Synthesis, Characterization and Optoelectronic device application of ZnO nano structure

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Abstract: A clear ZnO nanowire was obtained using the Pulse laser deposition technique on a silicon and quartz substrate. Thermal oxidation at 650°C for 1 hour was used, employing conventional tube furnace. The structural properties ensure the formation of quantizing ZnO. The electrical properties of prepared ZnO NWs/Si films reveal a good rectification with maximum optical Responsivity in the UV region reach to 0.3A/W.

Keywords: ZnONWs, Zinc oxide, Photodetector.

1. Introduction

In recent years, the low-dimensional nano-devices for instance field effect transistor [1], photodetectors [2,3] and lasers [4,5] have attracted significant attention as a result of their unique properties and large surface-to-volume ratios. In the optoelectronic nanodevices fabrication the Zinc oxide nano wires (ZnO NWs) have turn out to be the most important element as a result of its simplistic fabrication properties and wide band gap [6]. Some exciting results were got in many previous works for example nano laser at room temperature [3] features of the ultraviolet (UV), the high internal gain (108) UV detectors [6], etc. For synthesize of ZnO nanowires several techniques have been successfully used, such as pulsed laser deposition (PLD) [7], sol-gel [8], chemical vapor deposition (CVD) [9], thermal evaporation [10]. Since PLD consider a cold wall processing method, utilize only the focused laser beam on the target, it facilitate a clean environment. The laser deposition method is highly convenient for the preparation of nanostructure material with high Stoichiometry and good chemical purity of various materials including semiconductors [11]. This technique has many other properties such as creating particles with high energy source, allowing good growth quality at low temperatures [12], inexpensive and simple experimental system, high pressure inner gas could be employed, and target of multi-component could be used to make it essentially suitable for the preparation of oxide nano structured films. As a future material ZnO has got more attention within the research area groups, especially as an optoelectronic materials research. It has been widely studied return back to 1935 [13], including a lot of currently industry and everyday lives critically depending on this material. The regenerate ability of synthesize material has affect on the development of growth technologies for the preparation of good quality epitaxial layers and single crystals, which permit the satisfying action of ZnO based optoelectronic and electronic
devices. This work presents the preparation of nano wire collected together around a center point which repeated along the film surface to give a novel surface morphology, the obtained zinc oxide nano wires was used to prepare an optoelectronic device based on the silicon substrate with a peak response at UV region.

2. Experimental work

A 2cm diameter and 1cm height Zn pellet were prepared using 99.999 Zinc powder from Aldrich using a mechanical compressor using 5 tons pressure. The target was ablated using laser pulses (10-20 min) to get single-layered thin films on silicon and quartz substrate. As Perrier stage, the substrates were cleaned using ethanol and acetone for 15 mints in the ultrasonic bath followed by washing in distilled water and finally dried in air. The prepared samples placed in a pulsed laser deposited chamber to be ablated employing (750mJ) Q-switching laser using 50 pulses. The pure zinc film thermally oxidized using a furnace type ((KSL-1100X) as an oxidation source at 650°C for 1 hour. The ZnO NWs thin films were characterized using XRD (X’Pert Pro MRD PW3040) with Cu-Kα emission wavelength at $\lambda = 0.15418$ nm, SEM uses (SPM-9600) Scanning Probe Microscope, respectively. The optoelectronic and electrical properties of the preparation device were also characterized. The deposited film had a thickness of approximately 150 nm, which is measured using laser techniques.

3. The Results and Discussion

XRD pattern of the as-synthesized ZnO NWs is shown in Figure(1). It's clear, that the observed diffraction peaks appeared has the polycrystalline Wurtzite structure with sharp and strong peaks observed at diffraction angles (2θ) of (31.83°, 34.49°, 36.32°) corresponded to the (100), (002), (101) planes respectively. Besides, it’s clear in ZnO films patterns, the very small peaks observed at angles (2θ) (48.7° and 57.2°) corresponded to the (102) and (110) plans respectively. The XRD peaks of ZnO NWs films found to match with the card No.36-1451 in JCPDS. The position of peaks match with the pure phase of ZnO material. The grain size of the polycrystalline films can be estimated depending on the X-ray results utilizing Full Width at Half Maximum method [14-16]. The value of crystal size calculated from the scherrer equation about 81.4 nm.

