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A high responsivity spectrum in the near ultraviolet (UV) and the vacuum UV (VUV) region was realized using Schottky UV detectors consisting of $Al_{0.5}Ga_{0.5}N$ on an AlN epitaxial layer. The cut-off wavelength of AlGaN UV detectors was 4.7 eV (265 nm), a value that corresponds to the band gap of $Al_{0.5}Ga_{0.5}N$. The contrast of responsivity between the near UV and the visible was about $10^4$. The GaN Schottky detector had a high responsivity region in the near-UV from 3.4 to 5.0 eV (250–360 nm), whereas the AlGaN UV detector had a high responsivity in the UV–VUV region from 4.7 to 12.4 eV (100–265 nm). From these results, the fabricated AlGaN-based UV photodetectors can likely be used in detectors for the UV–VUV region.

**1 Introduction** Ultraviolet (UV) detection is one of the most attractive uses for group III-nitride semiconductors. Various UV detectors based on GaN or AlGaN include the photoconductor type [1], the Schottky type [2–5], the Schottky-based metal-semiconductor-metal type [6, 7], and the p–n and p–i–n types [8–10]. All have good responsivity from 3.4 to 5.0 eV (250–360 nm) and clear cut-off characteristics at a cut-off wavelength that corresponds to their band gaps.

On the other hand, the next generation photolithography system, which will use a stepper with an excimer laser such as an ArF laser ($\lambda$ = 193 nm) and an F2 laser ($\lambda$ = 157 nm), will require vacuum UV (VUV) light detection. Currently, Si-based photodetectors (SPDs) are primarily used to detect UV light. However, they require filters to stop low energy photons (visible and infrared light), they easily degrade, and have low efficiency. Photodetectors based on type III-nitrides should overcome these limitations. Although GaN UV detectors have recently been shown to respond in the near UV and the VUV regions [11], their low responsivity in the VUV region due to their shallow penetration depth is a problem for their use in steppers. Fabricated AlGaN-based UV photodetectors can be used in such short-wavelength photolithography systems. However, it is extremely difficult to grow thick AlGaN with high AlN molar fraction on GaN because the AlGaN cracks under the large in-plane tensile stress [12]. We described a technique of using a high-temperature-grown AlN film as an underlying layer for the growth of AlGaN

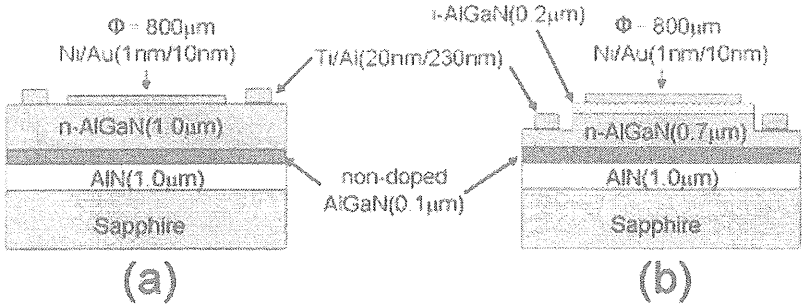


**Fig. 1** UV detectors with a transparent Schottky electrode. a) The Schottky contact was directly on n-AlGaN. b) The Schottky contact was on i-AlGaN. The diameter of the detectors is 800 μm.

[13], and we also have reported on a detailed characterization of the crystalline quality of the n-type AlGaN [14].

In this paper, we describe our fabrication of two types of Schottky UV detectors consisting of $Al_{0.5}Ga_{0.5}N$ on an AlN epitaxial layer. We also describe the *I–V* characterization and measurement of the responsivity spectra in the UV–VUV region for the Schottky UV detectors with transparent electrode.

**2 Experimental procedure** Crack-free and high-quality AlGaN layers with high Al contents of 0.51–0.54 were grown on high-quality epitaxial AlN films on sapphire by low-pressure metalorganic vapor phase epitaxy (LP-MOVPE) [13–14]. Growth pressure and temperature were 40 Torr and 1100–1120 °C, respectively. Ammonia ($NH_3$), trimethylgallium (TMG) and trimethylaluminum (TMA) were used as source materials, and $H_2$ was used as carrier gas. $CH_3SiH_3$ was used as an n-type dopant. The FWHM values of X-ray rocking curves (XRCs) for the (0002) and (10–12) diffraction peaks are approximately 200 and 1100 arcsec, respectively [14]. It indicates that the AlGaN layer on epitaxial AlN/sapphire has better quality than AlGaN on sapphire with a low temperature buffer layer. Figures 1a and 1b show the device structures used in this study. In Fig. 1a, the UV detectors have a semitransparent Schottky electrode that consists of a 0.1-μm-thick undoped-AlGaN layer and a 1-μm-thick n-AlGaN layer ($n = 5.0 \times 10^{17}$ cm$^{-3}$) on an AlN epitaxial layer. The Ni (1 nm)/Au (10 nm) semitransparent Schottky contact was deposited on n-AlGaN, and then annealed at 400 °C in $N_2$ ambient. The transmittance of the Ni/Au electrode in the near UV and VUV region is about 40–60% [11]. Ohmic contacts were formed with Ti(20 nm)/Al(230 nm). For the device in Fig. 1b, i-AlGaN of thickness 0.2 μm was deposited on n-AlGaN of thickness 0.7 μm in order to decrease the dark current of the UV detector with reverse bias. The mesa structure was fabricated by using reactive ion etching (RIE), and the Ohmic and the Schottky contacts were formed by deposition. The diameter of the Schottky contacts for both detectors is 800 μm.

