Fabrication and Characteristics Study of Bismuth Oxide/Silicon Heterojunction for Photodetector Applications

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Abstract: This work presents the fabrication of bismuth oxide/Silicon Heterojunction for Photodetector applications. Bismuth oxide nanoparticles investigation by simple chemical Tanique. The Bi₂O₃ thin film was deposited onto n-type Silicon and glass substrate by drop casting technique. The structural and optical properties of Bi₂O₃ thin film were studied; also, XRD show that the thin film is polycrystalline. The optical properties showed the having direct optical band gap of 2.5 eV, Dark and illuminated I-V, C-V, spectral responsivity and quantum efficiency of Bi₂O₃/n-Si photodetector ware investigated and discussed.

Keywords: Bismuth oxides, Thin film, solar cell, simple chemical method, Optical properties.

1. Introduction

A bismuth oxide Bi₂O₃ with peculiar properties becomes The main objective is between the bismuth containing substances [1].This composite has large values of refractive index. The polarization of Bi⁺ cation is highly sensitive to light [2]. Also, the energy gap is wide [1.73- 3.98] eV , it is close to CdS, which is considered a prominent Filter for solar cells application [3-5], besides .These properties have four multi-forms α- Bi₂O₃,β- Bi₂O₃, δ- Bi₂O₃, γ- Bi₂O₃ [6] and the unequal stages are Bi₂O₂,33,Bi₂O₂,75 [7].These interesting properties have been recommended for a wide range of applications in solid state technology such as optical coatings, photovoltaic and ceramic glass manufacturing [8,9].Different method was used to prepare Bi₂O₃ such as sol-gel, magnetron reaction and sputtering Thermal evaporation [10-12], in this
paper, the preparation and characterization of Bi$_2$O$_3$ thin film on n-silicon Si in order to study their characterization for the solar cell applications.

2. Experimental work

About 1.6 g of Bi(NO$_3$)$_2$ and 224.98 g/mol (BDH /Chemicals Ltd Pool /England) was dissolved in 45 ml of Polyvinylpyrrolidone (Sigma Aldrich USA) 1%wt. and Re-distilled water was used through this work.

The solution was added in a round flask with flipping. The mixture was yellow. About 20 mL of NaOH (1M) was rapidly added to the mixture, and nanoparticle suspension was formed. The suspension was maintained at 80°C for two hours. After cooling to room temperature, nanoparticles were separated by centrifugation, then washed by distilled water to get rid of any pollution:

\[
\text{Bi(NO}_3\text{)}_2 + 2\text{NaOH} \rightarrow \text{Bi}_2\text{O}_3 + \text{Na}_2\text{NO}_4 + \text{H}_2\text{O} \]

Figure 1 shows that the Bi$_2$NO$_3$ molecular nanoparticles, which are prepared by the chemical method, are grounded by the technique of droplet casting on glass and silicon substrates. The solution has been taken by pipette and then drops onto the glass surface and the n-silicone substrate only 3 drops, then the particles dried up by using heater at 80 °C, then the thin film is ready. Weight difference method can be used to measure thickness. The difference for the film before and after the deposition on a glass substrate is the mass of Bi$_2$O$_3$ the film (m), also, the area of the thin film (A) and density (d) of the film material. The thickness (t ≈ 200 nm) determined using following relation:

\[
t = \frac{m}{Ad} \]

Figure 1. Diagram of the projection method of casting experimental mode
3. Resultants and desiccation

TEM image shows in Figure 2 confirmed that the Bi$_2$O$_3$ colloidal was ball shaped, which different diameter, about 13 to 25 nm, TEM studies were done to find the surface morphology of synthesized Bi$_2$O$_3$. TEM studies shows Bi$_2$O$_3$ is in pure form and particles are improve black colored nanoparticles.

