Metal-Semiconductor-Metal Photodetector Based On Porous $In_{0.08}Ga_{0.92}N$

Saleh H. Abud, Z. Hassan, F. K. Yam

***Abstract*—**Characteristics of MSM photodetector based on a porous $In_{0.08}Ga_{0.92}N$ thin film were reported. Nanoporous structures of n-type $In_{0.08}Ga_{0.92}N$/AlN/Si thin films were synthesized by photoelectrochemical (PEC) etching at a ratio of 1:4 of HF:C_2H_5OH solution for 15min. The structural and optical properties of pre- and post-etched thin films were investigated. Field emission scanning electron microscope and atomic force microscope images showed that the pre-etched thin film has a sufficiently smooth surface over a large region and the roughness increased for porous film. Blue shift has been observed in photoluminescence emission peak at 300 K for porous sample. The photoluminescence intensity of the porous film indicated that the optical properties have been enhanced. A high work function metals (Pt and Ni) were deposited as a metal contact on the porous films. The rise and recovery times of the devices were investigated at 390nm chopped light. Finally, the sensitivity and quantum efficiency were also studied.

***Keywords*—**Porous InGaN, photoluminescence, SMS photodetector.

I. Introduction

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

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II. Experimental Procedure

In this work, we used commercial unintentionally doped n-type $In_{0.08}Ga_{0.92}N$/AlN grown on two inches diameter Si(111) substrate. The thickness of the InGaN thin film is 1μm. 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. Porous InGaN synthesized using the UV-PEC etching technique. The etching cell was made from Teflon with a platinum wire as a cathode and an InGaN wafer as an anode. The samples were then etched with 1:4 of HF (49%): C_2H_5OH (99.99%) solution under UV lamp illumination and a constant current density (25 mA/cm^2) for 15min. All experimental processes were conducted at room temperature. Field emission scanning electron microscope (FESEM, Model FEI Nova NanoSEM 450) and atomic force microscope (AFM, Model Dimension EDGE, BRUKER) were used to determine the surface morphology, whereas the optical properties of the thin films were investigated using photoluminescence spectroscopy system (PL, Model Jobin Yvon HR 800 UV). A high work function metals Pt and Ni contacts of 200nm thickness were deposited on the thin films using radio frequency-magnetron sputtering system and thermal evaporator for Pt and Ni, respectively.

III. Results and Discussion

Fig. 1 shows the FESEM image of the n-$In_{0.08}Ga_{0.92}N$ thin film grown on Si(111) substrate. In Fig. 1 (a) the image reveals that the thin film has sufficiently smooth surface and uniformity over a large region. Inset is the cross section of the film, in which the thickness of the $In_{0.08}Ga_{0.92}N$ thin film is 1μm with 0.1μm of AlN as a buffer layer. Fig. 1 (b) shows the top view FESEM image of the porous $In_{0.08}Ga_{0.92}N$ surface, the pores were very regular with sizes around 60-100nm.

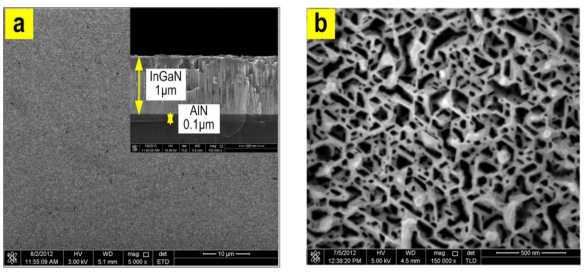

Fig. 1 FESEM image of the (a) pre-etching, (b) post-etching

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Fig. 2 (a) shows 3D-AFM image of the thin film grown on Si(111) with root mean square (RMS) roughness of 2.2nm, whereas Fig. 2 (b) reveals that the RMS roughness of the porous thin film increased to 200nm for porous film. This observation could be further supported by FESEM images shown in Fig. 1 (b).

