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Research Letter

Low Dark Current Mesa-Type AlGaN Flame Detectors

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This study characterizes and reports on the fabrication process of AlGaN flame photodetectors with an $Al_{0.1}Ga_{0.9}N$/GaN superlattice structure. The AlGaN flame photodetectors exhibited a low dark current ($\sim 1.17\times10^{-10}$ A at bias of -5 V) and large rejection ratio of photocurrent ($\sim 2.14\times10^{-5}$ A at bias of -5 V) to dark current, which is greater than five orders of magnitude. Responsivity at 350 nm at a bias of -5 V was 0.194 A/W. Quantum efficiency, η, was 0.687 at a reverse bias of 5 V.

1. INTRODUCTION

Recently, the detector for blue/ultraviolet (UV) wavelengths has been studied widely. An effective UV detector should operate even in strong visible background light. Correspondingly, detector sensitivity in a UV region should be larger than that in the visible region. Ultraviolet detectors are practical at flame sensing, missile plume detection, and space-to-space communications [1, 2]. Since flame luminescence in the UV spectrum is weak, high responsivity and low current noise are necessary to prevent misdetection. Also a large spectral selectivity is important to efficiently reject solar light [2].

The effectiveness of applying III-V nitride detectors for UV wavelengths has been demonstrated [2–10]. By adjusting the aluminum fraction of $Al_xGa_{1-x}N$-based photodiodes, the band gap energy varies at 3.4–6.2 eV and shifts the cutoff wavelength from 365 nm ($x = 0$) to 200 nm ($x = 1$) [1]. However, the ratio of the UV light photocurrent to the visible light photocurrent is roughly 3–4 orders of magnitude or lower. Yeh et al. reported that AlGaN/GaN strained-layer superlattice (SLS) structure can increase acceptor ionization efficiency and hole concentration in the GaN p-i-n photodiode [10]. This study describes the fabrication of and characterizes mesa-type $Al_{0.1}Ga_{0.9}N$ flame photodetectors with an $Al_{0.1}Ga_{0.9}N$/GaN superlattice structure that has a low dark current and a visible-to-UV light rejection ratio of 6 orders of magnitude.

2. EXPERIMENT

Wafers utilized in this study were grown on c-plane (0001) sapphire substrate by metal-organic vapor phase deposition (MOCVD) technology. A 2000-nm-thick Si-doped GaN layer ($n = 1 \times 10^{18}$ cm^{-3}) was grown on sapphire substrate, followed by a 1000-nm-thick unintentionally doped $Al_{0.1}Ga_{0.9}N$ absorption layer ($n = 9 \times 10^{16}$ cm^{-3}), a 300-nm-thick unintentionally doped $Al_{0.1}Ga_{0.9}N$/GaN (12 nm/8 nm) SLS structure consisting of 15 layers, and a 400-nm-thick Mg-doped GaN cap layer ($p = 3 \times 10^{17}$ cm^{-3}). Heat treatment was subsequently performed at 650°C for 10 minutes in ambient nitrogen to activate the p-type dopant.

The surface of the p-type GaN layer was then partially etched using photolithography and inductively coupled plasma-reactive ion etching (ICP-RIE) technology until the n-type GaN layer was exposed, indicating that the mesa structure was formed. The SiN_x layer was then evaporated as an insulation layer. An open was formed by photolithography to expose the surface of the p-GaN layer. The Ni/Au (50 Å/80 Å) transparent contact was evaporated onto the surface of the p-GaN using an electron-beam evaporator, and thermally annealed in ambient pure oxygen at 550°C for 10 minutes to form the p-metal. Finally, the Ti/Al/Ti/Au (15 nm/50 nm/100 nm/1000 nm) contacts were formed simultaneously on the exposed n-type GaN layer as n-metal and a bonding pad, and on the Ni/Au transparent contact as a bonding pad. Figure 2 shows the optical microscope top-

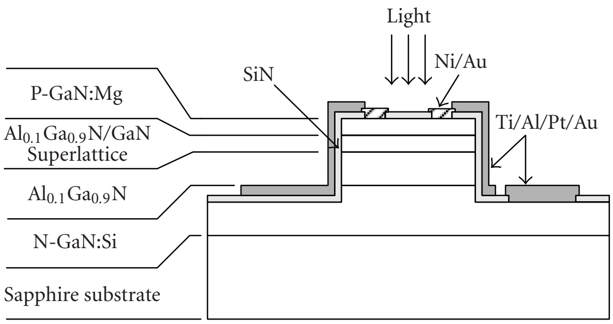

FIGURE 1: Schematic cross-section of AlGaN UV photodiode.

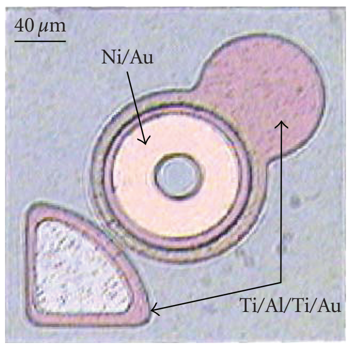

FIGURE 2: Optical microscope top view of AlGaN UV photodiode.

