Materials Chemistry and Physics 144 (2014) 86–91

Contents lists available at ScienceDirect

Materials Chemistry and Physics

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

Fabrication and characterization of metal–semiconductor–metal photodetector based on porous InGaN

Saleh H. Abud [a,b,*], Z. Hassan [a], F.K. Yam [a]

[a] Nano-Optoelectronics Research and Technology (N.O.R) Laboratory, School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia
[b] Dept. of Physics, College of Science, University of Kufa, Najaf, Iraq

HIGHLIGHTS

- $In_{0.27}Ga_{0.73}N$/GaN/AlN layers with an indium mole fraction of 0.27 have been epitaxially by PA-MBE.
- Nanostructured porous film was synthesized using the UV-assisted electrochemical etching technique.
- The fabricated MSM photodetector shows photovoltaic characteristics at the green region of the electromagnetic spectrum.
- The sensitivity of the MSM photodetector is directly proportional to the applied bias.

ARTICLE INFO

Article history:
Received 22 July 2013
Received in revised form
25 October 2013
Accepted 16 December 2013

Keywords:
Molecular beam epitaxy (MBE)
Nitrides
Etching
Electrical properties

ABSTRACT

In this study, the characteristics of metal–semiconductor–metal (MSM) photodetector based on a porous $In_{0.27}Ga_{0.73}N$ thin film were reported. Nanostructured porous film was synthesized using the UV-assisted electrochemical etching technique. The formed pores were dissimilar in terms of shape and size. The effect of annealing in the range of 300–500 °C on Pt/$In_{0.27}Ga_{0.73}N$ was investigated by *I–V* measurements. Schottky barrier height was at maximum value under 500 °C. The fabricated MSM photodetector shows photovoltaic characteristics in the green region of the electromagnetic spectrum. The device responsivity increased with increasing the bias voltage. Moreover, the rise and recovery times of the device were investigated at 10 mW cm^{-2} of a 550 nm chopped light. Finally, the sensitivity and quantum efficiency were also investigated.

1. Introduction

Great attention has been received in recent years for the development of photodetector based on III-nitride semiconductors. Among III-nitride compounds, the ternary InGaN alloys with their band gaps (0.7–3.4) eV are very promising for photodetectors, by controlling the In/Ga ratio [1]. MSM photodetectors are subjected to keen interest among different type of detectors because of ease of fabrication, low dark current, small capacitance, and the suitability for integration in an optical receivers [2]. Many research groups [3–5] have extensively fabricated MSM photodetector based on GaN, whereas few reports are available concerning the InGaN photodetectors [6]. Porous III-nitride compounds are promising materials for optoelectronic [7], chemical and biochemical sensors [8] because of their unique optical and electrical properties compared with bulk materials [9], but the reports on it are still very rare [10]. Many researchers [11–13] have used the photoelectrochemical (PEC) etching technique to synthesize porous GaN, whereas, Abud et al. [14] has used this technique to synthesize porous InGaN for the first time. In this work, we report the fabrication and characterization of MSM photodetoctor based on porous InGaN.

2. Experimental procedure

InGaN/GaN/AlN epitaxial layers were grown on Si(111) substrate by using a plasma-assisted molecular beam epitaxy (PA-MBE) system (Veeco Gen II). The native oxide of the samples was initially removed using $NH_4OH:H_2O$ (1:20) followed by $HF:H_2O$ (1:50). Boiling aqua regia, $HCl:HNO_3$ (3:1), was subsequently used to clean the samples. To synthesize porous InGaN, the samples were etched in an HF (49%):C_2H_5OH (99.99%) solution at a ratio of 1:5 under current density of 25 mA cm^{-2} for 15 min at room temperature. The morphology and structural properties of the as-grown and porous thin films were determined using field emission scanning electron microscope (FESEM), (Model FEI Nova NanoSEM 450), atomic force

* Corresponding author. Nano-Optoelectronics Research and Technology (N.O.R) Laboratory, School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia.
E-mail address: salehhasson71@gmail.com (S.H. Abud).

0254-0584/$ – see front matter
http://dx.doi.org/10.1016/j.matchemphys.2013.12.018

microscopy (AFM, Model Dimension EDGE, BRUKER), and high-resolution X-ray diffractometer system (HR-XRD), (Model PANalytical X'Pert PRO MRD PW3040), respectively. The optical properties were investigated using photoluminescence spectroscopy system (PL), (Model Jobin Yvon HR 800 UV), excited by an He–Cd laser at 325 nm. A Pt metal contact of 200 nm thickness was deposited on the porous films by using A500 Edward radio frequency-magnetron sputtering system. The contact then annealed at 300, 400, and 500 °C in an ambient N_2 atmosphere for 15 min. The electrical characteristics of Pt/InGaN were investigated by *I–V–T* measurements under 3 V by using Keithley Model 4200-SCS. The photoelectric behavior of the fabricated photodetector was investigated using a 550 nm LED with intensity of 10 mW cm^{-2} at bias voltages of 0, 0.5, and 1 V.

