Characterization and Photodetector of Zinc Oxide/Si thin films prepared by Spray Pyrolysis Technique

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Abstract: Zinc oxide (ZnO) nanoparticles via spray pyrolysis technique on the glass and Si substrates, was employed as a photodetector. XDR analysis shows, the sharp and strong peaks observed at diffraction angles 2θ of 31.83°, 34.49°, 36.32° corresponded to the, (100) (002) and (101) planes respectively. Some added peaks with small intensities were noticed with orientation (110), (102), (103) and (200). Optical properties of prepared films show a peak position at 365 nm and energy gap value is 3.8eV of ZnO nanoparticles. The AFM indicates that the product is approximately a spherical shape and that the average diameter of the particles about 63.96 nm. The current voltage characterization shows in the case of reverse bias, a stream of illumination was greater than the current of darkness. In the front bias, the current of darkness is a close value and the current of light changes greatly. The detector parameters (responsivity and quantum efficiency) of ZnO NPs also calculated.

1. Introduction
Wide band gap materials, for instance GaN, ZnSe, ZnS, SiC, and ZnO have drawn excessive devotion due to their requests in short wavelength photonic devices [1, 2], window layers of hetero junction solar cells [3, 4], transparent electrodes [5, 6], UV light emitting/receiving devices [7-9] and exhibiting many motivating electrical and optical properties [10, 11], especially a latest discovery of ultraviolet luminescence at room temperature [12, 13]. A high melting of ZnO allow one to discover a variety of heat treatments entailed to alloying purposes and device creation [14, 15]. Today, UV photodetectors have been fabricated with wide direct band gap materials. Usually, ZnO is a n-type semiconductor, which incomes electrons are a main carrier charges. A frequently noted unintentional n-type conductivity has regularly been accredited to oxygen opportunities and zinc interstitial junction is Ohmic contact [16-18].

Diverse techniques were used to prepare ZnO thin films such as pulsed laser deposition [19], sputtering [20], chemical bath deposition [21], chemical-vapor deposition [22], sol gel [23], plasma-assisted molecular beam epitaxy [24], and chemical spray pyrolysis techniques [25, 26]. The purpose of this work is to analysis a structural, morphological and optoelectronic properties of ZnO nanostructure via spray pyrolysis method. By this technique show good UV-photodetector at room temperature.

2. Experimental part
A system of chemical spray set up consists of simple parts shown in fig. 1 and at numerous process parameters in a film deposition are recorded in Table1.
Figure 1. A scheme of a spray pyrolysis setup.

Table 1. Activity parameters for a spray deposition of the ZnO NPs.

| Spray parameters       | Optimum value/item |
|------------------------|--------------------|
| Nozzle                 | Glass              |
| Nozzle-substrate distance | 30 cm             |
| ZnO nanopowder sanction | 300μg             |
| Solvent                | Distilled water    |
| Solution flow rate     | 3.5ml/min          |
| Carrier gas            | Compressed air     |
| Substrate temperature  | 450 °C             |

2.1 Substrates cleaning & Solution preparation
The substrates used in this study, which are glass and silicon by dimensions (2-2) cm² were cleaned primary by dipping in distilled water to remove a dust before they were ultrasonically cleaned in ethanol (purity 99%) for 15 min. After that, the ZnONPs sprayed on the clean substrates. ZnO white nanopowder dissolving in distilled water with the molarities (300μg/ml). The aqueous solution was diluted in distilled water with alcohol (50ml) and mixed by a magnetic stirrer for 10 min.

2.2 Characterizing
A transmittance of the all films was measured by a double beam UV-Vis spectro photometer (CECIL C.7200 (France). AFM measurement by atomic force microscope (AFM)AA300 scanning probe microscope AngstromAdvanced Inc and the structure of the ZnO NPs are studied by X-ray diffraction (XRD) (SHIMADZU JAPAN, XRD – 6000) withCuKα radiation (λ = 1.542 A°) used. Current – voltage (I-V) curves were measured with the use of a DC power supply (FARNELL E 350 ) in the range of (0– 350) volt and (0 – 100 ) mA , and the current read out by a digital multi-meter (Tektronix (CDM250)).

3. Result and discussion
3.1 Optical properties of ZNO nanoparticles
Optical analysis of ZnO NPs was conceded out in a wavelength range 330–890 nm at room temperature a film dumped on a glass substrate. Absorbance spectra documented for ZnONPs as a function of wavelength shows in Fig.2 (a). It’s clear that the peak position around 380 nm and this
result good agreement with [27, 28]. Optical energy gap values (Eg) for ZnO films have been resolved by using Tauc equation [29-32].

\[ a\hbar = B (\hbar \nu - E_g)^r \]  

This equation expended to find a type of the optical transition through scheming the relationships \((a\hbar)^{1/2}, (a\hbar)^{1/3}, (a\hbar)^{2/3}, \) and \((a\hbar)^2\) versus energy of photon\((\hbar \nu)\). It is originate that a relation for \(r=1/2\) yields linear dependence, which denotes direct transition that allow. A energy band gap is then resolute by extrapolation of the portion at \((\alpha =0)\) as shown in Fig. 2 (b). The obtained band gap values for ZnO NPs about \((3.8 \text{ eV})\) as compared with the ZnO bulk \((3.6)\), the shift of band gap energy is interrelated to the compressed lattice will afford a broader band gap for the increased repulsion between oxygen 2p and zinc 4s bands. This result is consistent with other researchers such as Harish Kumar Yadav [33] and V.R. Shinde [34]. These optical properties are in a good agreement compared with other reported results [32-35].

