Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp514-515

Nitride-based MSM Photodetectors with InN/GaN Multiple Nucleation Layers

C. H. Chen, H. J. Chien, K. R. Wang, S. Y. Tsai, and S. L. Wu

Cheng Shiu University, Department of Electronic Engineering
Kaohsiung County 833, Taiwan R.O.C
Phone: +886-7-7310606-3216, E-mail: chchen@csu.edu.tw

1. Introduction

Recently, nitride-based materials have attracted much attention with large direct bandgap energy and high saturation electron drift velocity. Nitride-based laser diodes (LDs), light-emitting diodes (LEDs) and ultraviolet (UV) photodetectors (PDs) prepared by metalorganic chemical vapor deposition (MOCVD) have all been successfully commercialized [1-3]. For PD applications, various types of GaN-based PDs have been reported [4-5]. Among them, GaN-based metal-semiconductor-metal (MSM) PDs can be operated with high speed. To achieve high performance MSM PDs, it is important to achieve a high Schottky barrier height at the metal-semiconductor (MS) interface. A large barrier height can lead to small leakage current and high breakdown voltage which could result in improved responsivity and photocurrent to dark current ratio. It is known that leakage current at MS interface depends strongly on the quality of the semiconductor. For GaN prepared on sapphire substrates, dislocation density is quite high due to the large mismatches in lattice constant and thermal expansion constant between GaN epitaxial layer and sapphire substrate. Conventional method to overcome this problem is to deposit a thin low-temperature (LT) GaN nucleation layer prior to the epitaxial growth. However, the resultant dislocation density still remains unacceptably large. It has been reported that one can reduce the defect density in nitride-based epitaxial layer using GaN/SiN or MgN/GaN as the nucleation or buffer layer [6, 7]. InN/GaN double layer is always used in multiple quantum well (MQW) [8] and its crystal quality seems as same as GaN/SiN and MgN/GaN. With such the InN/GaN multiple layer, we should be able to reduce the number of leakage current paths at metal/GaN interface and thus improve the performance of GaN-based MSM PDs. In this study, we report the fabrication of GaN MSM PDs with a 10-pairs of InN/GaN multiple nucleation layer. The optical and electrical properties of the fabricated MSM PDs will be discussed. Noise characteristics of these devices will also be analyzed.

2. Experimental and Result Discussions

The GaN-based MSM photodetectors in this experiment were all epitaxial grown on c-face (0001) sapphire substrates by metalorganic chemical vapor deposition (MOCVD) system. Before epitaxial growth, the sapphire substrates were annealed at 1150℃ in H_2 ambient to remove surface contamination. A 10-pair of InN/GaN multiple nucleation layers was deposited as 550 ℃. For the growth of InN and GaN multiple nucleation layers, trimethylgallium (TMGa), trimethylindium (TMIn), and NH_3 were used as source materials. When the 10-pairs of InN/GaN multiple nucleation layers was grown, the growth times of the InN and GaN were 80 and 25 sec, respectively. The thickness of InN and GaN layer were 1.2 and 2.3 nm, respectively. After the nucleation layer was grown, the temperature was raised to 1060℃ to grow a 3-μm-thick unintentionally doped GaN epitaxial layer with a growth rate of 2μm/h. For comparison, conventional LT-GaN nucleation layer was also grown. The growth time of the single LT-GaN nucleation layer was set to 380 sec so as to achieve a LT-GaN layer thickness of 35nm. The GaN grown on 10-pairs of InN/GaN multiple nucleation layer and LT-GaN layer were labeled as samples A and B, respectively. The MSM PDs were then fabricated. Ni/Au (3/7 nm) contact electrodes were subsequently deposited onto the samples. The contacts of the device form two inter-digitated contact electrodes. The fingers of the contact electrodes were 10 μm wide and 150 μm long with a spacing of 10 μm.

Figure 1 shows room temperature current-voltage (I-V) characteristics of the fabricated MSM PDs measured by an HP4156 semiconductor parameter analyzer in dark and under illumination, respectively. With 5 V applied bias, it was found that leakage current of sample A was 8.85×10^{-9}A while that of sample B was only around 1.86×10^{-8}A. The much smaller leakage current observed from sample A should be attributed to reduced threshold dislocation density by the use of 10 pair InN/GaN multiple nucleation layer. With a 5V applied bias, it was found that photocurrent measured from samples A and B was both around 1.6×10^{-6}A. With a much smaller dark current, we thus achieved a much larger photocurrent to dark current ratio from sample A, as compared to sample B.

The spectral response of sample A and B were shown in Fig.2. It can be seen that cutoff occurred at around 360 nm for both samples. With incident light of 360 nm and an applied bias of 3V, it was found that the measured responsivity of sample A was 0.202 A/W while that of sample B was around 0.194 A/W. Here, we defined UV to visible rejection ratio as the responsivity measured at 360 nm divided by that at 450 nm. With 3 V applied bias, it was found that UV to visible rejection ratios were 4.16×10^{2} and 4.76×10^{1} for sample A and B, respectively. This finding indicate an

enhancement of UV to visible rejection ratio as result of inserting a 10-pairs InN/GaN multiple nucleation layer into the photodetectors.

