculated from [13]:

$$R = 1 - \sqrt{\frac{T}{\exp(-\alpha t)}} \quad (3.2)$$

Where, T is a transmittance and (α) is the absorption coefficient. The refractive index (n) was calculated from [13]:

$$n = \frac{1 + R^{\frac{1}{2}}}{1 - R^{\frac{1}{2}}} \quad (3.3)$$

Fig. 5 and 6 shows the plot of the reflectance and refractive index as a function of wavelength for as deposition ZnO thin films on glass and PET substrates. The refractive index gives information on the electronic polarizability, local field and for determining the density of colours inside the material [16]. For, the deposition of ZnO thin films on glass and PET substrate, both R and n decreased rapidly to approach constant values at long wavelengths.

From Fig. 2 and 5, it is found that the films exhibited high transmittance and low reflectance less than 18% .This property makes these films a good candidate as transparent front contact of solar cells.

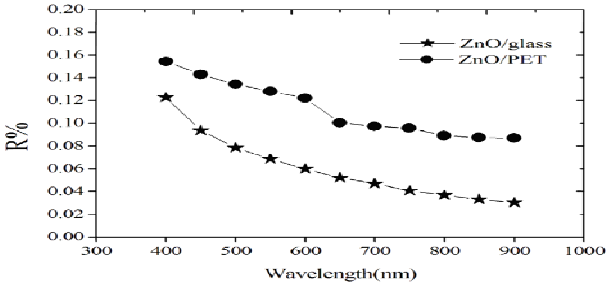

Fig. 5. The reflectance as a function of the wavelength for ZnO thin films deposited on glass and PET substrate.

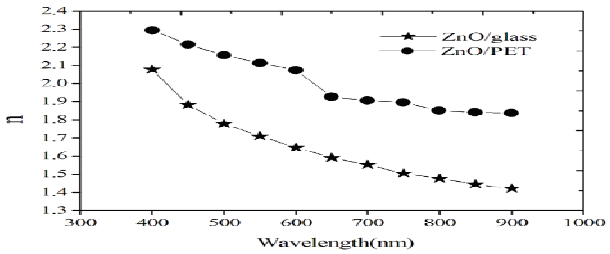

Fig. 6. Refractive index as a function of wavelength for ZnO thin films deposited on glass and PET substrate.

3.3. Electrical properties

Table 2 shows the comparison between electrical resistivity ZnO on glass and ZnO on PET. ZnO on glass have much lower resistivity around 2.682×10^{-4} Ω. cm, compared to ZnO on PET 13.64×10^{-4} Ω. cm. similarly to other reports [17, 18]. A sheet resistance for ZnO on glass and ZnO on PET is 3.326 Ω/□ and 22.96 Ω/□ respectively. These values show low resistivity for both samples, therefore possibility as transparent front contact of solar cells.

Table 2. Shows the comparison between electrical resistivity and sheet resistance ZnO /glass and ZnO /PET substrates.

	ZnO on glass	ZnO on PET
Resistivity (average)	2.682×10^{-4} Ω.cm	13.64×10^{-4} Ω.cm
Sheet resistance (average)	3.326 Ω/□	22.96 Ω/□

4. Conclusions

Zinc oxide thin films were successfully deposited on glass and PET substrates by thermal evaporation method. AFM surface study shows the surfaces of the ZnO thin films deposited on glass and PET substrate a smother with root mean square 4.77 nm and 13.07 nm, respectively. The optical properties of the films deposited onto both PET and glass substrates show almost 70% to more than 92% in the visible/ near infrared region from ~ 400 nm to 900 nm,. Calculations of the bandgap values show the existence of direct bandgap of the material ranging from 3.35 to 3.45 eV for the films deposited on PET and glass substrates, respectively. The resistivity of the films deposited on glass and PET substrate is 2.682×10^{-4} and 13.64×10^{-4} Ω. cm, respectively. These films are suitable for transparent front contact of solar cells

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