Asian Journal of Chemistry; Vol. 25, No. 4 (2013), 2080-2082

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2013.13329

Internal Gain of InGaN/GaN Metal-Insulator-Semiconductor Photodetector

HAO LUO, KAI-XIAO ZHANG*, AI-BIN MA, JING-HUA JIANG, HAI-YAN XIE, JIANG-FENG GONG, HUA ZOU and WEI-HUA ZHU

College of Science, College of Mechanics and Materials, Hohai University, P.R. China

*Corresponding author: E-mail: kxzhang@126.com

(*Received*: 24 December 2011; *Accepted*: 12 October 2012) AJC-12284

In this paper, an InGaN/GaN metal-insulator-semiconductor photodetector with an ultra-thin Al_2O_3 insulation layer deposited by atomic layer deposition was studied. The high photoelectric responsivities of 0.31 and 0.27 A/W from the GaN and InGaN layer respectively and a spectral responsivity rejection ratio of about three orders of magnitude at 1 V reverse bias were achieved for this metal-insulator-semiconductor photodetector. The internal gain of the InGaN/GaN metal-insulator-semiconductor photodetectors measured at different reverse bias. The results indicate that the internal gain of the InGaN/GaN metal-insulator-semiconductor photodetector was 3.5 at 350 nm, 2.7 at 380 nm and the bias voltage at -3V.

Key Words: InGaN/GaN, Photodetector, Metal-insulator-semiconductor, The internal gain.

INTRODUCTION

$In_{1-x}Ga_xN$ alloys are excellent candidates for photodetectors in the range of ultraviolet to visible light region due to their adjustable bandgap energies, high theoretical responsivity and high radiation hardness[1]. However, few researches have been reported on InGaN photodetectors because of the difficulty in fabricating high-quality InGaN films on the GaN layer, especially with high in composition[2-4]. First, *p*-type doping of InGaN still remains a big challenge due to the high *n*-type background carrier concentration and strong surface electron accumulation[5]. Furthermore, the presence of a high density of surface states also makes another challenge in obtaining high quality Schottky contacts[6,7]. Therefore, the researches on InGaN photodetectors based on *p-n* junctions or Schottky contacts are seriously restricted. The current development status of InGaN semiconductor materials remains a chance for the development of the InGaN photodetector based on metal-insulator-semiconductor (MIS) structure. In this structure, a very thin insulating layer with thickness of 1-3 nm is inserted between the metal contact and the semiconductor. The metal-insulator-semiconductor structure can increase the effective barrier height and hence can reduce the leakage current[3,8].

In this work, we aim to develop high performance InGaN/GaN photodetectors. To realize this purpose, a high-qulity Al_2O_3 dielectric layer deposited by atomic layer deposition technique is introduced as an insulation layer between the metal contact and InGaN film. The current transport mechanisms and photoelectric responsivity of the InGaN/GaN metal-insulator-semiconductor photodetector were investigated.

EXPERIMENTAL

InGaN/GaN samples under investigation were grown by metal-organic chemical vapour deposition on (0001) sapphire substrates. Trimethylgallium, trimethylindium and ammonia were used as the precursors. The samples consisted of a 30-nm-thick low-temperature GaN buffer layer deposited at 500 ºC, a 2.0-μm-thick high-temperature GaN layer deposited at 1050 ºC and a 120-nm-thick unintentionally doped InGaN layer deposited at 750 ºC. After a mesa structure with an active area of 0.5 × 0.5 mm^2 was formed by etching, Ti/Al/Ni/Au (20/120/30/50 nm) layers were deposited on the GaN layer by using e-beam evaporation as the ohmic contact and then annealed at 800 ºC for 30 sec in a flowing N_2 atmosphere. A 3-nm-thick Al_2O_3 dielectric was deposited by atomic layer deposition at 250 ºC with 30 cycles in a Picosun Sunaletm R-150 B system equipped with trimethylaluminium and water as precursors and N_2 as a carrier and a purge gas. In each cycle, the time sequence for the trimethylaluminium pulse, the first purge, the water pulse and the second purge was 0.1, 4, 0.1 and 4 s, respectively and the pressure was 1000 Pa. Finally, a Ni/Au (30/80 nm) finger electrode was deposited by e-beam evaporation on the insulating layer in the mesa structure. The spectral response was carried out using a standard lock-in detection technique with the light source of a 500 W Xe arc lamp and a calibrated monochromator. The power of the monochromatic light was measured with a calibrated silicon photodiode.

RESULTS AND DISCUSSION

Fig. 1 shows the (105) asymmetric plane X-ray diffraction 2θ-ω scan of the InGaN/GaN sample. High-resolution X-ray diffraction is a particular method to determine the lattice constants of thin films, the change of peak position is considered to relate the change of lattice constant, consequently the composition can be deduced according to the Vegard's law:[9]

$$a_{InGaN} = xa_{InN} + (1-x)a_{GaN} \quad (1)$$

where, a_{InGaN}, a_{InN} and a_{GaN} is the lattice constant of InGaN, InN and GaN, respectively. The indium composition (x) of the InGaN layer was determined to be about 18 % (Fig. 1).

