Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 538-539

P-7-6

GaN Metal-Semiconductor-Metal Photodetectors with an un-activated Mg-doped GaN Cap Layer

P. C. Chang[1], Y. C. Wang[2], K. H. Lee[2], C. L. Yu[2], and S. J. Chang[2]

[1] Department of Electronic Engineering, Nan Jeon Institute of Technology
No. 178, Chau-Chin Road, Yen-Hsui, Tainan County 737, Taiwan, ROC
Phone: +886-6-6523111Ext. 153 E-mail: ping@mail.njtc.edu.tw
[2]Institute of Microelectronics and Department of Electrical Engineering, National Cheng Kung University
No. 1, University Road, Tainan 701, Taiwan, ROC

1. Introduction

Nitride-based semiconductor materials have excellent optical and electrical properties. Recently, nitride-based light emitting diodes (LEDs) have been successfully commercialized. Nitride-based materials are also potentially useful for high sensitive visible-blind ultraviolet photodetectors (PDs) due to their large direct band-gap and good chemical stability. In the last few years, various types of nitride-based UV PDs have been reported [1-3]. Among them, metal-semiconductor-metal (MSM) PDs offer various attractive advantages, such as high speed and low capacitance. The fabrication processes of MSM PDs are also compatible with field effect transistor (FET) based electronics. Thus, MSM structure can be used easily in opto-electronic-integrated circuits (OEICs) [4]. However, the large differences in lattice constant and thermal expansion coefficient between GaN and sapphire inevitably lead to high dislocation density in the GaN epitaxial layer. Thus, the leakage current in GaN-based Schottky barrier PDs is large in general. To reduce the leakage current, we can adopt metal-insulator-semiconductor (MIS) structure. Without activation, it is known that Mg-doped GaN is considered highly resistive ($>10^6\,\Omega$-cm) owing to compensation for residual donors [5]. Hence, we believe this semi-insulating layer can served as a semi-insulator and help in suppressing the leakage current. In this study, we report the fabrication of GaN MSM PDs with and without the in-situ grown un-activated Mg-doped GaN.

2. Experiments

In this work, two different MSM structures were grown on c-face (0001) sapphire substrates by metal-organic chemical vapor deposition (MOCVD). Sample_A consisted of a 30-nm-thick low-temperature GaN nucleation layer, a 2-μm-thick Si-doped GaN layer serving as a buffer layer, a 0.3-μm-thick un-intentionally doped GaN active layer, and a 30-nm-thick un-activated Mg-doped GaN cap layer. For comparison, samples without an un-activated Mg-doped GaN cap layer (i.e., sample_B) were also prepared. Then, MSM PDs were fabricated based on these two samples by standard photolithography and liftoff. Ni/Au (40nm/100nm) contact electrode was deposited onto sample_A and sample_B by thermal evaporation. The fingers of the contact electrodes were 14μm wide and 100μm long with 6μm spacing. The active area of the fabricated PDs was 100μm×234μm. An HP 4145 semiconductor parameter analyzer was then used to measure room temperature current-voltage (I-V) characteristics of the fabricated PDs both in dark and under illumination. For responsivity measurements, a Xe lamp and a monochromator were used. The monochromatic light was collimated onto the PDs using an optical fiber.

3. Results and Discussions

Figure 1 shows measured dark I-V characteristics of the two PDs. We observed that the dark current of sample_A was smaller than that of sample_B. It was also found that the dark current was near a constant of around 1×10^{-10} A for sample_A. In contrast, dark current of sample_B increased rapidly as the bias increased. This could be attributed to a thicker and higher potential barrier as a result of inserting a semi-insulating Mg-doped GaN cap layer into the photodetector (i.e., sample_A). It is also possible that the detrimental effect of interface states situated near the metal-semiconductor interface [6] was less pronounced on sample_A, owing to the insertion of semi-insulating Mg-doped GaN cap layer. In other words, it is also possible that the reduced leakage dark current can be attributed to the effective surface passivation. Using simple thermionic emission theory, it can be found that the effective Schottky barrier heights were 0.86eV and 0.8eV for sample_A and sample_B, respectively. The larger effective Schottky barrier height observed for sample_A could again be attributed to the insertion of an un-activated Mg-doped GaN layer.

