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GaN Metal-Insulator-Semiconductor Ultraviolet Detectors with Lanthanum Fluoride (LaF_3) insulating layers

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Abstract

GaN metal-insulator-semiconductor (MIS) ultraviolet (UV) photodetectors (PDs) with a LaF_3 insulating layer were proposed and successfully faricated. The dark current was substantially reduced and the UV-to-visible contrast ratio was enhanced by inserting the LaF_3 insulating layer. With incident light of 340 nm and 5 V applied bias, it was found that measured responsivities were 0.234 A/W for the GaN MIS UV PD with a LaF_3 insulating layer. The large UV-to-visible rejection ratio was achieved by inserting a LaF_3 insulating layer.

1. Introduction

GaN-based materials have attracted much attention with large direct bandgap energy and high saturation electron drift velocity. For photodetectors (PDs) applications, various types of GaN-based PDs have been reported [1-3]. 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. To reduce leakage current, it is possible to insert an insulating layer between metal and the underneath semiconductor [4,5]. The PDs with this insulating layer was called metal-insulator-semiconductors (MIS) PDs. To our knowledge, GaN-based MIS PDs with various insulating materials, such as oxides and nitrides were reported [6,7]. Previously, it has been shown that one can significantly reduce leakage current in GaN or InGaN MSM photodetectors by utilizing a fluoride-based insulators such as CsF or CaF_2 [8,9]. Fluoride-based materials with a large band gap, low-atomic-number anions, small linear refractive indices, and a small dispersion are currently being investigated as optical crystals or coating films for application in optic devices [10]. In this study, for the first time, we reported the fabrication process and characteristics of GaN based metal-insulator-semiconductors (MIS) ultra-violet (UV) PDs using LaF_3 insulating layer. The influence of inserting LaF_3 insulating layer on performance of MIS UV PDs will also be discussed.

2. Experimental

The GaN-based MIS 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 low temperature GaN nucleation layer was deposited as 550 ℃. After the nucleation layer was grown, the temperature was raised to 1060℃ to grow a 2-μm-thick unintentionally doped GaN epitaxial layer with a growth rate of 2μm/h. For the growth of undoped GaN layers, trimethylgallium (TMGa) and NH_3 were used as source materials. The MIS PDs were then fabricated. The LaF_3 insulating layers were deposited on GaN layer by thermal evaporation. The thickness of LaF_3 insulating layer were 0 nm for PD_A (i.e., convention MSM PD), 1.5 nm for PD_B, 6 nm for PD_C, and 20 nm for PD_D. In the following, Ni/Au (5/5 nm) contact electrodes were subsequently deposited on the GaN and insulation layers as the Schottky contact pad by thermal evaporation with a metal mask. The contacts of the device form two inter-digitated contact electrodes. The fingers of the contact electrodes were 65 μm wide and 1200 μm long with a spacing of 85 μm. Figure 1 shows the schematic structure of fabricated GaN MIS PDs with a LaF_3 insulating layer. An Agilent E5270B semiconductor parameter analyzer was then used to measure dark current-voltage (I-V) characteristics of these photodetectors both in dark and under illumination at room temperature. For photocurrent measurements, a 300 Watt Xe arc lamp was used as the light source. Spectral responsivities of the MIS photodetectors were also measured using a Xe arc lamp and a calibrated monochromator as the light source. Output power of the monochromatic light was measured with a calibrated Si photodiode and then projected onto the front side of photodetectors.

3. Results and discussion

Figure 2 shows current-voltage (I-V) characteristics measured from the fabricated PDs at dark and under illumination. With a 4 V applied bias, it was found that dark current measured from PD_A without a LaF_3 insulating layer was 2.5×10^{-10} A. With a LaF_3 insulating layer, the dark currents measured from PD_C and PD_D were 7.8×10^{-11} A and 4.7×10^{-11} A, respectively. The small dark currents measured from the PD_C and PD_D are due to the use of a LaF_3 insulating layer between GaN and metal. It should be noted that the bandgap of LaF_3 layer is approximate from 9.7 to 10.3 eV, which is larger than SiO_2 layer. Thus the inserted LaF_3 should form a high potential barrier between the metal electrode and GaN. As a result, we could significantly reduce dark current of the fabricated PDs. Furthermore, it was also found that photo current measured from the PDs without and with LaF_3 under illumination were approximate in the range from 4.8×10^{-7} to 8.4×10^{-7}A with a 4 V applied bias. With a 1.3 V applied bias, the photocurrent-to-dark current contrast ratios were determined to be 5.1×10^{4}.