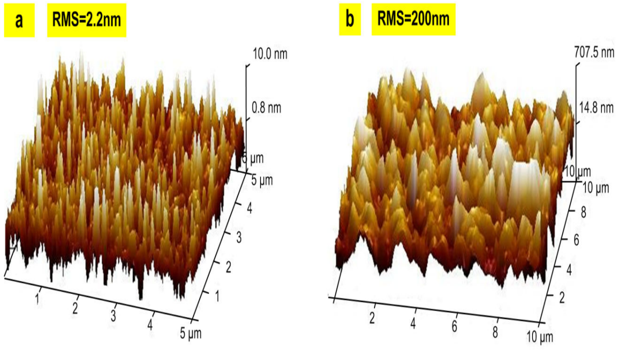

Fig. 2 AFM (3-D) views of the (a) pre-etching, (b) post-etching

Fig. 3 shows the PL spectra of the pre- and post-etched thin films. The PL intensity of the etched film increased with blue shift compared to the pre-etched film. Abud [14] also observed and reported similar blue shift.

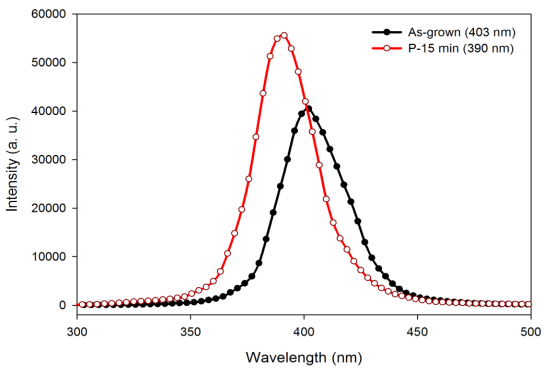

Fig. 3 PL spectra of the pre- and post etched InGaN

High porosity-induced PL intensity can be explained by the extraction of strong PL via light scattering from the sidewalls of the sample crystallites [15]. Porous film has higher surface area per unit volume compared with as-grown film, and thus, the porous InGaN provides much more exposure to the illumination of PL excitation lights for the as-grown molecules. This phenomenon may result in a higher number of electrons taking part in the excitation and recombination process in porous films compared with the smaller surface area of the as-grown films [16]. The energy gap increased from 3.08 eV for pre-etched thin film to 3.18 eV for the porous thin film. Thus, the energy gap has been shifted from the visible to the ultraviolet region of the electromagnetic spectrum. Fig. 4 (a) shows the time dependence of the photocurrent for the MSM photodetector based on porous InGaN with Ni contact under a bias voltage of 1 V and 390 nm chopped light. The detector has a good repeatability; however, the response duration following the fast growth in the beginning cannot approach to the saturation current. Mello et al. [17] reported the similar result, whereas Fig. 4 (b) shows one completed cycle, in which the rise time is 10 sec and the recovery time is 10 sec.

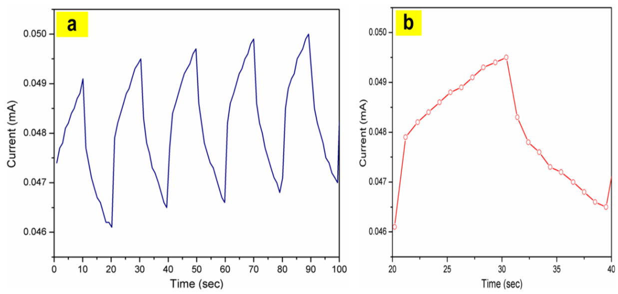

Fig. 4 (a) Photoresponse of the MSM photodetector based on porous InGaN with Ni at 390 nm, (b) one completed cycle (on-off switching)

Time dependence of the photocurrent for the device based on porous InGaN with Pt contact is shown in Fig. 5 (a). The photocurrent reaches to saturation value (1.68 mA) with a good photoconductivity and repeatability, whereas Fig. 5 (b) shows the one completed cycle. The rise and recovery times of the devices are summarized in Table I. The fast rise-time component of response is due to the electrons, because of their superior mobility [18]. From Figs. 4 and 5, it is observed that the device with Pt is more stable and repeat than that with Ni.

