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 ($\sim 1.17 \times 10^{-10}$ A at bias of $-5$ V) and a large rejection ratio of photocurrent ($\sim 2.14 \times 10^{-5}$ 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, $\eta$, was 0.687 at a reverse bias of 5 V.

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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$_x$Ga$_{1-x}$N-based photodiodes, the band gap energy varies from 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-
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 $2.14 \times 10^{-5}$ A and the dark current was approximately $1.17 \times 10^{-10}$ 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 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 electric 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]

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

where $I_{\text{ph}}$ is the photocurrent, $P_{\text{inc}}$ is the incident power, and $\eta, q, c, h,$ and $\lambda$ are quantum efficiency, electron charge, velocity of light, Planck constant, and light wavelength, respectively. Using (1), quantum efficiency, $\eta$, 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 photode-
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 $1.17 \times 10^{-10}$ A and $2.14 \times 10^{-5}$ A at a bias of $-5$ V, and the photocurrent rejection ratio was 6 orders of magnitude. Responsivity and quantum efficiency, $\eta$, 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.

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