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Design and Growth of Visible-Blind and Solar-Blind III-N APDs on Sapphire Substrates

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GaN-based visible-blind and AlGaN-based solar-blind avalanche photodiodes (APDs) have been grown and fabricated on sapphire substrates. The GaN *p*-i-*n* APDs show low dark current with high gain. The AlGaN layers for the $Al_{0.55}Ga_{0.45}N$-based APDs are grown using a newly developed pulsed metal-organic chemical vapor deposition (MOCVD) process, and the material characterization results show excellent material quality. The spectral responsivity of the devices show a bandpass characteristic with cutoffs in the ultraviolet (UV) visible-blind and solar-blind spectrum for GaN- and $Al_{0.55}Ga_{0.45}N$-based APDs, respectively.

Key words: avalanche photodiode, solar-blind, AlGaN on sapphire, pulsed MOCVD, ultraviolet photodiode

INTRODUCTION

Advancements in UV astronomy, remote flame sensing, and biological agent detection will require significant detector advances, particularly in quantum efficiency (QE), noise, resolution, and pixel count, over currently available UV detectors.[1] Avalanche photodetectors (APD) are capable of detecting low-intensity light with very high quantum efficiency while providing high signal-to-noise ratio without the need for external amplification. Detectors made from $Al_xGa_{1-x}N$ with $x > 45\%$ can achieve solar blindness without the use of filters, are capable of operating under harsh environmental conditions, and can be fabricated into multipixel arrays.[2] However, many challenges in material quality and device design need to be addressed in order to achieve the detection characteristics, performance, and yield requirements of multipixel APD arrays.

One of the major challenges is the low doping and activation efficiency of Mg acceptors in *p*-AlGaN. An Mg-doped *p*-GaN contact layer is commonly used in the *p*-i-*n* AlGaN device to minimize contact resistance and leakage current. However, this is limiting as it reduces the quantum efficiency of the device when front-illuminated due to photon absorption in the *p*-GaN layer.[3] Another challenge is the presence of high density of dislocations in III-nitride-based APDs. Detectors grown on bulk substrates have the advantage of higher material quality and low dislocation density, which are necessary for reliable operation of APDs; however, in this case the detector cannot be used in back-illumination mode due to light absorption by the substrate.[4] This makes devices on UV-transparent, double-side-polished sapphire substrates an attractive option if the material quality can be improved.

There are few reports on AlGaN APD[5–7] operation due in large part to the difficulty in growth of high-quality AlGaN material with low dislocation density capable of sustaining a field greater than 3 MV/cm. We have recently developed high-Al-composition (Al >40%), high-quality AlGaN layers by the use of a novel pulsed metalorganic chemical vapor

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