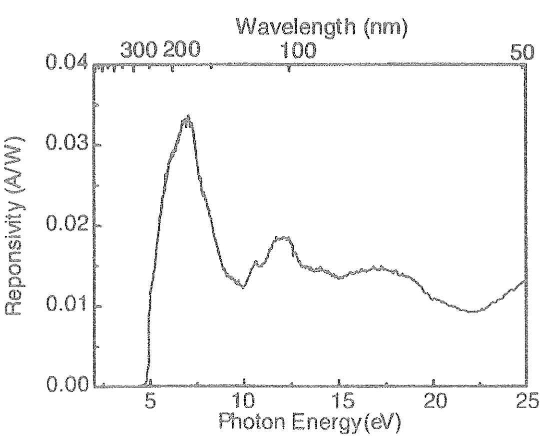


**Fig. 2** Responsivity spectrum of an AlGaN UV detector. The Schottky contact was directly on n-AlGaN. The measurements used an aperture of 600 μm diameter.

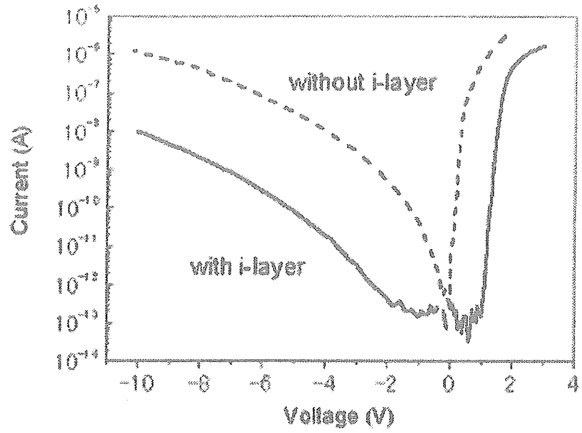


Fig. 3 *I–V* characteristics of the AlGaN UV detecters in Fig. 1 without i-AlGaN.

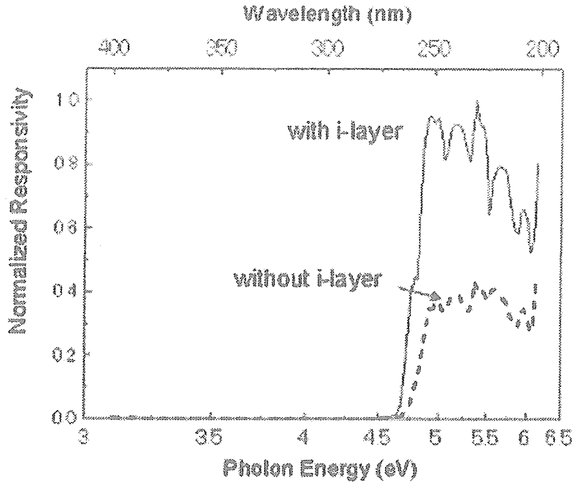


Fig. 4 Responsivity spectrum of AlGaN UV detectors in Fig. 1 without i-AlGaN and with i-AlGaN. The measurement was performed using a D2 lamp.

**3 Results and discussion** Figure 2 shows the responsivity spectra of the AlGaN detector of the type shown in Fig. 1a. The responsivity spectra of the UV detectors were determined by measuring the photocurrent from monochromatic near-UV and VUV light at the beam line 7B (BL7B) of the UVSOR facility, Institute for Molecular Science. The measurements used an aperture of diameter 600 μm. The cut-off wavelength of AlGaN UV detectors is 4.7 eV (265 nm), a value that corresponds to the band gap of $Al_{0.5}Ga_{0.5}N$. The contrast of responsivity between the near UV and visible region is about $10^4$. Whereas the GaN Schottky detector has a high responsivity region in the near-UV from 3.4 to 5.0 eV (250–360 nm) [11], the AlGaN UV detector has a high responsivity region in the UV–VUV from 4.7 to 12.4 eV (100–265 nm). The maximum responsivity of the AlGaN detector is 0.035 A/W at 6.5eV (190 nm), and the responsivity decreases with wavelength. It is considered that smaller responsivity for VUV light with higher energy may be due to the recombination process with interface defect level and the VUV light was absorbed in the vicinity of the interface of Schottky contact and AlGaN layer [15]. The detailed mechanisms are under investigation.

Figure 3 shows the *I–V* characteristics of the AlGaN UV detectors not containing i-AlGaN, as in Fig. 1a, and detectors with i-AlGaN, as in Fig. 1b. The dark current of the UV detector with i-AlGaN decreased by about two orders of magnitude at reverse bias than that without i-AlGaN. Figure 4 shows the responsivity spectra of the AlGaN detectors with and without i-AlGaN; in this case we used a deuterium (D2) lamp with $\lambda = 200–400$ nm. The cut-off wavelength is about 4.7 eV (265 nm) for both detectors. The responsivity of the AlGaN detectors with i-AlGaN was higher than that without i-AlGaN. Because of low intensity of the D2 lamp at energy over 5 eV (250 nm), the responsivity for both detectors decreased. The responsivity spectra in the VUV region and those with reverse bias of the AlGaN detectors with i-AlGaN will be published elsewhere.

**4 Conclusion** Schottky UV detectors of $Al_{0.5}Ga_{0.5}N$ were fabricated on an AlN epitaxial layer. A high responsivity spectrum in the UV–VUV region (100–265 nm) was then realized using these detectors. The cut-off wavelength of the AlGaN UV detectors was 4.7 eV (265 nm), a value corresponding to the band gap of $Al_{0.5}Ga_{0.5}N$. The contrast of responsivity between the near UV and the visible region is about $10^4$. From these results, the fabricated AlGaN-based UV photodetectors have strong possibilities of being used in detectors for the UV–VUV region and have a strong potential of being used in steppers for next generation photolithography systems.

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