Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp172-173

GaN Metal-Insulator-Semiconductor Ultraviolet Photodetectors with a Magnesium fluoride insulator

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Abstract

GaN metal-insulator-semiconductor (MIS) ultraviolet (UV) photodetectors (PDs) with the use of magnesium fluoride (MgF_2) as an insulating layer were fabricated and investigated. It was found that we can achieve a small dark current and a large photocurrent to dark current contrast ratio using the proposed device with the MgF_2 insulator. These results should be attributed to the use of the MgF_2 insulating layer, which is formed large barrier between the metal and the semiconductor. Furthermore, the noise equivalent power was substantially reduced, and detectivity was increased using the MgF_2 insulators.

1. Introduction

Recently, GaN-based semiconductor materials have attracted considerable attention and have been used in various optoelectronic devices in short-wavelength regions because of the benefits of their high saturation voltage, high thermal stability, and high direct band-gap energy [1, 2]. GaN-based UV photodetectors are potentially useful in many commercial applications in engine control, solar UV monitoring, UV astronomy, flame detection, secure space-to-space communication, biology, and chemistry [3]. In previous studies, various GaN UV PDs have been successfully proven their advantages, such as metal-semiconductor-metal (MSM) [4], Schottky barrier [5] and p-i-n photodetectors [6]. Among them, MSM PDs have attracted much attention owing to their fabrication simplicity, low intrinsic capacitance, high operation speed, and low noise. However, leakage current in the GaN-based MSM PDs is large in general due to the large differences in lattice constant and thermal expansion coefficient between GaN and sapphire substrate. To reduce the leakage current of GaN MSM PDs, it is possible to fabricate GaN metal-insulator-semiconductor (MIS) PDs by inserting an insulator between metal and GaN. Thus, we can achieve a large potential barrier height at the metal/semiconductor (MS) interface by using the MIS structure. Several types of insulator consisting of metal oxides and high-dielectric constant (k) oxides were previously used to substantially reduce leakage current in GaN MIS PDs [7].

Magnesium fluoride (MgF_2) with a high band-gap energy of 12.8 eV and a low refractive index is a promising material and has attracted considerable attention in the deep/vacuum ultraviolet (DUV/VUV) optical coating applications with the high optical transparency, good adhesion, and high mechanical strength [8-10]. In the literature, however, there are few studies that focused on the application of a MgF_2 insulating layer in GaN MIS UV PDs. In this paper, we report the fabrication of GaN MIS UV PDs with a MgF_2 insulator. The electro-optical properties of the fabricated PDs are also discussed.

2. Experimental and Result Discussions

The GaN-based MIS UV PDs 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. The MgF_2 insulating layers with various thicknesses (that is, 1 nm for PD_1, 30 nm for PD_2, and 40 nm for PD_3) were deposited by using the thermal evaporation system. Ni/Au (5/5 nm) contact electrodes were subsequently deposited onto the samples and annealed at 500℃for 3 min. Fig. 1 shows the schematic structure of GaN MIS UV PDs with the MgF_2 Insulator. The contacts of the device form two inter-digitated contact electrodes. The fingers of the contact electrodes were 65 μm wide and 1150 μm long with a spacing of 85 μm.

Figure 2 shows current-voltage (I-V) characteristics measured from the fabricated PDs at dark and under illumination. It was found that the dark currents were 5.9×10^{-11}, 4.58×10^{-12}, and 6.87×10^{-12} A for the fabricated PD_1, PD_2, and PD_3 with 5V bias, respectively. The low dark current measured from the PD_2 sensor is due to the effective insertion of the MgF_2 insulating layer between GaN and the metal electrode. It will lead to the large Schottky barrier height between GaN and the metal electrode, and thus reduce the metal to the semiconductor thermionic emission. Fig. 2 also shows the I-V characteristics of the fabricated GaN MIS PDs under illumination with the illumination wavelength of 360nm. It was found that photocurrent measured from PD_1, PD_2, and PD_3 with 5V bias were 8.76×10^{-7}, 2.96×10^{-7}, and 1.62×10^{-7} A, respectively. In addition, with a 5V bias, the photo-to-dark current contrast ratios were 1.48×10^{4}, 6.46×10^{4}, and 2.36×10^{4} for PD_1,

PD_2, and PD_3, respectively. We achieved the highest photo-to-dark current contrast ratio for sensors with a 30-nm-thick MgF_2 insulating layer (that is, PD_2). This case indicates that the insertion of the MgF_2 insulating layer considerably enhances the performance of GaN MIS UV PDs.

