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Characteristics of back illumination type UV photodetector fabricated by $Al_xGa_{1-x}N$ heterostructure

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1. Introduction

Ultraviolet (UV) photodetection has drawn a great deal of interest in recent years, due to the many new requirements brought about by various technological developments [1]. UV photodetectors have many potential applications in such areas as solar astronomy, missile plume detection, space-to-space transmission, fire alarms and combustion monitoring [2-3]. For these applications, a photodetector should be able to sensitively respond in the visible and UV spectra regions. III-nitride based photodetectors are very promising candidates for various applications because of their potentially high quantum efficiency, low noise and sharp, tunable band edge [1]. Especially, because of their direct wide band gap ranging from 3.4 to 6.2 eV, $Al_xGa_{1-x}N$ compound semiconductors are suitable for opto-electronic device applications in the visible and the ultraviolet part of the spectrum. In order to realize device applications, thick $Al_xGa_{1-x}N$ films with high Al mole fraction and high crystalline quality are essential. However, low-doping efficiencies typically associated with high aluminum content in $Al_xGa_{1-x}N$ layer can limit the fabrication of highly doped p- and n-type layers [4~5]. Although these difficulties exist, several groups have reported promising results for the development of UV photodetectors [6~7]. Structures of p-i-n photodetector are attractive because they are compact, consume less power, rugged and reliable, and are easily integrated with other electronic circuitry. Also, for convenience of flip-chip bonding with electronic signal processing circuits, back-illuminated p-i-n photodetectors are of high interest [8].

In this paper, we have reported the successful fabrication and chraterization of a backside-illuminated UV detector based on an AlGaN p-i-n hetetostructure for flip-chip mounting including fast response time, low dark current.

2. Experimental procedure

The $Al_xGa_{1-x}N$/GaN heterostructures of this work are grown by low-pressure metalorganic chemical vapor deposition (MOCVD) in a Marble 260A using a vertical-flow reactor that employs high-speed substrate rotation during film growth. Prior to the growth of epitaxial layers, sapphire substrates were heated to 1100 ^oC to remove surface contamination. A 20 nm-thick low-temperature (LT) AlN buffer layer is deposited at 550 ^oC and 200 Torr. The next, device layers are grown at 1040 ^oC and 100 Torr. The thin LT-AlN nucleation layer is first deposited followed by a 1.2 μm thick $Al_{0.3}Ga_{0.7}N$ "window layer", 0.16 μm thick $Al_{0.08}Ga_{0.92}N$ i-layer, 0.46 um thick $Al_{0.08}Ga_{0.92}N$ p-layer, 0.1 μm thick GaN p-layer and followed by a 30nm GaN:Mg p^+-contact layer. All device processing are completed using standard semi-conductor processing techniques that included photolithography using appropriately-designed masks, reactive ion etching to define mesa structures, metallization to provide ohmic contacts to the n-type and p-type layers of the devices. The metalized devices are then thermally annealed in N_2 ambient to form good ohmic contacts for both n- and p-electrodes. Characteristics of fabricated photodiodes, responsivity, response time and dark current, are then measured.

3. Results and Discussion

Fig. 1 shows spectral responsivity at zero-bias for p-i-n UV photodetector. The spectral responsivity measurement was found to be in the 270 ~ 500 nm range, using a 150 W Xenon arc lamp light source and a Jobin-Yvon H10-UV monochromator. The monochromated output light was coupled into a multimode UV fiber, by means of which the sample was illuminated. The calibration of the light source output was performed using a calibrated Si photodetector and a Newport 1385-C optical power meter. The maximum responsivity is measured to be around 0.1 A/W at 350 nm, corresponding to an external quantum efficiency of 8.5%. The p-i-n UV photodetector is absorbed within the 310 ~ 350 nm visible blind region. Also, UV/visible contrast of more than 4 orders of magnitude is obtained. It indicates a good spectral selectivity.

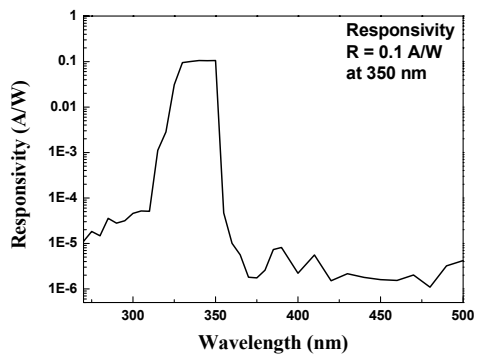

Fig. 1 Spectral responsivity at zero bias for p-i-n UV Photodetector.

Response time is another important characteristic in the performance of the device. Fig. 2 shows the response time of p-i-n UV photodetector. The response time of the device is estimated by using the fourth frequency of an Nd YAG laser (266 nm) with 6 ns Gaussian pulses. We have obtained a very fast response time of a FWHM of 4.1 ns at zero-bias. This suggests that our device is of high quality, which is to be expected, because of the fabrication-based high-quality epilayer and the optimized device geometry used in this study.

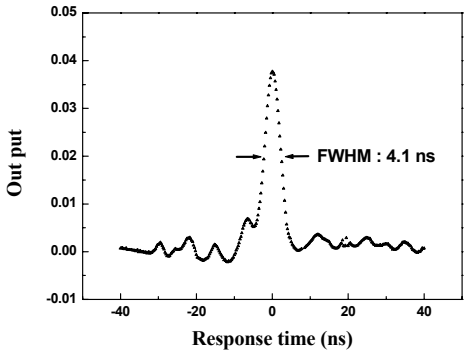

Fig. 2 Response time for p-i-n UV photodetector.

The dark current measurements were obtained with a very low noise measurement system, using an HP 4145B parameter analyzer. Fig. 3 shows current-voltage (I-V) characteristic of the p-i-n UV photodetector measured in the dark current at room temperature. As can be seen from figure, we obtain a very low dark current of 31.9 pA at zero-bias. It was found that the performance of the p-i-n UV photodetector was improved. Also, our device is a very sensitive, due to the very low dark current.

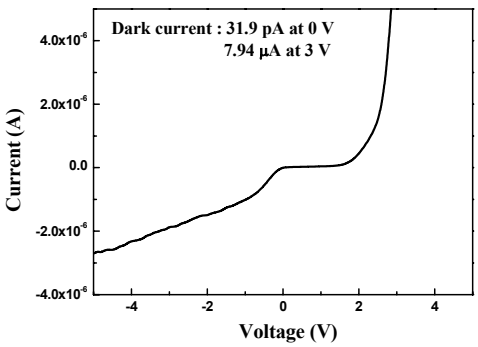

Fig. 3 Current-Voltage (I-V) curve showing the characteristic of p-i-n UV photodetector.

4. Conclusion

In this study, we report the successful fabrication and characterization of the $Al_xGa_{1-x}N$ heteroepitaxial back-illuminated visible-blind UV photodetector for flip-chip bonding. In this device, the zero-bias peak responsivity is obtained to be around 0.1 A/W at 350nm. The device has a response time of a 4.1 ns. And we obtain a very low dark current density of 31.9 pA/cm^2 at zero-bias. Therefore, we can obtain the fast response time and the low dark current through the back-illuminated p-i-n UV photodetector.

Acknowledgement

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