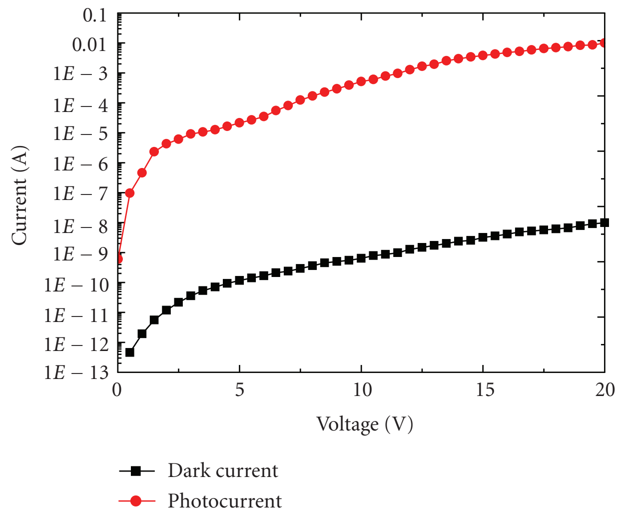

FIGURE 3: Dark and illuminated (λ = 350 nm) I-V characteristics of AlGaN flame photodetectors at reverse biased from 0 V to 20 V.

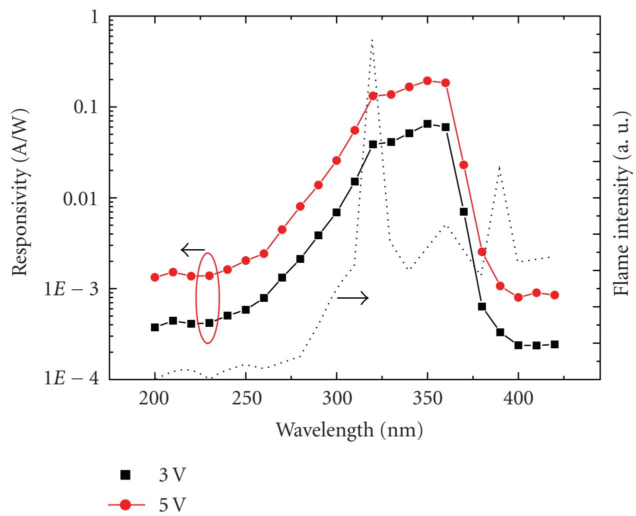

FIGURE 4: Responsivity as function of wavelength for an AlGaN flame photodetector at bias of 5 V.

view of AlGaN flame photodetectors. The diameter of the illuminated area is about 100 μm.

The current-voltage (I-V) characteristics of the AlGaN photodiode were measured using an HP 4155B semiconductor parameter analyzer. Responsivities were determined by a spectrum meter (Hitachi U-3010). All measurements were made at room temperature.

3. RESULTS AND DISCUSSION

Figure 3 shows plots of the I-V characteristics of photodiodes measured in the dark (dark current) and under illumination (photocurrent) at reverse biases from 0 V to 20 V. The photocurrent was approximately 2.14×10^{-5} A and the dark current was approximately 1.17×10^{-10} A at a bias of 5 V. Therefore, a large photocurrent-to-dark-current contrast ratio exceeded 5 orders of magnitude. The orders of magnitude were markedly higher than other structures in other studies due to the addition an unintentionally doped SLS structure between the p-GaN layer and $Al_{0.1}Ga_{0.9}N$ absorption layer in this study. The AlGaN/GaN superlattice structure could change the orientation of threading dislocations, so that it resulted in a low dark current. Also, the superlattice structure would cause the incline of the band gap in high electrical field, enhanced the impact of the hole to grow many electron-hole pairs and increased the photocurrent.

Figure 4 presents a plot of responsivity as a function of wavelength for an AlGaN flame photodetector. High responsivity is evident at wavelengths of 360–320 nm at reverse biases of 3 V and 5 V. The responsivity at 350 nm at a bias of 5 V was 0.194 A/W. The response tails off at a wavelength of 380 nm. Responsivity at 380 nm at a bias of 5 V was 0.00254 A/W.

Responsivity R could be described as [11]

$$R = \frac{I_{ph}}{P_{inc}} = \eta \frac{q\lambda}{hc} = \frac{\eta\lambda(\mu m)}{1.24}(\text{A/W}), \quad (1)$$

where I_{ph} is the photocurrent, P_{inc} is the incident power, *and* η, q, c, h, and λ are quantum efficiency, electron charge, velocity of light, Planck constant, and light wavelength, respectively. Using (1), quantum efficiency, η, was 0.687 at a reverse bias of 5 V. On the other hand, the dashed line in Figure 4 is flame spectrum near the UV range of 200–420 nm. The portion of relative high intensity was at 030–400 nm, which matches the high responsivity region of the AlGaN photodetector. Therefore, the AlGaN photodetector can be used for flame detection under strong visible background light.

4. CONCLUSIONS

In summary, AlGaN p-i-n photodiodes grown by MOCVD technology are characterized. The dark current and photocurrent of AlGaN p-i-n photodetectors were 1.17×10^{-10} A and 2.14×10^{-5} A at a bias of -5 V, and the photocurrent rejection ratio was 6 orders of magnitude. Responsivity and quantum efficiency, η, at 350 nm at a bias of -5 V were 0.194 A/W and 0.687, respectively. The portion of relatively high intensity in the flame spectrum was at 300–400 nm, which matches the high-responsivity region of the AlGaN photodetector. Therefore, the AlGaN photodetector can be used for flame detection under a strong visible background light.

ACKNOWLEDGMENTS

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