Figure 3 shows noise power spectra measured at room temperature for sample A and B, respectively. It was found that spectra measured from both samples could be fitted reasonably well by 1/f law. This indicates that the noise power observed in our devices is dominated by carrier number [9] and/or mobility fluctuations [10] due to trapping-detrapping, which is strongly related to the dislocation density in the samples. With the same applied bias and under the same frequency, it was found that noise power density measured from sample A was at least one to two orders of magnitudes smaller than that measured from sample B. The much smaller noise power density should again be attributed to the effective suppression of dislocation density by the 10-pairs InN/GaN multiple nucleation layer.

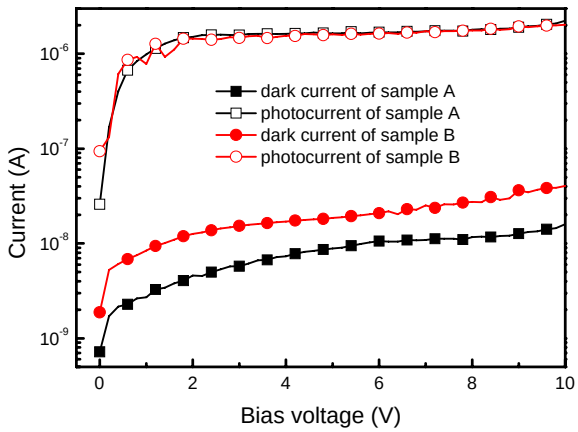

Fig. 1 I-V characteristics of the two fabricated MSM PDs measured in dark and under illumination.

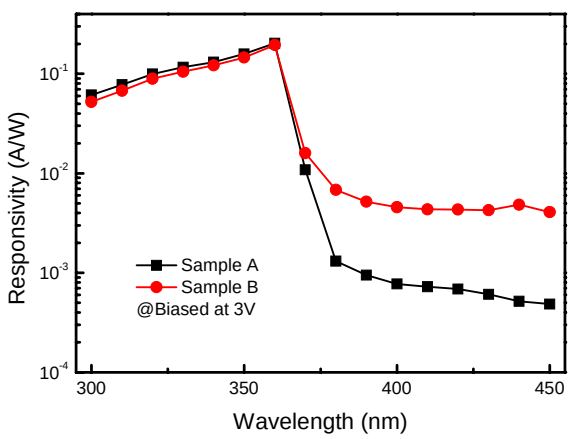

Fig. 2 The spectral response of the two MSM-PDs.

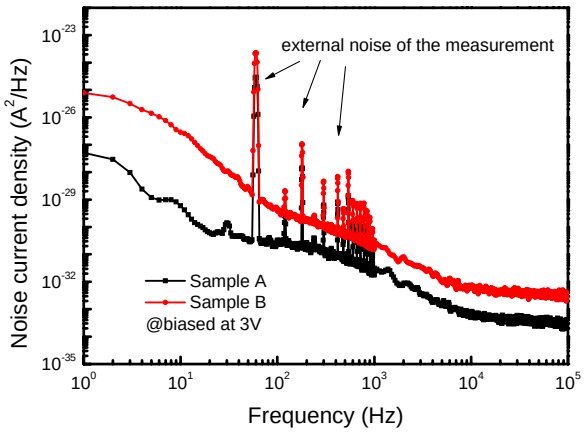

Fig. 3 Noise power spectra measured at room temperature for the two fabricated photodetectors.

3. Conclusions

In summary, GaN MSM UV photodetectors with InN/GaN multiple nucleation layer were fabricated and characterized. In the section of InN/GaN multiple nucleation layer, compared with the GaN MSM photodetector with conventional single LT-GaN nucleation layer, it was found that we can achieve much smaller dark current and much larger photocurrent to dark current contrast ratio from the proposed device. We also achieved much larger UV to visible rejection ratio from the photodectors with InN/GaN multiple nucleation layer. Furthermore, it was also found that we can significantly reduce noise current density by using this InN/GaN multiple nucleation layers.

Acknowledgements

This work was financially supported by National Science Council under contract NSC 95-2221-E-230-026.

References

[1] J. I. Pankove, *Mater. Res. Soc. Symp. Proc.* **162** (1990) 515.
[2] E. F. Shubert and J. K. Kim, *Science* **308** (2005) 1274.
[3] E. Monroy, T. Palacios, O. Hainaut, F. Omnes, F. Calle, and J. F. Hochedez, *Appl. Phys. Lett.* **80** (2002) 3198.
[4] C. J. Collins, U. Chowdhury, M. M. Wong, B. Yang, A. L. Beck, R. D. Dupuis, and J. C. Campbell, *Appl. Phys. Lett.* **80** (2002) 3754.
[5] M. Razeghi and A. Rogalski, *J. Appl. Phys.* **79** (1996) 7433.
[6] T. Kachi, K. Tomita, K.Itoh, and H. Trando, *Appl. Phys. Lett.* **72** (1998) 704.
[7] C. J. Tun, C, H, Kuo, Y. K. Fu, C. W. Kuo, C. J. Pan and, G. C. Chi, *Appl. Phys. Lett.* **90** (2007) 212109.
[8] W. C. Lai, S. J. Chang, M. Yokoyama, J. K. Sheu, and J. F. Chen, *IEEE Photo. Technol. Lett.* **13** (2001) 559.
[9] B. H. Leung, W. K. Fong and C. Surya, *Optical Materials* **23** (2003) 203.
[10] S. R. Morrison, *J. Appl. Phys.* **72** (1992) 4104.