![TEM image of synthesized Bi$_2$O$_3$ nanoparticles](image)

**Figure 2.** TEM image of synthesized Bi$_2$O$_3$ nanoparticles

XRD is an useful experimental technique used to calculate the crystalline structure of the stationary fixed-crystal orientation of the single crystal and the preferred Trends of Polycrystalline Crystals, [13] as shown in Figure 3. The X-ray diffraction model for the high-ready film on a sub-surface of the glass shows a multicolor structure with a peak of bismuth metal at 2 27 27.59, 32.4, 48.2 (111), (200) and (116) aircraft respectively, corresponding d-values were compared with the standard [JCPDS file, plane (Alpha Order): Bi$_2$O$_3$ 00-041-1449.
Figure 3. XRD pattern of Bi$_2$O$_3$ thin film which prepared by chemical method and deposited by drop casting technique on glass.

Figure 4 shows the magnification of 50 Kx for the SEM image of the Bi$_2$O$_3$ thin layer on the glass bottom layer. Also, the surface of the film consists of a regular distribution of anstructured grains with different grain sizes between 60 to 100 nm.

Figure 4. Scanning electron micrographs of the Bi$_2$O$_3$ thin film.
Morphology behavior of the thin film is showed in Figure 5. The film exhibited the lowest grain size of 91 nm, root mean square roughness (\textit{rms}) of 2.14 nm, and the roughness average is about 1.84 nm. This behavior can be explained by the high oxygenation rate in the air, leading to lower roughness and volume in this atmosphere.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{AFM_images.png}
\caption{AFM images of Bi$_2$O$_3$ thin film}
\end{figure}

Figure 6 presents their optical absorption spectra in a 300 to 900 nm spectral range, proving their relatively good absorbance in the visible and much higher absorbance at 330 nm.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Absorption_Spectrum.png}
\caption{Optical absorption spectrum of Bi$_2$O$_3$ thin film}
\end{figure}

The energy gap can be found through the absorption coefficient by using to it by the following equation [19]:
\[(\alpha \nu)^2 = A(\nu - E_g)^n \quad \ldots \ldots \ldots (3)\]
Where $\alpha$ is the refractive index, $h\nu$ is the energy gap of the incident photon, $A$ is a band edge parameter and $n$ is an refractive index that characterizes the optical absorption process which is equal 2 eV or 0.5 eV for indirect and direct allowed conversions, respectively. $E_g$ is calculated by extrapolating the straight line portion $(h\nu \alpha)^2 = 0$. The result of the energy gap at the range from 2.5 eV as shown in Fig. 7. The small energy gap value may attributed to the bismuth Bi ions and atoms available in the plume thus Fermi level move into the conduction band and thus made the material act as dissolve semiconductor [15].

![Graph](image_url)

**Figure 7.** $(\alpha h \nu)^2$ versus photon energy gap of Bi$_2$O$_3$ thin film.

Figure 8 shows the dark properties of (I-V) in the front and back direction of Al/Bi$_2$O$_3$/n-Si/Al Photodetector. The forward current of photodetector is very small at voltage less than 2V. This current is known as recombination current which occurs at low voltages only. It is generated when each electron excited form valence band to get the balance back. The second high-voltage zone represents the propagation or bending region that relies on serological resistance. In this region, the bias voltage will equip the electrons or holes with enough energy to break the barrier between the two sides of the intersection. In this region; the bias voltage will release electrons or holes with enough energy to penetrate the barrier between the two sides of the junction. These results agree with the other workers [16].
Figure 8. Dark I-V characteristics of Al/ Bi$_2$O$_3$/n-Si/Al photodetector

Figure 9 show that the contrast ln (I/I$_0$) with bias voltage of Bi$_2$O$_3$/n-Si prepared. The ideality factors of heterojunctions are estimated and it is found to be around (2.44) for Bi$_2$O$_3$/n-Si prepared. When the chassis has a resistive chain and interface state, the ideal factor n becomes higher than the unit; most Schottky diodes process show deviation from the ideal thermionic theory. The fact that such recombination currents are flowing not homogeneously in the structure, But always at local sites. These results agree with the other workers [17].
Figure 9. Variance of the value of $\ln \left( \frac{I}{I_0} \right)$ with the deviation voltage of $\text{Bi}_2\text{O}_3 / \text{n-Si}$.