3. Results and discussion

Fig. 1 shows the FESEM images of the as-grown and porous thin films. Fig. 1a shows some small grains with irregular shapes and sizes; this may most probably be due to relatively low lateral growth rate of the film. This result shows that the film has been grown with two-dimensional growth mode or layer-by-layer plus island three-dimensional growth mode [15]. Whereas Fig. 1b shows the effect of the etching current density (25 mA cm^{-2}) on the film surface morphology, irregular pores with different shapes and sizes were distributed all over the area. Fig. 2(a–c) shows the AFM images of the as-grown, porous, and 500 °C post-annealed porous samples with root mean square equal to 12.5, 15.6, and 57.3 nm, respectively. Fig. 3 shows the X-ray diffraction (XRD) patterns of the as-grown and porous InGaN thin films. In Fig. 3a, the diffraction peaks were located at 33.61°, 34.54°, and 36.02° relative to the (0002) InGaN, GaN, and AlN films, respectively. The intensity of the InGaN diffraction peak was significantly lower than that of GaN, which indicates that the InGaN film is thinner than the GaN film [12], Similar result was found by Lee et al. [16]. Fig. 3b shows broadening diffraction peaks of the porous film, which implies a reduction in crystalline size. Full width at half maximum (FWHM) and the lattice constants of the as-grown and porous films are listed in Table 1. The indium mole fraction (x) based on the chemical formula, $In_xGa_{1-x}N$, can be calculated using the XRD symmetric $\omega/2\theta$ scans of the (0002) plane (Eq. (1)) [17] and Vegard's law (Eq. (2)) [18] as follows:

$$c = \frac{\lambda l}{2 \sin \theta} \tag{1}$$

where λ is the wavelength of the X-ray radiation (0.15406 nm), θ is the Bragg angle, and l is the Miller index; and

$$x = \frac{c_{InGaN} - c_{GaN}}{c_{InN} - c_{GaN}} \tag{2}$$

where c_{InGaN}, c_{GaN}, and c_{InN} are the actual c-plane lattice constants of InGaN, GaN, and InN, respectively. The Indium mole fraction value of the InGaN epilayer was 0.27.

Fig. 4 shows the photoluminescence (PL) spectra of the as-grown and porous thin films. The GaN near band-edge emission was at a wavelength of 365 nm, whereas the PL wavelength emission peak at 556 nm is related to the as-grown $In_{0.27}Ga_{0.73}N$. A slight blue shift was observed in the porous film at a wavelength of 554.3 nm. The PL peak intensity of the porous film was higher than that of the as-grown film, which indicates that porosity strongly affects peak intensity. The emitted light intensity is proportional to the number of emitted photons. Thus, the number of photons emitted by the porous film was much higher than the number emitted by the as-grown film. The high porosity-induced PL intensity can be due to the strong PL extraction via light scattering from the film crystallite sidewalls [19]. Porous film has a higher surface area per unit volume compared with as-grown film. Thus, the porous InGaN film provides more exposure to illumination by PL excitation lights for the InGaN molecules. This aspect may result in a higher number of electrons that take part in the excitation and recombination process in porous films compared with the smaller surface area of the as-grown films [13]. The relatively wide pore statistical size distribution can be attributed to the broadening of the porous film linewidth. The porous $In_{0.27}Ga_{0.73}N$ film has enhanced optical properties compared with the as-grown film. Therefore, the porous film was chosen to fabricate an MSM photodetector. Fig. 5 illustrates the forward and reverse *I–V* characteristics of the Pt contact on the porous $In_{0.27}Ga_{0.73}N$ film. *I–V* characteristics were measured as a function of annealing temperature. These characteristics were uniform at different annealing temperatures, and were strongly dependent on the temperature. It can be seen that the leakage current was increased with increasing temperature up to 400 °C. This increment can be interpreted on the basis of the presence other current transport mechanism. In other words, if the thermionic emission over the barrier is neglected, then the direct tunneling into the current transport mechanism has to include [20]. At 500 °C, we can note that the leakage current decreases to be at the less value compared with other

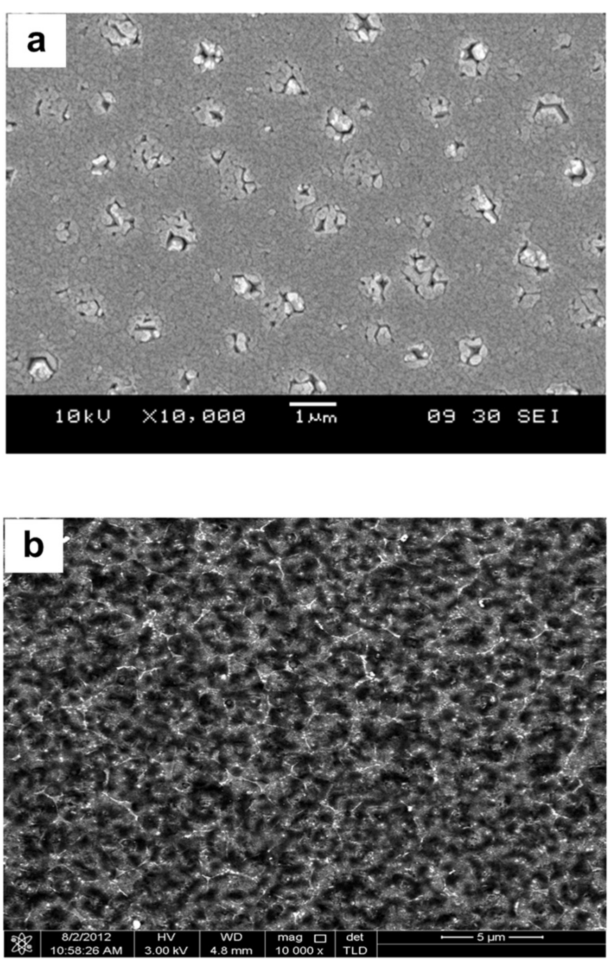

Fig. 1. FESEM images of the as-grown and porous InGaN. (a) as-grown, (b) porous at 25 mA cm^{-2}.