

Effect of Multilayer Configuration on Spectral Response of Thin Film TiO₂/NiO Heterojunction Photodetector

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Research Article

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Abstract

In this work, a multilayer design for the TiO₂/NiO heterojunction device is proposed. In this design, layers of TiO₂ nanostructures are consecutively deposited on layers of NiO nanostructures deposited on ITO substrates. This design was compared to the conventional design of thin film TiO₂/NiO heterojunction device by measuring the spectral response of both designs in the spectral range of 200–1200 nm. The proposed design showed increased response intensity by 14%, narrowing spectral width by 23% and single peak of response at 440nm.

1. Introduction

Thin films still have their outstanding position in photonics and optoelectronics systems and networks due to the irreplaceable characteristics to be provided by the bulk structures [1–3]. Therefore, the research interests to thin films are continuously increased to achieve better characteristics those would develop the performance of the devices based on thin films [4–6].

As thin films are prepared by several different methods and techniques, many options are available for the designers of thin film devices. However, no single method or technique could produce thin films with the best characteristics. Therefore, continuous evaluation of thin films prepared by any method or technique may provide useful data for designers to choose the optimum for their requirements and applications [1, 3].

More than six decades when first thin film heterojunctions were fabricated. Despite, thin film heterojunctions are the basis of the most effective photonic and optoelectronic devices used in many modern technologies, mainly optical communications and biomedical engineering [7–10]. The combination of thin film physics and engineering has established such basis. However, new aspects of this combination are explored to produce new photonic and optoelectronic devices [11, 12].

Titanium dioxide and nickel oxide are among the most common metal oxide semiconductors due to their excellent characteristics clearly shown in the devices fabricated from them [13]. Research works are motivated to use them because of the excellent energy outline formed due to their energy band gaps (3.20 eV for TiO₂ and 3.85 eV for NiO) [14, 15]. The different types of electrical conductivity allowed to fabricate pn heterojunctions of very attractive characteristics. Furthermore, they uniquely show some features making them unbeatable by other metal oxide or compound semiconductors. Photocatalytic activity of titanium dioxide and electrochromic behavior of nickel oxide are examples [14].

Nanotechnology has revolutionized the thin film technology as the designers are making use of nanostructures and their features in addition to those of thin films. So, the ultra-fast response, ultra-high reliability, ultra-high efficiency, ultra-high compactness, high reproducibility and low production cost could be achieved at once [7, 8]. Nevertheless, relatively simple ideas and inexpensive developments – those might not be seen before – still possible to design and produce new photonics and optoelectronics [9].

In this work, the multilayer configuration of TiO₂/NiO thin film heterojunction is proposed to enhance the spectral response of photonic devices based on such heterostructure.

2. Experimental Part

A dc reactive magnetron sputtering system was used in this work to deposit titanium dioxide (TiO₂) and nickel oxide (NiO) thin films on indium-doped tin oxide (ITO) substrates. A closed-field unbalanced dual-magnetron assemblies were employed at both electrodes of plasma discharge system. Such assemblies enables highly homogeneous sputtering of titanium and nickel targets as well as homogeneous deposition of thin films on the substrates. Experimental details on the sputtering system used in this work can be found elsewhere [16–24].

The structural characterization tests, mainly x-ray diffraction (XRD), atomic force microscopy (AFM), scanning electron microscopy (SEM), and energy-dispersive x-ray (EDX) spectroscopy, have confirmed the formation of nanostructures from both materials (TiO₂ and NiO). They have also confirmed the high structural purity of the prepared samples as no traces for other elements and compounds were found in the final products. The minimum nanoparticle size was 20 nm for TiO₂ and 15 nm for NiO. The deposition rates of TiO₂ and NiO films shown in Fig. (1) were finely controlled due to the sputtering system stability.

Two multilayer structures shown in Fig. (2) were prepared in this work and their spectral response were compared to introduce the advantages of the proposed design as a heterojunction device. In the first structure, a TiO₂ thin film of 150 nm thickness was deposited on the ITO substrate after deposition time of 105 minutes. Then, a NiO thin film of 150 nm thickness was deposited on the TiO₂ layer after deposition time of 90 minutes.

In the second structure, a NiO thin film of 80 nm thickness was deposited on the ITO substrate after deposition time of 30 minutes. Soon after, two consecutive layers of NiO of 105 and 120 nm were deposited after deposition time of 45 and 60 minutes, respectively. Then, three layers of TiO₂ (105, 75 and 40 nm) were consecutively deposited after deposition times of 60, 45 and 30 minutes, respectively.