![Figure 2. (a and b) spectrum of absorption and energy gap of ZnONPs prepared by Spray Pyrolysis.](image)

3.2 Structure properties

3.2.1 Surface topography

Fig.3 illustrations the (2D), (3D) and a grain size distribution of the ZnO nanoparticles deposited on glass substrates via Spray Pyrolysis technique. A product is a nearly spherical shape and the average grain size for ZnO NPs measured from Fig.3 (c) is about 64nm. The evaluated AFM parameters, of Sq/ root mean square (Sq), and Sa/average roughness (Sa), are 2.09 nm and 2.67 nm respectively.

![Figure 3. (a) and (b) illustrate the surface topography of ZnO NPs.](image)
4.2.2 XRD analyses

Figure 4 shows XRD patterns of the ZnO NPs that prepared by the spray pyrolysis method at room temperature. A polycrystalline wurtzite structure with sharp and strong peaks observed at diffraction angles $2\theta$ of 31.83, 34.43 and 36.32 corresponded to the (100), (002) and (101) planes respectively. Additional peak with small intensities was detected with orientation (110) corresponded to the angle 57.83. X-ray diffraction magnitude has been ensured and compared to a standard ASTM (American Society of Testing Materials) cards, by Philips PW 1840 X-ray diffractometer of $\alpha=1.54$ Å for Cu – Kα. This results in good agreement with papers [36-38]. The structure, properties such as (hkl), inerplaner distance and grain size of ZnONPs are listed in Table 2. Middling grain size (GS) of polycrystalline material can be resolved from the X-ray spectrum by incomes of Full Width at Half Maximum (FWHM) way (Scherrer relationship) [39, 40].

Table 2. Difference among experimental and standard dhkl, grain size (nm) ZnONPs.

| Substrate temperature | 20 Exp. (degree) | dhkl (hkl) | dhkl Std. (Ao) | dhkl Exp. (Ao) | Avarge grain size (Dnm) from AFM | Partical size (Dnm) from Scherer’s formula |
|-----------------------|------------------|-----------|----------------|----------------|---------------------------------|-------------------------------------------|
| 450°                  | 31.83            | 100       | 2.810          | 2.817          | 64                              | 4.38                                     |
| 34.43                 | 002              | 2.610     | 2.602          |                |                                 |                                           |
| 36.32                 | 101              | 2.460     | 2.475          |                |                                 |                                           |
4.2.3 Current –voltage characterization

Fig. 5 a and b displays a current(I) to voltage(V) curvatures of ZnO thin film under dark and light at dissimilar power densities. It can be detected from Acurve in figure 5 a, that ZnO films dumped on silicon substrate act similar back to back Schottky diode. Figure 5 (b) designates that photocurrent of a device increases with the increase of power intensity (The optical power supplied to light source was varied through variable resistance (Variac)). This sensation happens is billed to the oxygen absorbed with asurface of ZnO film. Then increase in a electron density in ZnO film and thinning the width of a Schottky barrier which shaped between film and electrodes [41, 42]. Preceding studies proposed ZnO crystallites remained influencing the photo-response of films. A white light (halogen lamp) is irradiated to the ZnO film surface, photo-desorption of oxygen adsorbed on grain boundaries, so A barrier height of grain boundaries will convert lower [43, 44]. So, it terminate be determined that a number of power light intensities increased, additional electrons excited and travels from the valence band to the conduction band and A current is increased as UV irradiances increased. The obtained results are good agreement with paper [45, 46].

Figure 4. XRD pattern of ZnO nanoparticles.

Figure 5. I-V characteristics of the ZnO photodetector in a) the dark and b) under illumination at different power densities.
4. Photodetector parameters

The responsivity (R) and quantum efficiency of the ZnO NWs UV detector, have been calculated by using the equation 2 and 3 respectively [47-50].

\[
R = \frac{(I_{ph} - I_d)}{P_{op}} \quad \text{(2)}
\]

\[
\eta = R \times (hc) / (q\lambda) \quad \text{(3)}
\]

Where \(P_{op}\) stands for the excitation incidence optical power of at a range wavelength (200-1200) nm. Where R is the detector responsivity, h is Planck constant, c is speed of light, q is electric charge, and \(\lambda\) is wavelength of incident light nm. Fig. 6 a and b displays the spectral response and quantum efficiency of the fabricated ZnO nanoparticles photodetector for a light of different wavelengths using a 300-W Xe lamp dispersed by a monochromator as the excitation source. Under -5V applied reverse bias, it’s clear that the ZnO PD response was 0.23 A/W at wavelength about (380) nm and this agreement with reference [38, 51], and another peak position in IR region at wavelength about 840 (due to silicon substrate). The quantum efficiency (\(\eta\)) is an important evaluation parameter for photodetector performance. It is linked to the number of electron-hole pairs excited through absorbing photons [44, 52]. The quantum efficiency values of ZnO nanoparticles photodetector (refer Figure 6(b)) are 60% (at 375 nm) and 45% (at 840 nm). These values suggest that the synthesized ZnO nanoparticles exhibited a high detection performance to UV light.

![Figure 6. (a and b) A spectral response and quantum efficiency of a photocurrent measurement of ZnO photodetector.](image)

5. Conclusion

Zinc oxide (ZnO) photo detector prepared via spray Pyrolysis technique. XRD results show that the sharp and strong peaks observed at diffraction angles 2\(\theta\) of (31.83°, 34.49°, 36.32°) corresponded to the (100), (002) and (101) planes respectively. From optical results an absorption peak position in the ultraviolet region around 380 nm with band gap about 3.8 eV. AFM images show a spherical shape and that the average diameter of the particles is equal 63.96 nm. I-V characteristic of the ZnO/Si photodetector, shows Schottky diode and on the front bias, the current of darkness is a close value and the current of light changes greatly.

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