![Figure 1. XRD results of prepared ZnO nanostructure.](image-url)
The morphology of ZnO NWs grown on Si is shown in Figure (2). This figure shows a different magnification of low, medium and high magnified SEM images. It can observe a high density, randomly oriented and well-distributed ZnO nanowires in large areas. The estimated lengths of the wires are about 3.33 μm, and the diameters of the measured wires were ranging with 228 - 330 nm.

Figure 2. SEM images of ZnONWs at different magnification(a,b and c).

Using silicon substrate ZnONWs/Si was obtained, the current -voltage characteristics were measurements have been achieved with dark and light at different power densities (0.36, 0.64, 1.15 and 1.87) mW/cm$^2$ at room temperature could be shown in Figure (3). It shows the observed behavior of rectifying and nonlinear relationship .So, this behavior indicates that the formation of Schottky barrier at the semiconductor –metal contact. Thus, the observed Schottcky contact can be attributed to the differences between ZnO and Al work functions [17, 18].
Figure 3. I–V characteristics of the Dark (a), and the light of ZnO NWs photo detector (b).

For fabricated ZnO NWs UV detector, the responsivity (R) has been calculated by using the equation (1) [19-21]:

$$R = \frac{I_{ph} - I_d}{P_{op}}$$  \hspace{1cm} (1)

Where $P_{op}$ stand for the excitation incidence optical power of at a range wavelength (200-1200) nm. Fig.4 (a) and 4(b) represents the obtained Responsivity and quantum efficiency of the photodetector device (Al/ZnO NWs/Si/Al) prepared via pulse laser deposition technique (PLD) respectively. Figure 4 (a) shows obviously that the ZnO NWs possess the highest photo response and the behavior in the region of short wavelength keeps the horizontal level. The $\lambda$ cutoff was recorded ~390 nm at the range of UV light and recorded (corresponding silicon substrate) at 840 nm. Therefore this result signify that ZnO NWs is UV-active with high responsivity reaches 0.30 A/W with (0.5volt) bias, which is larger than that of Sabah M. Mohammad et al and Q. Q Mohammed et al [22, 23] at UV range under 5 V bias the responsivity of 0.07 A/W was highest, and larger than the calculated result by Chai et.al and J. M Taha et al [24, 25]. The responsivity of photo sensor records 15 mA/W at UV region with (1 Volt) bias. As said by several recent reports, a highly crystalline [26, 27] and high surface-to-volume ratio [28, 29] of ZnO nanowires, have an significant role in the photo response mechanism enhancement.

In UV photo detector the ZnO NWs film has been used, with quantum efficiency ($\eta$) which considered as [19, 30].

$$\eta = R \times \left(\frac{hc}{q\lambda}\right)$$  \hspace{1cm} (2)

Where $R$ is the detector responsivity, $h$ is the Planck constant, $c$ is the speed of light, $q$ is the electric charge, and $\lambda$ is the wavelength of incident light. Figure 4b shows the measured external quantum efficiency with the range of 350–1050 nm wavelength illumination. The ZnO NWs have maximum quantum efficiencies about 95%. This result is possibly due to the high absorption of light by considerable surface area of the nano wires structure [31].
Conclusion

From the obtained results we could conclude that ZnO nanowires could be successfully prepared using the PLD deposition method followed by a thermal oxidation process at a specific temperature. The good quality optical detector is obtained using Si substrate with a proper response in UV region.

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Figure 4. (a) ZnO NWs photo detector responsivity at Room temperature and (b) quantum efficiency (η) with 0.5V applied bias.
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