Thin films of aluminum were deposited on the top surface of the prepared samples to act as electrodes for the electrical measurements. The optoelectronic measurements were carried out using different light sources with different wavelengths and intensities. The spectral response of the prepared samples was measured in the spectral range 200–1200 nm using a monochromator equipped with ceramic heater light source and chopper.

3. Results And Discussion

Figure (3) shows the spectral response of both configurations of multilayer thin film structures prepared in this work. The conventional configuration containing of one layer of NiO deposited on one layer of TiO₂ shows two peaks at 400 and 460 nm with spectral width of 300 nm, while the other configuration

containing of three layers of NiO deposited consequently on three layers of TiO₂ shows single peak at 440 nm. There three observations in these spectra, they are (1) disappearance of the two peaks at 400 and 460 nm and appearance of new peak at 440 nm, (2) increase in the intensity by 14%, and (3) narrowing of spectral width by 23%.

As the TiO₂ layers are receiving the incident radiation before NiO layers, then they may act as filtration layers to transmit the photons whose wavelengths are within the absorption band of TiO₂, which is narrower than that of NiO. Therefore, the absorption peak of NiO and corresponding response at 400 nm disappeared from the spectral response spectrum of the multilayer configuration. As the absorption cross section of the TiO₂ nanoparticles is highly increased with decreasing particle size, then the absorption peak and hence the spectral response at 460 nm is shifted towards shorter wavelengths (440nm) as photons of higher energies are efficiently absorbed in the TiO₂ layers as well as in the heterojunction region.

When the TiO₂ and NiO films are deposited as in the conventional configuration with thickness of 220 and 300 nm, respectively, the opportunity for the nanoparticles to get bigger and aggregate is reasonably available. Therefore, the radiation should traverse throughout these regions of aggregated particles before reaching the heterojunction. Consequently, this would limit the number of photons to be absorbed. In the multilayer configuration, the thickness of each layer is smaller than that in the conventional configuration. Therefore, the opportunity for the nanoparticles to get bigger and aggregate is relatively lower. The radiation traverses faster throughout the TiO₂ layers to reach the heterojunction with larger number of photons and hence higher absorbance. This may interpret the higher intensity of spectral response in the multilayer configuration.

The narrowing observed in the spectral width may be attributed to the high homogeneity in the absorption of incident photons by the nanoparticles that normalizes the absorption in the heterojunction region.

4. Conclusion

In concluding remarks, a multilayer design for the TiO₂/NiO heterojunction device is proposed. In this design, layers of TiO₂ nanostructures are consecutively deposited on layers of NiO nanostructures deposited on ITO substrates. This design is based on the fine control of deposition rate of TiO₂ and NiO films. This design was compared to the conventional design of thin film TiO₂/NiO heterojunction device by measuring the spectral response of both designs in the spectral range of 200–1200 nm. The proposed design showed increased response intensity by 14%, narrowing spectral width by 23% and single peak of response at 440nm. The proposed design is simple, low cost and efficient for heterojunction devices.

Declarations

Availability of data and materials

The author declares that all data and materials included in this work are available.

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Conflict of Interest

The author declares that he does not have any conflict of interest related to this work.