Optical properties are the best use of photoreceptor mass imaging since these properties determine how light energy is converted to photocurrent. Figure 10 shows that the characteristics of the inverted power of the instrument are measured in the dark and under the lighting of the tungsten ceiling lamp $41 \text{W/cm}^2$. The reverse current value can be observed at a standard voltage of Heterojunction $\text{Bi}_2\text{O}_3/\text{Si}$ under illumination higher than those in the dark. They increase with increasing light intensity. The current that starts at low voltage is a typical thermal emission pattern. In the linear area, the heat emission and the carrier velocity will increase when the sample is lit with a light intensity of varying intensity.

Figure 10. Dark and luminous characterization (I-V) of $\text{Bi}_2\text{O}_3 / \text{n-Si}$ Photodetector
Figure 11 shows that the linear relationship between the $C^{-2}$ and the reverse voltage was obtained to bias the structure. This linear relationship represents the Bi$_2$O$_3$/Si image detector. The potential internal voltage values were obtained at 0.4 volts. It represents the energy required of the electron to transfer it from Bi$_2$O$_3$ to Si.

![Graph](image.png)

**Figure 11.** $1/C^2$ versus reverse voltage of Al/ Bi$_2$O$_3$/Si/Al photodiode.

Figure 12 shows the spectral responsivity and Quantum efficiency of Al/Bi$_2$O$_3$/n-Si/Al photodiode is investigated in the wavelength range from 400 nm to the 900 nm with 5 volt bias, which is calculated by following equation:

$$R_x = \frac{I_{ph}}{P_{in}}$$

(3)

Where $I_{ph}$ is the stream of the optical vessel and the pin is the input power. Spectral responsivity $R_x$ is an important function to find out the amount of detector signal that will be available for application [16]. The structure of the Bi$_2$O$_3$/n-Si sandwich (photodetector) consists of approximately 600 nm peaks representing the absorbance edge of Bi$_2$O$_3$/Si as shown in figure) and the other in 700 nm related to Bi$_2$O$_3$/n-Si as shown in Figure 12. The photoresponse magnitude painted in Figure 12 is calculated after subtracting the dark current when aligned opposite. The result of the response means that the portion of high-energy light, such as 600-700 nm, is absorbed by a Bi$_2$O$_3$ film (Zone 1) and the portion of light with less energy, such as 800-900 nm (Zone 2), completely in Si substrate and absorbed. These results due to absorption edges Bi$_2$O$_3$ and Si. The $R_x$ of photodetector Al/ Bi$_2$O$_3$/Si/Al is increased from 0.68
A/W. Quantum efficiency (Q) can be defined as the ratio of generated electrons to the incident photons when the light strikes the surface of photodetector. The Q is the number of photons that occur if the detector is a semiconductor (p-n) junction device, in which (hole-electron) pairs are produced. Over a period of time $10^5$ photons are incident on the detector and $10^4$ (e-h) pairs are produced, then, the Q is about 10%. The Q of photodetector is basically another way of expressing the effectiveness of the incident optical energy for producing an output of electrical current, the $Q$ (in percent) may be related to the $R(\lambda)$ by the relation:

$$Q = R(\lambda) \frac{1.24}{\lambda (\mu m)} \times 100\% \quad (4)$$

$R(\lambda)$: is the responsively (A/W) of the photodetector as a function of wavelength $\lambda$ (μm) [18].

The quantum efficiency $Q$ found to be 14% at wavelength 740 nm for Bi$_2$O$_3$/Si Photodetector.

![Figure 12. Spectral response and Quantitative efficiency as a function of wavelength for Bi$_2$O$_3$/n-Si photodetectors](image)

4. Conclusions:

The synthesised Bi$_2$O$_3$NP$_S$ are in nanosized about 13 to 25 nm prepared by simple chemical method which it has a good characteristics of Bi$_2$O$_3$ NP$_S$. Also, X-ray diffraction detection measurement that Bi$_2$O$_3$ NP$_S$ are polycrystalline. Deposition of Bi$_2$O$_3$ NP$_S$ on porous silicon gives suspensions photodetector
characteristics. The spectral responsivity (R) of Al/ Bi2O3/Si/Al photodetector is 0.72 A/W at ≈ 740 nm wavelength due to the absorption edge of Si and 0.6 A/W at ≈ 650nm wavelength due to the absorption edge of Bi2O3 NPs.

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