Optik - International Journal for Light and Electron Optics 172 (2018) 35–42

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Hydrothermally synthesized zinc oxide nanoparticle based photodetector for blue spectrum detection

H. Ahmad[a,b], M. Tajdidzadeh[a], K. Thambiratnam[a,*], M. Yasin[b,*]

[a] Photonics Research Centre, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Dept. of Physics, Faculty of Science and Technology, Airlangga University, 60115 Surabaya, Indonesia

ARTICLE INFO

Keywords:
Photodetector
Hydrothermal synthesis
Zinc oxide nanoparticles
ITO glass
Blue light

ABSTRACT

A photodetector, based on zinc oxide nanoparticles (ZnO-NPs) is designed and fabricated using the drop casting method. Two glass slides coated with Indium tin oxide (ITO) thin films approximately 2.5 μm thick are used as source and drain electrodes, together with Schottky contacts fabricated with ZnO-NPs for the efficient transfer of photo-generated charge carriers. The proposed photodetectors showed significant sensitivity under white light emitting diode (LED) illumination at 468 nm, which is near the blue light spectrum. The current–voltage *(I–V)* characteristics of the proposed photodetectors indicate the generation of electron-hole pairs under white LED illumination at 265 μW, and stable photocurrent is achieved at high direct current (DC) bias voltages. Photodector response and recovery times of approximately 66.52 and 134.36 μs respectively are obtained at LED frequency modulation of 100 Hz at a bias voltage of 5 V. This represents an enhancement of the capabilities of ZnO-NPs, which is typically used for detection in the UV region only.

1. Introduction

Photodetectors based on wide band-gap materials such as ZnO, SiC and GaN are capable of enhancing sensitivity in the ultraviolet (UV) spectra region [1–3]. Among these materials, ZnO nanostructures in particular are advantageous due to their inherent characteristics such as quantum confinement, reduced dark current, increased absorption efficiency and potential for large area and lower cost devices [4]. ZnO has a wide direct band gap of ~3.37 eV at room temperature and a large exciton binding energy of 60 meV which is sensitive to the UV region [5–7] and is thus a promising material for a wide range of applications such as varistors [8], transistors [9], solar cells [10], sensors [11], and UV-photodetectors [12–15]. As a result of this, the use of ZnO as a base material for photodetectors has seen significant interest and uptake, with numerous works using ZnO as a photosensitive elements component of these devices [16,17].

In this regard, metal–semiconductor-metal (MSM) photodetectors comprise of two interdigitated metal contacts on top of a semiconducting two dimensional (2D) material [18]. In comparison to common PIN photodiodes of similar size, the active region's dark current is reported to be lower than in MSM photodetectors due to interdigitated electrodes, making them good candidates for high speed photodetection [18–21]. Schottky diodes and MSM photodetectors based on ZnO nanostructures have also been successfully demonstrated in the UV region [22]. Therefore, higher performance MSM-UV photodetectors can be realized through improvised crystal quality so as to obtain significantly larger Schottky barrier heights at the metal–semiconductor interface. A large barrier height results in less leakage of current and an enhancement in responsivity, which can be obtain using metals with high work

* Corresponding authors.
E-mail addresses: kavintheran@gmail.com (K. Thambiratnam), yasin@fst.unair.ac.id (M. Yasin).

https://doi.org/10.1016/j.ijleo.2018.07.002
Received 29 January 2018; Received in revised form 27 April 2018; Accepted 1 July 2018

functions [23]. However, the unstable high work function of metal is a significant problem that could cause intense inter diffusion at the metal-ZnO interface. To overcome this issue, an insulator layer can inserted between the metal and ZnO layers [24,25]. Few reports have indicated that under certain synthesis and processing conditions, ZnO nanowires are made sensitive to UV exposure [26–28]. Colloidal ZnO nanoparticles (NPs) also exhibit the same characteristics, and are an attractive alternative to ZnO nanowires due to their low cost, ease of fabrication and large active area [29]. Chang et al. demonstrated the high responsivity of ZnO-NP photodetectors to be about 3.75 A/W, although its high ON and OFF states were recorded at 204 and 486 s respectively [30]. Dual wavelength photodetection using a solution processed ZnO-NP showed narrow-band photoconductivity due to electron transfers to discrete shallow donors from deep defects, which can be assigned to neutral oxygen vacancies [31]. In this work, a MSM photodetector based on colloidal ZnO-NPs deposited on a SiO_2/p-Si substrate with ITO source and drain electrodes is proposed and demonstrated. The ZnO-NPs were synthesized hydrothermally and dispersed in distilled water. The ZnO-NPs were characterized for blue light detection based on the current-voltage *(I–V)* characteristics of the photodetectors in darkness and under illumination by a 468 nm white light emitting diode (LED) source. The proposed ZnO nanoparticle based photodiode of this work is intentionally analysed for its ability to detect wavelengths higher than the UV region, as ZnO nanoparticles are typically used for UV detection. The recorded response and recovery times of the photodetectors are found to be significant when compared to other reported works.