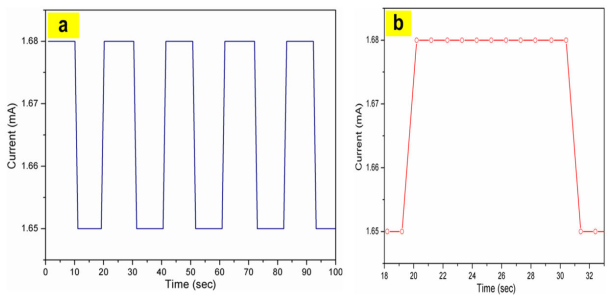

Fig. 5 (a) Photoresponse of the MSM photodetector based on porous InGaN with Pt at 390 nm, (b) one completed cycle (on-off switching)

The sensitivity (S) of fabricated detectors is given by [19]:

$$S(\%) = \frac{I_{light} - I_{dark}}{I_{dark}} \times 100 \quad (1)$$

where I_{dark} and I_{light} are the photocurrent in the dark and under illumination, respectively.

Quantum efficiency (η) is an important factor that estimates the photosensitive device performance. This factor is related to the number of electron-hole pairs that are excited by the absorbed photons and is given by [20]:

$$\eta = \frac{hc}{e\lambda} R, \quad (2)$$

where *h* is the Planck's constant, *c* is the velocity of light, *e* is the electron charge, λ is the wavelength of the incident light, and *R* is the spectral responsivity $\left[R = I_{light} / (A \cdot P_{opt})\right]$. The quantum efficiency value of the fabricated devices was listed in Table I.

TABLE I
RISE AND RECOVERY TIMES, SENSITIVITY (R) AND QUANTUM EFFICIENCY (H) OF THE FABRICATED DEVICES BASED ON POROUS FILM AT AN INCIDENT WAVELENGTH OF 390 NM

Device	Rise time (sec)	Recovery time (sec)	*S* (%)	η
With Ni	10	10	7.4	16.7
With Pt	0.82	0.82	1.8	51

IV. CONCLUSION

In summary, we demonstrated a 1-µm-thick layer of n-type $In_{0.08}Ga_{0.92}N/Si(111)$. The thin film has a sufficiently smooth surface with an RMS of 2.2nm. The porous nanostructures were synthesized using the UV-assisted electrochemical etching method. The roughness of the post-etched film was increased compared to the pre-etched film. Blue shift in the PL spectra changed the energy gap of the thin films from 3.08 eV for the pre-etched film to 3.18 eV for the etched film. By selecting appropriate etching factors, we can fabricate an optoelectronic devices that operate in both regions (UV and visible). The fabricated MSM photodetector based on porous thin film with Pt has a good photoconductivity and repeatability compared with that fabricated with Ni. This study pointed out that the potential application of electrically porous InGaN MSM photodetector can be expected in the future.

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REFERENCES

[1] Ž. Gačević, V. Gómez, N. G. Lepetit, P. Rodríguez, A. Bengoechea, S. F. Garrido, R. Nötzel, and E. Calleja, "A comprehensive diagram to grow (0001) InGaN alloys by molecular beam epitaxy," *Journal of Crystal Growth,* 2012.

[2] E. Monroy, F. Calle, J. L. Pau, E. Muñoz, F. Omnès, B. Beaumont, and P. Gibart, "Present Status of III-Nitride Based Photodetectors," *MRS Online Proceedings Library,* vol. 622, 2000.

[3] M.-L. Tu, Y.-K. Su, S.-J. Chang, and R. W. Chuang, "GaN UV photodetector by using transparency antimony-doped tin oxide electrode," *Journal of Crystal Growth,* vol. 298, pp. 744-747, 2007.

[4] S.-P. Chang, S.-J. Chang, C.-Y. Lu, Y.-Z. Chiou, R. W. Chuang, and H.-C. Lin, "Low-frequency noise characteristics of GaN-based UV photodiodes with AlN/GaN buffer layers prepared on Si substrates," *Journal of Crystal Growth,* vol. 311, pp. 3003-3006, 2009.