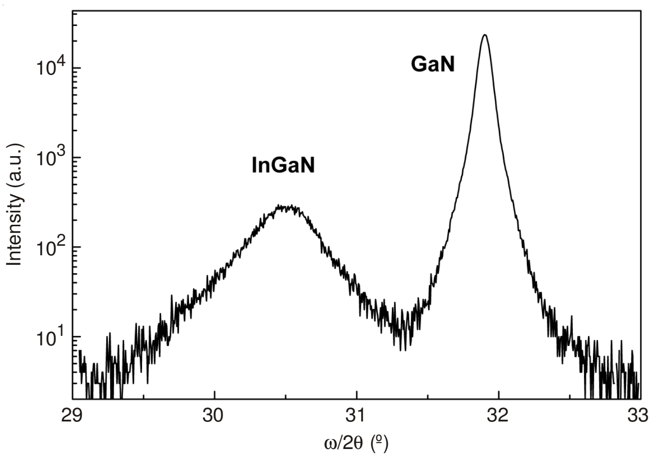

Fig. 1. (105) Asymmetric plane HRXRD 2θ-ω scan of the InGaN sample

Fig. 2 shows the spectral responsivities of the InGaN/GaN metal-insulator-semiconductor photodetectors measured at 1V reverse bias. In Fig. 2, the response spectra have two steps with the cutoff wavelengths at 365 and 428 nm, respectively, from the GaN and InGaN layer. The measured peak responsivities from the GaN and InGaN layers are 0.31 and 0.27 A/W, respectively, at 1 V reverse bias and the rejection ratio of the spectral responsivity from the InGaN layer is near three orders of magnitude. This ultra-thin Al_2O_3 insulation layer deposited by atomic layer deposition allows a higher responsivity for the InGaN metal-insulator-semiconductor photodetector compared to other insulation layers such as Si_3N_4 and SiO_2 where relatively thick insulators, 10-nm-thick Si_3N_4 and 88-nm-thick SiO_2 respectively, were employed[2,4]. The thinner the insulation layer is, the smaller fraction of bias voltage drops across the insulator layer. So the metal-insulator-semiconductor photodetectors with ultra-thin insulator layer can work effectively in a small reverse bias. The small bias may reduce the probability of local tunneling, which is the most-common conduction mechanism through insulators under high fields. Meanwhile, the ultra-thin insulation layer has a higher light transmittance that increases the photoelectric response of the metal-insulator-semiconductor photodetectors.

The internal gain, which is defined as the ratio between the number of electrons collected per unit time and the number of absorbed photons per unit time,can be expressed as[10,11]:

$$g = \frac{Rhc}{q\lambda\eta} \quad (2)$$

where, R is the responsivity, η is the quantum efficiency of the photodetector, for simplicity, that η = 1, λ, h, c and q are the UV light wavelength, the Plank constant, the speed of light and the electron charge, respectively. The internal gain of the InGaN/GaN metal-insulator-semiconductor photodetectors measured at different reverse bias. Fig. 3 shows the internal gain of the InGaN/GAN metal-insulator-semiconductor photodetector measured at -1 V, -2 V and -3 V bias. The results indicate that the internal gain of the InGaN/GaN metal-insulator-semiconductor photodetector was 3.5 at 350 nm, 2.7 at 380 nm and the bias voltage at -3 V.

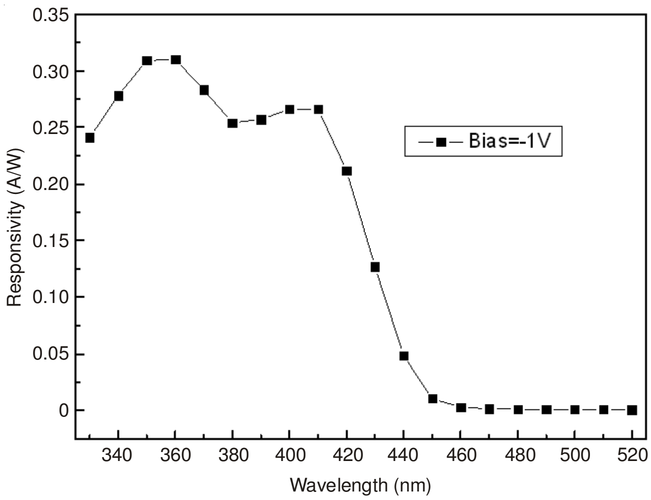

Fig. 2. Spectral responsivity of the InGaN metal-insulator-semiconductor photodetector measured at 1V reverse bias

