In this study, the characteristics of metal-semiconductor-metal (MSM) photodetector based on a porous In0.27Ga0.73N 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 ºC on Pt/In0.27Ga0.73N was investigated by I-V measurements. Schottky barrier height was at maximum value under 500 ºC. The fabricated MSM photodetector shows photovoltaic characteristics in the green region of the electromagnetic spectrum. The device responsivity increased with increasing the bias voltage.

**Keywords**: III-V; M-S-M; Characterization

### 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 suit-ability for integration in an optical receiver [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 photodetector based on porous InGaN.

2. EXPERIMENTAL

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 NH4OH:H2O (1:20) followed by HF:H2O (1:50). Boiling aqua regia, HCl:HNO3 (3:1), was subsequently used to clean the samples. To synthesize porous InGaN, the samples were etched in an HF (49%):C2H5OH (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 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 HeCdeep 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 oC in an ambient N2 atmosphere for 15 min. The electrical characteristics of Pt/InGaN were investigated by I-V 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

Figure 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 images of the as-grown, porous, and 500 oC post-annealed porous samples with root mean square equal to 12.5, 15.6, and 57.3 nm, respectively.
Figure 2 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 In0.27Ga0.73N. 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 [16]. 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 [17]. The relatively wide pore statistical size distribution can be attributed to the broadening of the porous film.

Schottky barrier height (fb) and the ideality factor (n) can be determined from the y-intercept and the slope of the fitted curve, respectively. The high ideality factor values are attributed to secondary mechanism that include interface dipoles caused by the fabrication-induced defects at the interface [18]. Other reasons include the image-force effect, recombination generation, and tunneling mechanism that could lead to an ideality factor value greater than unity [19]. The ideality factor is very close to unity at low doping and high temperature [20]. With the moderate doping of our samples (N w
1 x 1018 cm⁻³), we expected the substantial departure of the n value from unity. The higher values of the ideality factor could be attributed to the inhomogeneous barrier height. The same high ideality factors were reported [21-26]. Low leakage current, high SBH, and ideality factor approaches to unity are essential to obtain high-performance electronics devices. These preceding conditions were satisfied at 500 oC. Therefore, these conditions have chosen to fabricate an MSM photodetector based on porous InGaN. An MSM structure can be regarded as two Schottky contacts that are connected back-to-back. At a particular bias voltage, one of the contacts is forward biased and the other is reverse biased. The light responsivity (R) of the porous In0.27Ga0.73N MSM photodetector was calculated using the following relationship [27-29]:

![Figure 2 PL of the as-grown and porous InGaN.](image)

4. CONCLUSIONS

InGaN/GaN/AlN epitaxial layers with an indium mole fraction of 0.27 were grown by PA-MBE on Si(111) substrate. The etching current density of 25 mA cm⁻² for 15 min formed irregular pores with different shapes and sizes. The porous In0.27Ga0.73N film showed high PL emission intensity located at 554.3 nm, and shifted toward shorter wavelengths compared with the as-grown film. The properties of the Pt/porous-InGaN contact were uniform when annealed in the range of (300e500) oC with the smallest leakage current of 1.34 mA at 500 oC. Based on these results, the electrical characteristics of the Pt/porous-InGaN contact were enhanced at 500 oC. The fabricated MSM photodetector had a photovoltaic behavior with a responsivity that increased with increasing applied voltage. A faster 12 ms rise and 13 ms recovery times were obtained under a bias voltage of 0.5 V. The sensitivity of the device is directly proportional to the applied bias. Finally, the device showed high quantum efficiency at 1 V.

References
