Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 556-557

P-7-15

GaN Ultraviolet MSM Photodetectors by capping a Low-Temperature AlN Layer

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1. Introduction

Ultraviolet (UV) photodetectors (PDs) have a wide range of commercial applications, such as engine monitoring, UV calibration devices, flame sensors, and space-based optical communications. GaN-based compounds are the perfect choice for the fabrication of various UV detectors owing to their direct and wide bandgap. Among the different types of UV detectors, the metal-semiconductor-metal (MSM) photodetector is a promising candidate due to its ease of fabrication and integration with field-effect transistor (FET)-based preamplifiers. However, the large differences in the lattice constant and thermal expansion coefficient of GaN and sapphire inevitably lead to high dislocation density in GaN epitaxial layer and the leakage path then form, causing large dark leakage current [1]. To our knowledge, Ga_2O_3 and SiO_2 could be used to reduce leakage current in nitride-based devices to employ an insulating gate layer by adopting a metal-insulator-semiconductor (MIS) structure [2]. But these insulators were all deposited *ex-situ* so that contamination might occur at the insulator/semiconductor interface during process. Thus we try to develop an *in-situ* grown, low-temperature (LT) cap layer into a GaN-based PD as a good insulator aiming to reduce the leakage current.

Recently, it has been shown that one can use a LT-GaN layer to reduce leakage current of MSM PDs [3]. However, it was also found that detector responsivity decreased slowly as the wavelength of the incident light increased from UV to visible region because of the absorption of defect levels within the band-gap of LT-GaN cap layer. Therefore, UV to visible rejection ratio of the PDs with LT-GaN cap layer became significantly smaller. Instead of LT-GaN, we adopt the LT-AlN to solve this problem. With a much larger band-gap (i.e. 6.2eV), below band-gap absorption of LT-AlN should be less significant in the visible region. Besides, its high dielectric constant (ε=9.14), good thermal conductivity, and large breakdown electric field, making it very suitable to serve as a good insulator to block the leakage current. In this study, we report the fabrication of GaN-based MSM PDs with and without the *in-situ* grown LT-AlN cap layer. A detailed study on the material and electrical properties of these PDs will also be discussed.

2. Experiment

Samples used in this study were grown using a metalorganic chemical vapor deposition (MOCVD). A sapphire c-plane (0001) substrate with a two-inch size was used for the growth. Trimethylgallium (TMGa), trimethylaluminium (TMAl), and ammonia (NH_3) were used for source gases of the GaN and AlN growth. First, a 30nm low-temperature thin GaN nucleation layer was deposited onto the sapphire substrate. Subsequently, we grew a 2-μm-thick Si-doped GaN layer served as buffer layer, and a 0.3-μm-thick unintentionally doped GaN active layer ($n \sim 10^{17} cm^{-3}$), followed by a 30-nm-thick LT-AlN cap layer grown at 600°C (i.e., PD_A). For comparison, samples without the LT-AlN cap layer (i.e., PD_B) were also prepared.

MSM PDs were then fabricated based on these two samples. MSM structures with finger width and spacing of 14 and 6 μm, respectively, and an active area of 100×234 μm^2, were patterned on the surface of the samples using conventional photolithography and liftoff technique. The MSM electrodes consist of semi-transparent Ni/Au (40 nm/100 nm) for forming Schottky contacts. Figure 1 shows the cross-sectional diagram of PD_A. Room temperature current-voltage (I-V) characteristics of the fabricated PDs were then measured by an HP4145 semiconductor parameter analyzer. Spectral responsivity of these MSM PDs was measured using a Xe arc lamp and a calibrated monochromator as the light source. The monochromatic light was collimated onto the fabricated PDs using an optical fiber.

3. Results and Discussions

Figure 2 shows room temperature dark I-V characteristics for PD_A and PD_B. It can be seen that dark leakage current of PD_A was smaller than that observed from conventional MSM-PD (i.e., PD_B). With a -2 V applied bias, it was found that the dark leakage currents were 2.32×10^{-12} and 2.19×10^{-10} A for the PD_A and PD_B, respectively. That is, we could reduce reverse leakage current by around two orders of magnitude. This might be attributed to a thicker and higher potential barrier as result of inserting a LT-AlN cap layer into the photodetector. It is also possible that the LT-AlN cap layer can passivate and block the leakage current paths, i.e., the surface termination of threading dislocations.

