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Inverted GaN p-i-n photodiodes with a buried p^+/n^{++} tunneling junction

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Introduction

In traditional p-i-n structures, N- and P-type layers have a larger bandgap than the absorbing layer sandwiched between them. The P-type AlGaN layer must feature a high aluminum content to prevent the absorption of light by the top layer prior to light reaching the absorption layer (the i-layer). Accordingly, the application of a low-conductivity p-type $Al_xGa_{1-x}N$ top layer to a conventional solar-blind p-i-n photodiode limits the performance of such a photodiode, if the layer features III-nitride alloy with large Al content. Fortunately, this problem can be solved via backside illumination. In fact, the low-resistivity n-type (Si doping) $Al_xGa_{1-x}N$ with high aluminum content is more easily obtained than the p-type $Al_xGa_{1-x}N$ alloys [1]. In this study, we demonstrated an inverted AlGaN/GaN p-i-n photodiode(PD), which was designed with a buried p^+-GaN layer combining a heavy doped n^{++}-$In_{0.3}Ga_{0.7}N$ layer in order to form a p^+/n^{++} tunneling junction under the AlGaN/GaN n-i-p heterostructure, as shown in Fig.1(a)(sampleA). Compared to the conventional AlGaN-based p-i-n PDs, as shown in Fig. 1(b)(sample B), the inverted devices are capable of low-resistivity and high aluminum-containing n-type AlGaN top

contact layer. This arrangement allows the use of Mg-doped GaN rather than an AlGaN layer with high Al content to serve as the p-layer in a GaN-based p-i-n UV PDs. When a bias is applied to the device with the aforesaid inverted structure, the tunneling junction behaves like an “Ohmic contact”. Accordingly, an inverted p-i-n ultraviolet (UV)PD can operate like a conventional device. In contrast to the inverted PDs, the conventional PDs needed a thin Ni/Au bi-layer metal to be deposited onto the p-type $Al_xGa_{1-x}N$ layer to form an Ohmic contact (p-electrode). Therefore, the process steps used in the inverted PDs can be decreased.

Results

The inverted devices exhibited a typical unbiased peak responsivity of 0.1 A/W at 350 nm corresponding to a quantum efficiency of around 35%. The unbiased rejection ratio was about four orders of magnitude over the ultraviolet and visible regions of the spectrum. The typical dark current density of the inverted devices was below 5 nA/cm^2 at the reverse bias below 2 V. As shown in Fig.2, the responsivity of samples B decreased markedly as the incident light wavelength is shorter than 350 nm. The decrease can be attributed to the significant surface absorption in the p-type graded $Al_xGa_{1-x}N$ window layer and the p-GaN contact layer. In samples A, the short-wavelength(<350 nm) responsivity did not show a decrease and were higher than those of samples B. This can be attributable to the fact that the inverted p-i-n PDs have a low-resistivity and wide-bandgap window layer.

Conclusion

Concluding the study we should reinforce that the responsivity of samples B decreased markedly as the incident light wavelength is shorter than 350 nm. The decrease can be attributed to the significant surface absorption in the p-type graded $Al_xGa_{1-x}N$ window layer and the p-GaN contact layer. In the inverted devices(samplesA),the short-wavelength(λ<350nm) responsivity did not show a decrease and were higher than those of samples B. This can be attributable to the fact that the inverted PDs have a low-resistivity and wide-bandgap window layer.

References

[1]D. J. H. Lambert et al., *Appl. Phys. Lett.*, Vol.77, pp.1900-1902,(2000)

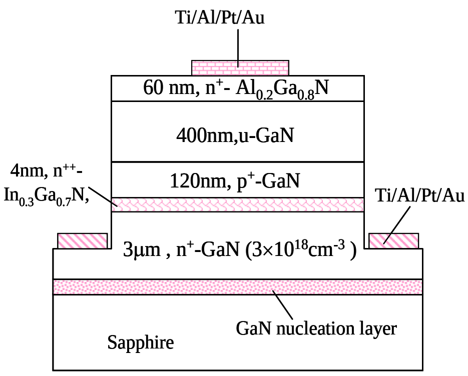

Fig.1(a)

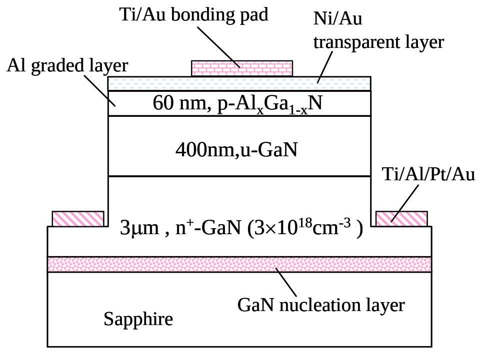

Fig.1(b)

Figure 1. Schematic device structure used in this study.

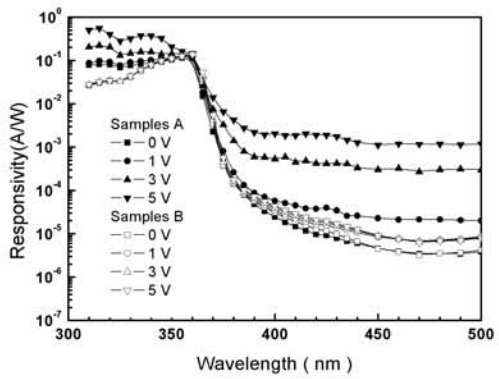

Fig.2 Typical spectral responsivity for the samples A and samples B taken at different biases.