Figure 3 shows spectral responses measured from the fabricated PDs. It should be noted that the photo responses were relative flat in the short-wavelength side while cutoff occur at approximate 360 nm, which corresponds to the bandgap of GaN for whole PDs. With incident light of 340 nm and 5 V applied bias, it was found that measured responsivities were 0.234 A/W for PD_B with a 1.5 nm-thick LaF_3 insulating layer. With the inserted LaF_3 insulating layers, photo-generated current should become larger due to their high transparency properties under UV region. As a result, the responsivities measured from the fabricated PD with LaF_3 insulating layers were also large, as compared to conventional PDs. Here, we defined UV-to-visible rejection ratio as the responsivity measured at 350 nm divided by that measured at 420 nm. With this definition, it was found that UV-to-visible rejection ratios were 1.26×10^{3} for the fabricated PD_D with a LaF_3 insulating layer with a 4V bias. These values also indicate that we can effectively enhance UV-to-visible rejection ratio by inserting the LaF_3 insulating layer. Such a result suggests the GaN MIS UV PDs with a LaF_3 insulating layer are potentially useful for practical detector applications.

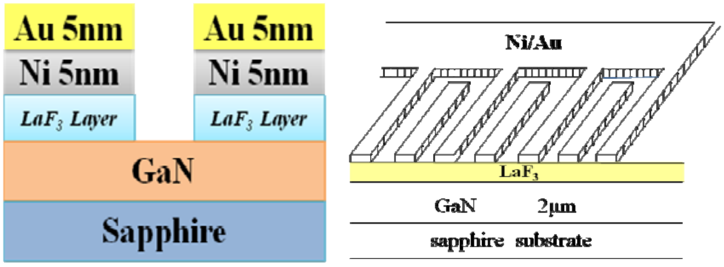

Fig. 1 The schematic structure of GaN MIS PDs with a LaF_3 insulating layer.

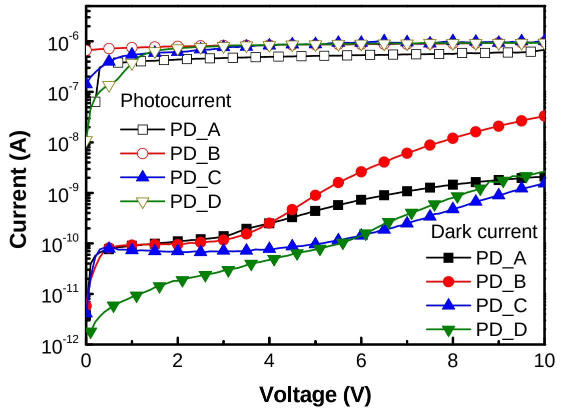

Fig. 2 I-V characteristics of GaN MIS PDs with LaF_3 insulating layers.

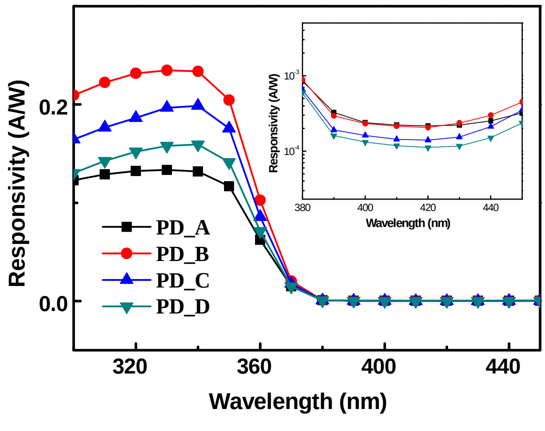

Fig. 3 Spectral responses of GaN MIS PDs with LaF_3 insulating layers. The inset is spectral responses of GaN MIS PDs with LaF_3 insulating layers at the range from 380 to 450 nm.

4. Conclusions

In summary, GaN MIS UV PDs with a LaF_3 insulating layer were proposed and successfully fabricated for the first time. It was found that we can obtain a reduced dark current and an enhanced UV-to-visible contrast ratio by inserting the LaF_3 insulating layer. With incident light of 340 nm and 5 V applied bias, it was found that measured responsivities were 0.234 A/W for the GaN MIS UV PD with a LaF_3 insulating layer. It was also found that we can achieve a large UV-to-visible rejection ratio for the fabricated PD with a LaF_3 insulating layer.

Acknowledgements

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