Figure 3 shows room temperature spectral responses of the both fabricated MSM PDs. From the spectral response curves, sharp cut-off at 360nm for both PDs is typical for the visible-blind UV PDs. With an incident light wavelength of 360 nm, it was found that measured responsivities were 0.22 and 0.53 A/W for the PD_A and PD_B, respectively. The smaller responsivity for PD_A could be attributed to the trapping effect of the photo-generated carriers by the deep level centers [4] occurred in LT-AlN layer, reducing the photoresponses. Nevertheless, it was also found that responsivity in the long wavelength stop band was much smaller for PD_A than for PD_B. Such a result can be attributed to smaller dark current and agrees well with the dark I-V result obtained from Figure 2. Although above-mentioned findings point out that the smaller responsivity for the PD_A with a LT-AlN cap layer than that for PD_B, we could be able to enhance the UV to visible rejection ratio by inserting a LT-AlN cap layer into the photodetector. Here, we define UV to visible rejection ratio as the responsivity measured at 360nm divided by the responsivity measured at 400nm. With a -5V applied bias, it was found that UV to visible rejection ratios were 7.26×10^2 and 2.10×10^2 for PD_A and PD_B, respectively. This indicates that we can achieve better UV to visible rejection ratio MSM PDs by inserting a LT-AlN cap layer. Therefore, the above-mentioned results prove that we can suppress the dark leakage current and enhance UV to visible rejection ratio by capping a LT-AlN layer onto GaN surface.

4. Conclusions

In conclusion, a novel GaN-based UV MSM PDs with LT-AlN cap layer was fabricated, and good device characteristics were observed. It was found that LT-AlN cap layers could effectively suppress dark current of the PDs and result in improved device characteristics. This is primarily due to the thicker and higher potential barrier and surface passivation when the LT-AlN cap layer was inserted. We also achieved larger UV to visible rejection ratio from the PDs with LT-AlN cap layers.

Acknowledgements

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

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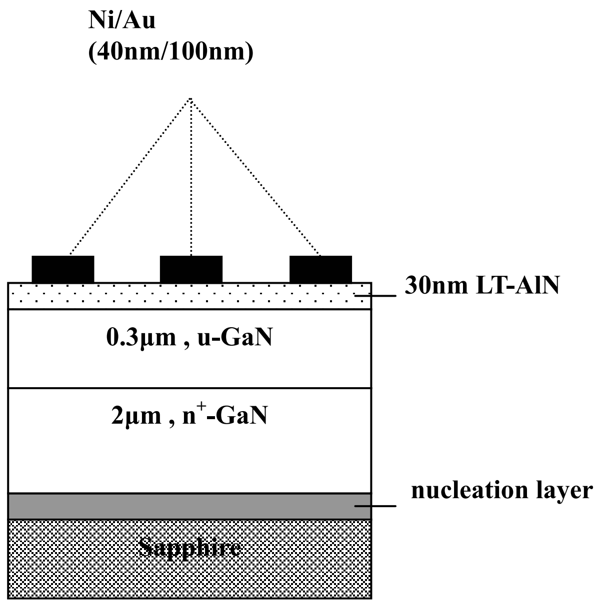

Figure 1 The cross-sectional schematic diagram of PD_A

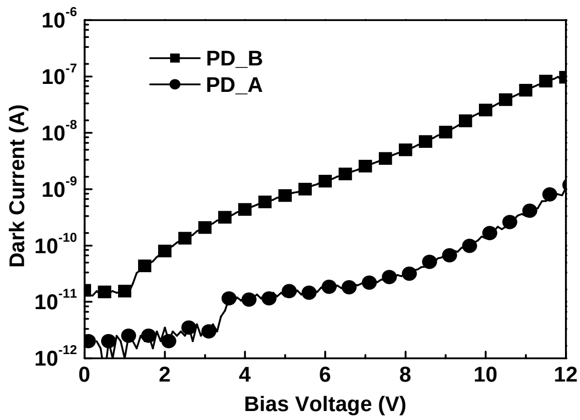

Figure 2 Dark I-V characteristics of both fabricated MSM PDs.

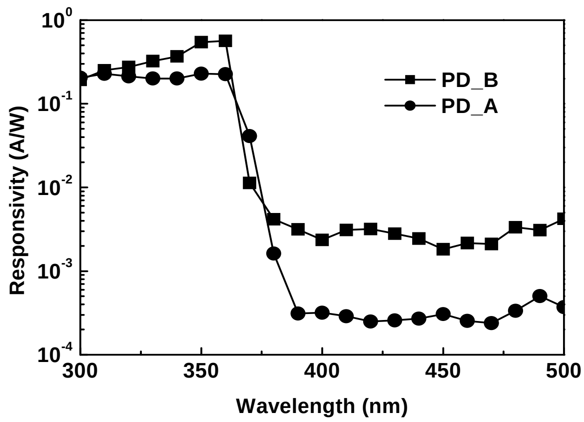

Figure 3 Room temperature spectral responses of the fabricated MSM PDs with 5V applied bias.