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Figures

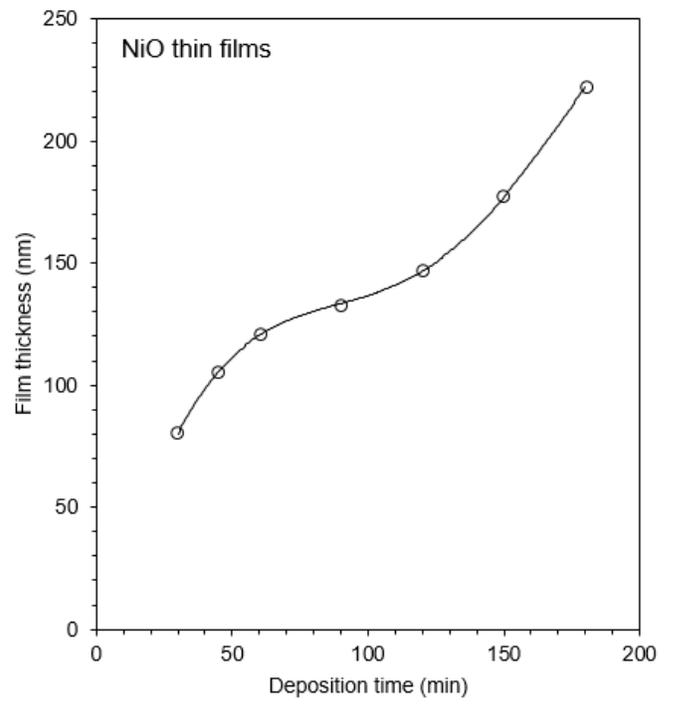
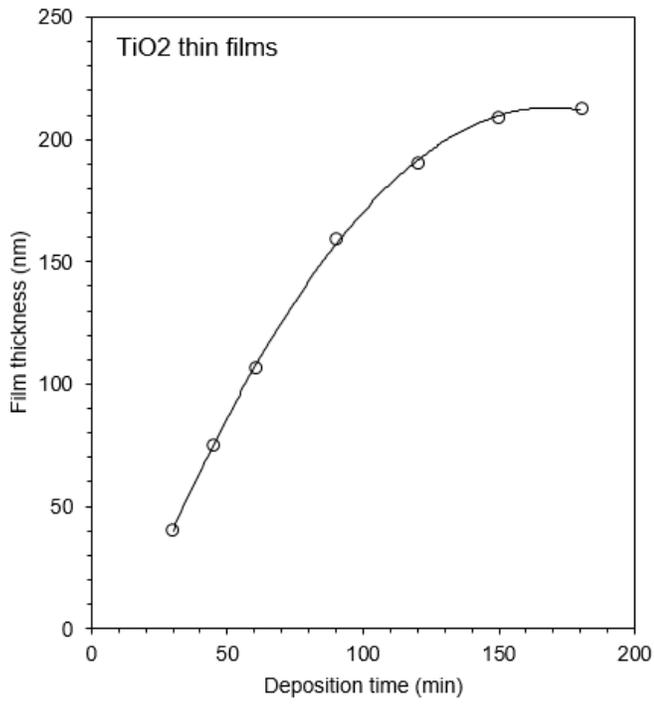