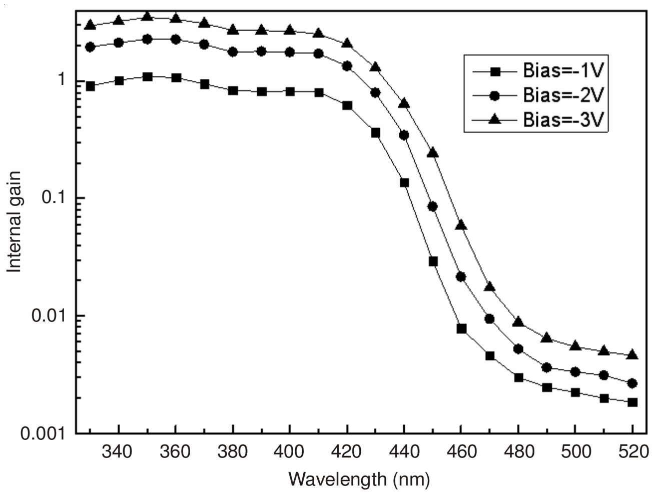

Fig. 3. Internal gain of the InGaN metal-insulator-semiconductor photodetector measured at different reverse bias

Conclusion

In summary, the photoelectric responsivity and internal gain of the InGaN/GaN metal-insulator-semiconductor photodetectors with the Al_2O_3 insulating layer have been investigated. The results show that the InGaN/GaN metal-insulator-semiconductor photodetector have high photoelectric responsivities of 0.31 and 0.27 A/W at 1 V reverse bias and a spectral responsivity rejection ratio of about three orders of magnitude. The internal gain of the InGaN metal-insulator-semiconductor photodetector was 3.5 at 350 nm, 2.7 at 380 nm and the bias voltage at -3 V.

ACKNOWLEDGEMENTS

This work was supported by the Fundamental Research Funds for the Central Universities (B1020270), the national innovation experiment program for university students, the promotion program for Scientific Research Industrialization of Colleges and University by Educational Commission of Jiangsu Province of China (JHZD09-3), the Program for Transformation and Industrialization of Scientific and Technological Achievements in the industrial field by Changzhou city of Jiangsu Province of China (CC20100004).

REFERENCES

1. J. Wu, W. Walukiewicz, K.M. Yu, J.W. Ager III, E.E. Haller, H. Lu, W.J. Schaff, Y. Saito and Y. Nanishi, *Appl. Phys. Lett*., **80**, 3967 (2002).
2. P.C. Chang, C.H. Chen, S.J. Chang, Y.K. Su, P.C. Chen, Y.D. Jhou, C.H. Liu, H. Hung and S.M. Wang, *Jpn. J. Appl. Phys., Part 1*, **43**, 2008 (2004).
3. D.J. Chen, B. Liu, H. Lu, Z.L. Xie, R. Zhang and Y.D. Zheng, *IEEE Elect. Device Lett.*, **30**, 605 (2009).
4. J.J. Zhou, B. Wen, R.L. Jiang, C.X. Liu, X.L. Ji, Z.L. Xie, D.J. Chen, P. Han, R. Zhang and Y.D. Zheng, *Chinese Phys.*, **16**, 2120 (2007).
5. T.D. Veal, P.H. Jefferson, L.F.J. Piper, C.F. McConville, T.B. Joyce, P.R. Chalker, L. Considine, H. Lu and W.J. Schaff, *Appl. Phys. Lett*., **89**, 202110 (2006).
6. S.X. Li, K.M. Yu, J. Wu, R.E. Jones, W. Walukiewicz, J.W. Ager III, W. Shan, E.E. Haller, H. Lu and W.J. Schaff, *Phys. Rev. B*, **71**, 161201-1 (2005).
7. D.J. Chen, Y. Huang, B. Liu, Z.L. Xie, R. Zhang and Y.D. Zheng, *J. Appl. Phys*., **105**, 061734 (2009).
8. V. Adivarahan, G. Simin, J.W. Yang, A. Lunev, M.A. Khan, N. Pala, M. Shur and R. Gaska, *Appl. Phys. Lett*., **77**, 863 (2000).
9. R. Singh, D. Doppalapudi, T.D. Moustakes and L.T. Romano, *Appl. Phys. Lett*., **72**, 1089 (1998).
10. C. Soci, A. Zhang, B. Xiang, S.A. Dayeh, D.P.R. Aplin, J. Park, X.Y. Bao, Y.H. Lo and D. Wang, *Nano Lett.*, **7**, 1003 (2007).
11. J.S. Liu, C.X. Shan, B.H. Li, Z.Z. Zhang, C.L. Yang, D.Z. Shen and X.W. Fan, *Appl. Phys. Lett.*, **97**, 251102 (2010).