2. Experimental setup

2.1. Synthesis of ZnO-NPs using hydrothermal technique

A polyethylene glycol (PEG)-assisted method is utilized to hydrothermally synthesize the polymeric mesoporous carbon-zinc (C-Zn) NPs. First, 6 mmol of Zn $(NO_3)_2.6H_2O$ and10 *g* of PEG Mn = 6000 $gMol^{-1}$ obtained from Fisher Scientific and 3 mmol of urea $(CO(NH_2)_2$ purchased from Sigma-Aldrich were mixed with 100 ml of deionized (DI) water and magnetically stirred until the solution becomes transparent with a pH level of 6. Subsequently, D-Glucose ($C_6H_{12}O_6$), obtained from Sigma-Aldrich was also dissolved in a 100 ml distilled water and sonicated at room temperature. The two resulting solutions are then gently mixed together whilst being stirred to obtain the final solution, which is in transparent. In order to ensure the resulting mixture is homogeneous, the obtained solution is transferred to a teflon-lined stainless steel 250 ml autoclave. The autoclave is sealed and then inserted into the chamber of an electric oven at 180 °C for 24 h under autogenous pressure. After this, the solution underwent centrifugation, and the obtained powder was washed several times with ethanol and double distilled water before being left to dry at 70 °C for another 24 h. Finally, the powder was put into a ceramic boat and transferred into the muffle furnace tube, where a post-calcination process is carried out from 25 °C to 550 °C under atmospheric pressure. This is to remove any residual volatilities produced from the decomposition of nitrate and urea in the sample [32,33].

2.2. Fabrication of photodetectors

The schematic design as in Fig. 1 (a) shows that the ZnO-NP based photodetectors based on a SiO_2/p-Si substrate in contact with the ITO source and drain electrodes. The substrate is first cleaned in an ultrasonic acetone bath for 30 min before being rinsed in distilled (DI) water in order to eliminate impurities and acetone stains. Then, the substrate is blown with nitrogen gas at room temperature to dry it. Meanwhile, two ITO thin films coated on glass pieces, each 2.5 µm thick with a high transmittance of ≥80% and sheet resistance of ≤7 Ω/sq are used as the source and drain electrodes. The ITO glasses are sonicated in a diluted hydrochloric (HCl) acid solution bath before being rinsed extensively in DI water in order to remove any residual HCl acid traces. Finally, the ITO glasses are sonicated in the acetone bath solution and then quickly dried using nitrogen gas at room temperature. The obtained ZnO powder is dispersed in DI water and about 1.5 µl is drop-casted onto the prepared SiO_2/p-Si using an Eppendorf-N16929E pipette. The sample is then heated in a furnace at 450 °C for 30 min to establish strong adhesion between the SiO_2 and ZnO layers. Immediately after being taken out of the furnace, the ITO glasses are clipped onto the ZnO-NPs/SiO_2/p-Si substrate. Finally, the fabricated

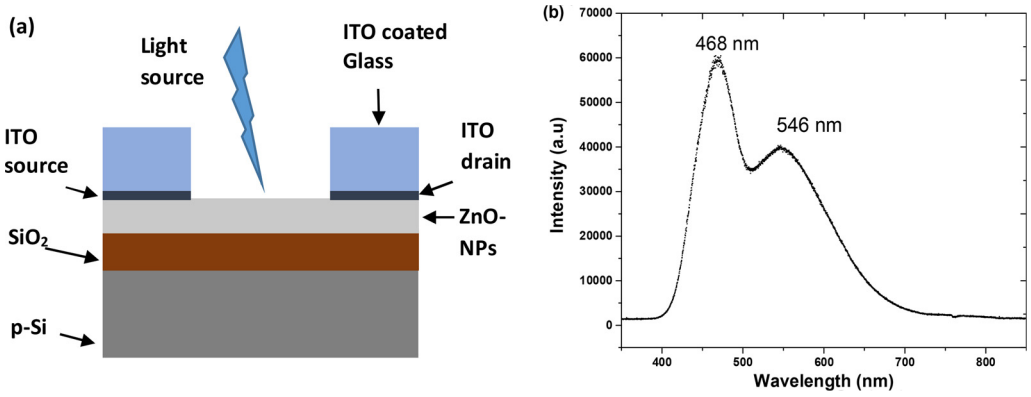

Fig. 1. (a) Schematic design of fabricated Zn-NPs based photodetectors and (b) luminescence spectrum of white LED.