Figure 1

Deposition rates of TiO₂ and NiO film deposition in this work

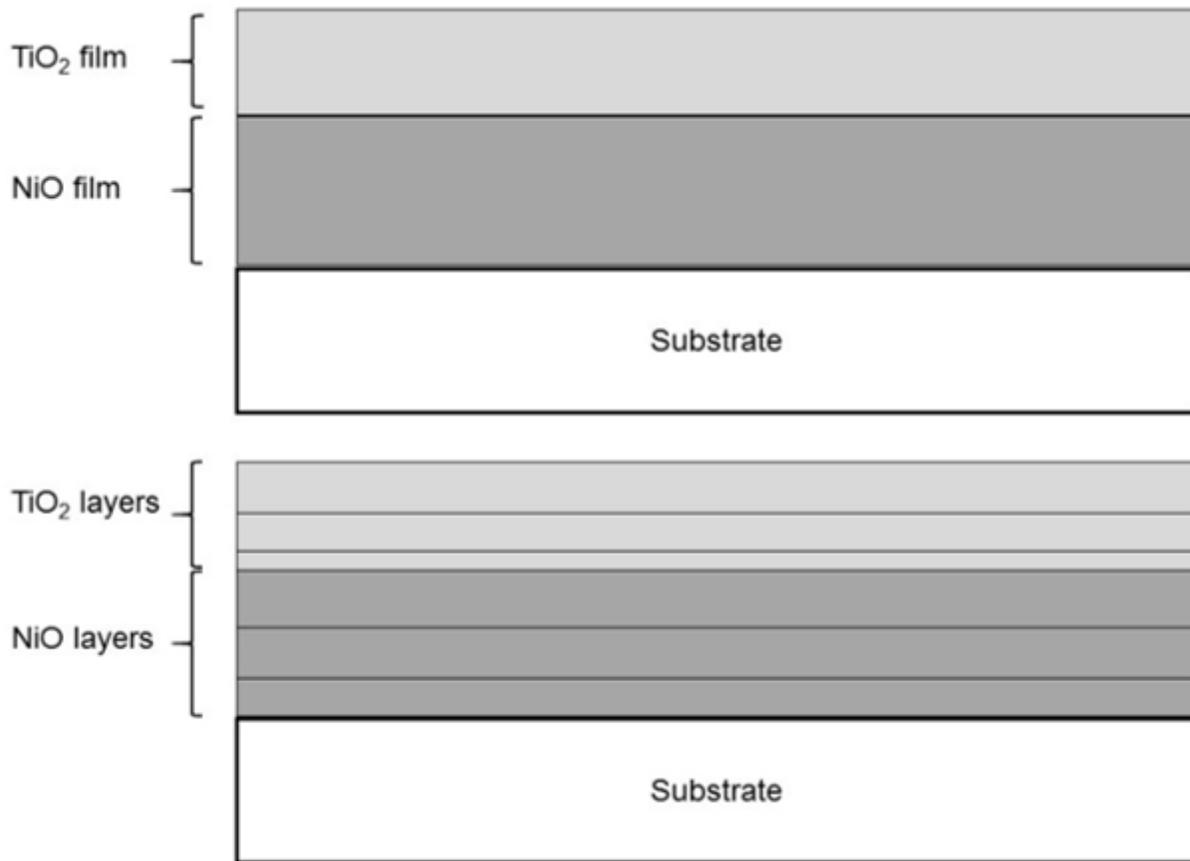


Figure 2

The two multilayer structures prepared in this work

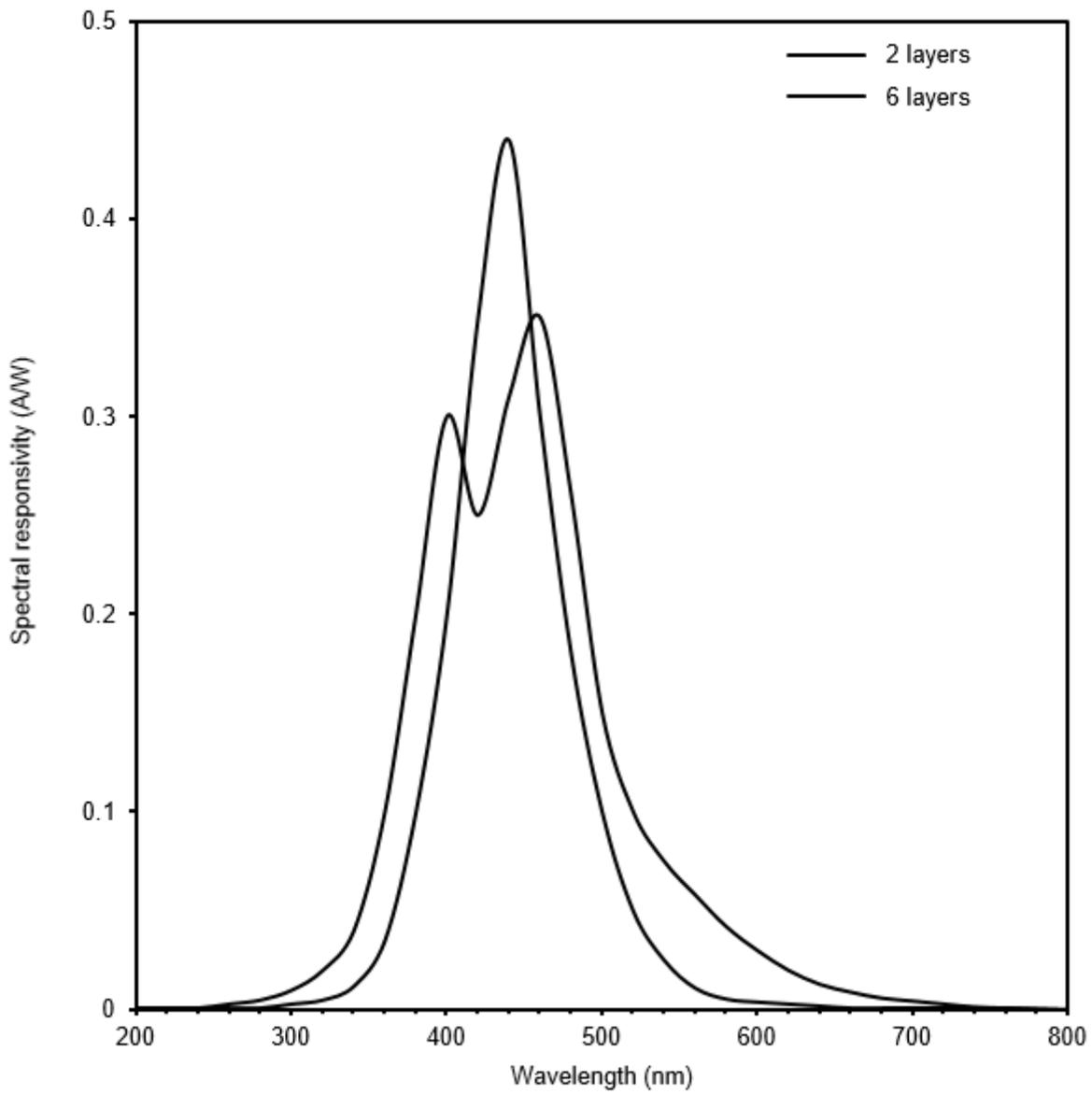


Figure 3

Spectral response of the multilayer structures prepared in this work