Influence of laser energy on the optoelectronic properties of NiO/Si heterojunction

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Abstract. In the current work, NiONPs/Si Heterojunction Photodetector was fabricated using a drop-casting method of the Nickel Oxide (NiO) nanomaterial (produced by laser ablation in the water) on silicon (Si) substrate. The impact of laser energy on the preparation of NiO nanoparticles was investigated. The shape of the NiO NPs was a quasi-spherical particle with average particles size 16, 20, and 24 nm with high aggregations. The bandgap was direct and varying from 3.8 to 3.6 eV; relies on the laser energy. The current-voltage characteristics of NiO/Si heterostructure photodetector have a good rectifying property with suitable high spectral responsivity at the UV region, which found that the best value is 0.8 A/W @ 330 nm for a sample produced at 700mJ.

Keywords: Photodetector, laser ablation, Nickel Oxide nanoparticles.

1. Introduction

Nickel oxide NiO nanostructured materials are very interesting as a result of their unique properties, which make it employing in numerous fields such as a light-emitting diode, Photo-detector, solar cells, gas sensor, and biological applications [1-12]. It is a typical wide bandgap semiconductor having a large $E_g$ of ~ 4.0 eV, high binding energy (60 meV), and strong cohesive energy (1.89 eV) [13]. These properties depend on the factors and requirements of the preparation methods. Thus, some processes have been adopted and developed to synthesis these nanostructured materials, such as spray pyrolysis [14], a sputtering technique [9], chemical methods [15], laser ablation [7], thermal evaporation [16], and sol-gel [17]. Among them, pulse laser ablation in the liquid considers a suitable way to prepare new types of nanomaterial with various shapes.

This technique was utilized to produce nanoparticles via ablating metals and/or metals oxide in water and different solvents with stable solutions comprising nano-sized materials without using any surface reagents. LAL process happens when high energy is focused on a target that immersed in a solution on a suitable time; caused quick heating and melting of the target at this focal point. Also, the liquid layer was heated. Thus, vaporized generating a high temperature, high-pressure plume containing ionized species, and the plume expands intensely shattering the molten target material into nano-sized clusters which are super-cooled via the adjacent liquid. This process among other techniques has many advantages like simple, low cost, high accuracy, and efficiency. Also, the
features of nanoparticles can be controlled via adjustment of the appropriate parameters like laser energy, pulse duration, wavelength, liquid type, and the number of laser pulses [18-25]. Furthermore, there is some research on the laser ablation of NiO nanoparticles and study their properties. Therefore here, in this work NiO nanostructured materials prepared via laser ablation in liquid and studied the impact of laser energy on optoelectronic properties.

2. Experimental work

Nickel plate (Ni, 99.99%) was fixed in the bottom of the container filled with 4ml deionized water DIW, which ablated with 1064nm Nd: YAG laser (7ns) with a beam diameter of 2 mm. The ablated was performed for 5 min and at different energies (500, 600 & 700) mJ. UV–Vis Spectrophotometer (Shimadzu) used for absorption measurement of the NiO NPs, and scanning electron microscopy (Tuscan VEGA3) was employed to examine the topography of samples. For optoelectronic properties, suspension of NiO was deposited on (111) Si substrate (1.5 - 4 Ω cm) via a drop-casting process at low temperature. Dark Current-voltage characteristics of the fabricated photodetector were measured, which held out using a Farnell power supply and A Tektronix multimeter to record the resultant current. The responsivity of the manufactured photodetector was measured in the range (200–500 nm) of wavelengths.

3. Results and Discussion

Figure 1 exhibits SEM images of the NiO NPs prepared under different laser energies. All images showed a quasi-spherical particle-like structure of NiO nanosized with average particles size 16, 20, and 24 nm, respectively, and these values are in agreement with published results [3,5]. Also, the aggregations among the particles nanostructures were noticed owing to the attractive force over the nanostructures surfaces.

Figure 2 shows the absorbance spectrum of NiO nanostructured materials synthesized at different laser energies (500, 600 & 700) mJ. The prepared nanostructured materials exhibited high absorbance in the UV region, and the absorbance intensity increased as laser energy increases due to the rise in the concentration of NPs in the solution. The direct bandgap of the NiO NPs was calculated via using a Tauc equation [9]:

$$\alpha h\nu = A(h\nu - E_g)^{0.5}$$

where $h\nu$ is photon energy, $\alpha$ is the absorption coefficient, and $A$ is constant, the energy bandgap values were estimated of about 3.6 eV (700mJ), 3.7 eV (600mJ) and 3.8 eV (500mJ) which is lower than its values of bulk NiO materials (4.0eV). This is due to the quantum confinement [26].

Fig. 3 describes the dark I-V features of NiO/Si heterojunction. It is clear from the figure that the current increase exponentially with the forward voltage bias, while it increases slowly in reverse voltage bias. In general, there are two sections in a forward current, the first at low voltage bias region, that known as recombination current, and has very small values. It generates when the electron excites from the valance band to the conduction band and will recombine with a hole in the valence band. In the second part at high voltage bias, the current is called diffusion current and occurs when the bias potential exceeds the voltage barriers. This voltage awards the electron sufficient energy to overcome the barrier height and drift in the junction [29, 30]. The ideality factor of the fabricated Heterojunction $\beta$ was ranging from 3.21, 2.12, and 1.21, respectively as laser energy increased. The latter values were calculated according to the equation [19]:

$$I = I_s \left( \exp \frac{qV}{n k T} - 1 \right),$$

from a linear line; is acquired by scheming the logarithm of the I-V characteristics, and these results are consistent with data reported in references [16,27]. Thus, the IV merits depended on the laser energy; are linked with the dense of NPs
in the solution, and also to the reducing of the resistivity with increasing the laser energy and therefore, rise the current.

Fig 1 SEM images of NiO NPs prepared at different laser energies
Fig 2: Absorbance spectra of NiO nanostructures synthesized under different laser energies.

Fig 3: (I–V) merits of the NiONPs/Si photodetectors.

Fig. 4 displays the response value represented as a function of the wavelength of the light power incident. It was measured under 3V reverse bias voltage. The peaks were noticed in the wavelength 310 nm to 330 nm range, with the best value was found 0.8 A/W @ 330 nm for a sample produced at 700mJ, this is attributed to the increase the concentration of nanoparticles as laser energy increased, that increases the absorbed photons in the depletion region, and consequently increases in the photoresponse for photodetector-based on those nanoparticles.
4. Conclusions

It has been confirmed a one-step preparation of NiO nanoparticles by pulsed laser ablation of nickel metal in a liquid solution. The morphology results exhibited a quasi-spherical particle. The UV-VIS spectra showed high absorbance in the UV region, and it’s increased as laser energy increased which is attributed to the increase in the concentration of NiO NPs in the solution. The current-voltage merits of NiO/Si heterostructure Photodetector (PD) have a good rectify feature with suitable a spectral Responsivity.

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