Figure 2 shows room temperature spectral responses of both fabricated PDs under 5V applied bias. It can be seen clearly that the photoresponses exhibited sharp cut-off at 360nm for both PDs. Such a spectral response is typical of the visible-blind UV PDs. We also found that the responsivity for sample_A is smaller than that for sample_B under the same applied bias. This result is probably due to the fact that the photogenerated carriers were compensated by deep level related trap states in the semi-insulating Mg-doped GaN cap layer. With 5V applied bias and an incident light wavelength of 360nm, the measured responsivities were 0.038 and 0.57A/W for sample_A and sample_B, respectively. However, it decreased to 5.34×10^{-5} and 2.36×10^{-3}A/W for sample_A and sample_B, respectively, when the light wavelength was increased to 400nm. Here, we define UV to visible rejection ratio as the responsivity measured at 360nm divided by the responsivity measured at 400nm. With such a definition, we found that UV to visible rejection ratios under 5V applied bias were 7.11×10^2 and 2.41×10^2 for sample_A and sample_B, respectively. The findings indicate an enhancement of UV to visible rejection ratio as a result of inserting a semi-insulating Mg-doped GaN cap layer into the photodetector.

4. Conclusions

In summary, nitride-based MSM UV PDs with and without the semi-insulating Mg-doped GaN cap layers were both fabricated and characterized. In conclusion, the benefits of enhancing the Schottky barrier height, suppressing the dark current and maximizing UV to visible rejection ratio can all be achieved via the insertion of a semi-insulating Mg-doped GaN cap layer into the nitride-based photodetector.

Acknowledgements

This work was supported by the National Science Council under contract number NSC 95-2221-E-232-004.

References

[1] N. Biyikli, I. Kimukin, O. Aytur, and E. Ozbay, *IEEE Photon. Technol. Lett.* **16** (2004) 1718.

[2] T. K. Ko, S. J. Chang, Y. K. Su, M. L. Lee, C. S. Chang, Y. C. Lin, S. C. Shei, J. K. Sheu, W. S. Chen, and C. F. Shen, *J. Cryst. Growth* **283** (2005) 68.

[3] C. L. Yu, C. H. Chen, S. J. Chang, and P. C. Chang, *J. Electrochem. Soc.* **154** (2007) J71.

[4] D. L. Rogers, *J. Lightwave Technol*. **9** (1991) 1635.

[5] N. Nagai, Q. S. Zhu, Y. Kawaguchi, K. Hiramatsu, and N. Sawaki, *Appl. Phys. Lett.* **73** (1998) 2024.

[6] E. H. Rhoderick and R. H. Williams, *Metal-Semiconductor Contacts* (1988) ch. 1.

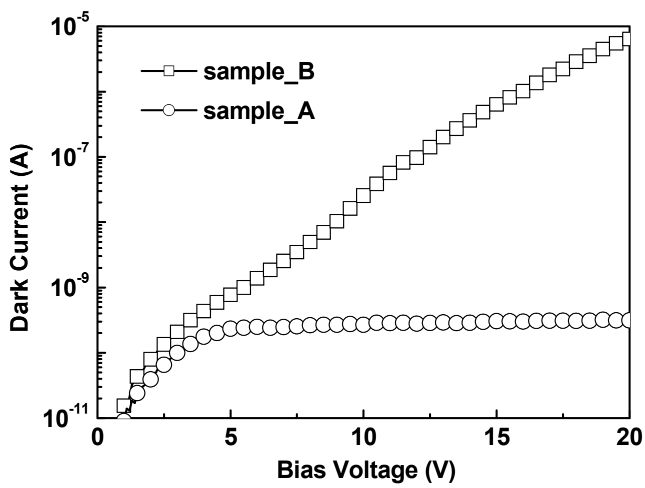

Figure 1 Room temperature dark I-V characteristics of sample_A and sample_B.

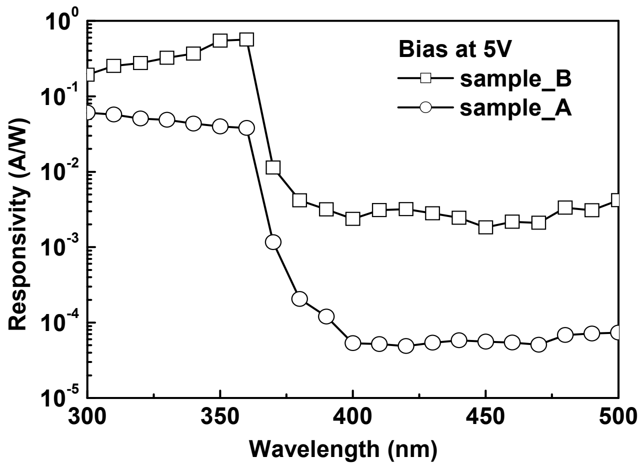

Figure 2 Room temperature spectral responses of sample_A and sample_B under 5V bias.