Fig. 3 shows spectral responses measured from the fabricated sensors. With incident light of 350 nm and 5 V applied bias, it was found that measured responsivities were 1.08×10^{-1}, 7.89×10^{-2}, and 4.73×10^{-2} A/W for PD_1, PD_2, and PD_3, respectively. Here, we defined UV-to-visible rejection ratio as the responsivity measured at 350 nm divided by that measured at 450 nm. With this definition, it was found that UV-to-visible rejection ratios were 13.84, 461.84, and 335.14 for PD_1, PD_2, and PD_3, respectively, when biased at 5 V. These values also indicate that we can effectively enhance UV-to-visible rejection ratio by inserting a 30nm-thick MgF_2 insulator (that is, PD_2).

3. Conclusions

GaN MIS UV PDs with MgF_2 insulating layers were successfully fabricated and characterized. We achieved a small dark current and large photocurrent to dark current contrast ratio from the proposed devices with the use of MgF_2 insulating layers. We also achieved large UV to visible rejection ratios from the sensors with MgF_2 insulating layers.

Acknowledgements

This work was partially supported by the National Science Council (NSC), Taiwan, under grant no. NSC-101-2221-E-230-007.

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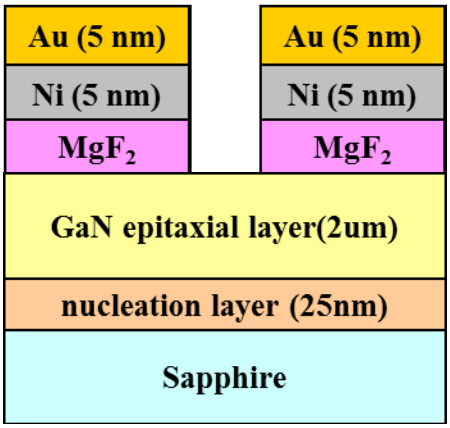

Fig. 1 The structure of GaN MIS PDs with MgF_2 insulators.

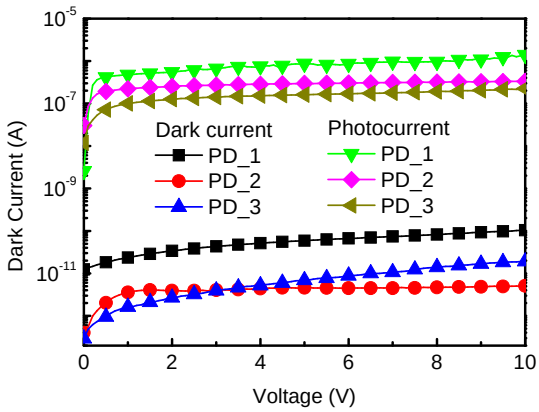

Fig. 2 I-V characteristics measured from the GaN MIS PDs.

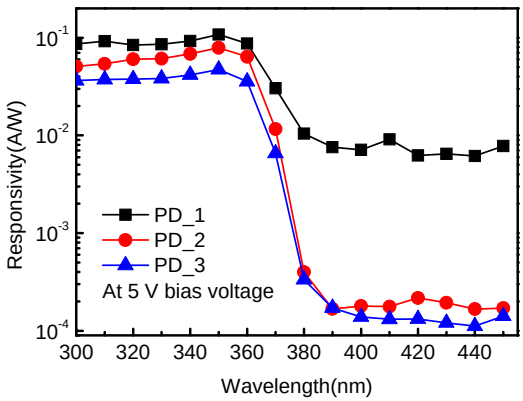

Fig. 3 Spectral responses measured from the GaN MIS PDs.