[5] F. Xie, H. Lu, X. Xiu, D. Chen, P. Han, R. Zhang, and Y. Zheng, "Low dark current and internal gain mechanism of GaN MSM photodetectors fabricated on bulk GaN substrate," *Solid-State Electronics,* vol. 57, pp. 39-42, 2011.

[6] Z. Hassan, Y. Lee, F. Yam, K. Ibrahim, M. Kordesch, W. Halverson, and P. Colter, "Characteristics of low-temperature-grown GaN films on Si (111)," *Solid state communications,* vol. 133, pp. 283-287, 2005.

[7] F. Yam and Z. Hassan, "Structural and optical characteristics of porous GaN generated by electroless chemical etching," *Materials Letters,* vol. 63, pp. 724-727, 2009.

[8] A. Ramizy, Z. Hassan, and K. Omar, "Porous GaN on Si(1 1 1) and its application to hydrogen gas sensor," *Sensors and Actuators B: Chemical,* vol. 155, pp. 699-708, 2011.

[9] F. Yam, Z. Hassan, and S. Ng, "Porous GaN prepared by UV assisted electrochemical etching," *Thin solid films,* vol. 515, pp. 3469-3474, 2007.

[10] L.-W. Ji, T.-H. Fang, S.-J. Young, C.-C. Liu, and Y.-L. Chai, "Characteristics of III-nitride photodiodes with self-assembled quantum dots," *Materials Letters,* vol. 61, pp. 1619-1621, 2007.

[11] K. Al-heuseen, M. R. Hashim, and N. K. Ali, "Enhanced optical properties of porous GaN by using UV-assisted electrochemical etching," *Physica B: Condensed Matter,* vol. 405, pp. 3176-3179, 2010.

[12] K. Beh, F. Yam, C. Chin, S. Tneh, and Z. Hassan, "The growth of III-V nitrides heterostructure on Si substrate by plasma-assisted molecular beam epitaxy," *Journal of Alloys and Compounds,* vol. 506, pp. 343-346, 2010.

[13] K. Al-Heuseen, M. R. Hashim, and N. K. Ali, "Effect of different electrolytes on porous GaN using photo-electrochemical etching," *Applied Surface Science,* vol. 257, pp. 6197-6201, 2011.

[14] S. H. Abud, Z. Hassan, and F. Yam, "Enhancement of Structural and Optical Properties of Porous In0. 27Ga0. 73N Thin Film Synthesized Using Electrochemical Etching Technique," *Int. J. Electrochem. Sci,* vol. 7, pp. 10038-10046, 2012.

[15] A. Vajpeyi, S. Tripathy, S. Chua, and E. Fitzgerald, "Investigation of optical properties of nanoporous GaN films," *Physica E: Low-dimensional Systems and Nanostructures,* vol. 28, pp. 141-149, 2005.

[16] S. Sze and K. K. Ng, "Metal-Semiconductor Contacts," *Physics of semiconductor devices,* vol. 2, pp. 245-311, 1981.

[17] M. Mello, M. De Vittorio, A. Passaseo, M. Lomascolo, and A. de Risi, "Optical system for CO and NO gas detection in the exhaust manifold of combustion engines," *Energy Conversion and Management,* vol. 48, pp. 2911-2917, 2007.

[18] Y. Tian, S.-J. Chua, and H. Wang, "Theoretical study of characteristics in GaN metal–semiconductor–metal photodetectors," *Solid-State Electronics,* vol. 47, pp. 1863-1867, 2003.

[19] M. A. Mahdi, J. J. Hassan, S. S. Ng, Z. Hassan, and N. M. Ahmed, "Synthesis and characterization of single-crystal CdS nanosheet for high-speed photodetection," *Physica E: Low-dimensional Systems and Nanostructures,* vol. 44, pp. 1716-1721, 2012.

[20] L. Li, P. Wu, X. Fang, T. Zhai, L. Dai, M. Liao, Y. Koide, H. Wang, Y. Bando, and D. Golberg, "Single-Crystalline CdS Nanobelts for Excellent Field-Emitters and Ultrahigh Quantum-Efficiency Photodetectors," *Advanced Materials,* vol. 22, pp. 3161-3165, 2010.