# Characterization of GaN Based UV-VUV Detectors in the Range 3.4-25 eV by Using Synchrotron Radiation

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The characterization of Schottky type ultraviolet (UV) detectors with transparent electrode between vacuum ultraviolet (VUV) and visible light region using synchrotron radiation is described. The responsivity spectrum of the detectors at 0 V bias was obtained in the wide range between 2 eV (563 nm) and 25 eV (50 nm). The photoemission current from Au electrode was able to be canceled by improving the measuring circuit, and thus we succeeded in operating the detectors without any photoemission current from Au and GaN. The responsivity of the detectors is about 0.15 A/W at 3.5 eV. These results show that these Schottky type detectors with the transparent electrode are effective to detect VUV-UV light (50–360 nm, 3.4–25 eV) without any photoemission.

**Introduction** Ultraviolet (UV) detectors are one of the most attractive devices in the group III-nitride semiconductors. Currently, for the measurement of UV light, photodetector components with Si such as photodiodes are mainly used. However, light sensitivity often deteriorates due to radiation damage in the vacuum ultraviolet (VUV) region. Several groups have reported on GaN- or AlGaN-based UV detectors such as photoconductor [1], the Schottky type [2–5] , the Schottky-based metal–semiconductor–metal type [6, 7], p–n or p–i–n type [8–10] have been reported. They have good responsivity from 250 to 360 nm and clear cut-off characteristics at a cut-off wavelength of $\lambda_c = 360$ nm.

Schottky barrier GaN photodetectors were first reported by Khan et al. [2] who demonstrated a Ti Schottky diode on p-type GaN. Using 50 Å Pd as a Schottky barrier on n-type GaN, Chen et al. [3] reported a responsivity of 0.18 A/W. Monroy et al. [4] reported Schottky barrier UV photodetectors using Au electrode on epitaxial lateral overgrown GaN. However, there are few reports on the responsivity spectra in the VUV region ($\lambda < 200$ nm) [5]. If UV detectors can detect VUV light, they will be available for detecting the light of an ArF ($\lambda = 193$ nm) or an $F_2$ laser ($\lambda = 157$ nm), which will be used as light sources incorporated into steppers for future photolithography systems.

In this paper, we adopted transparent Au electrode structure to suppress the photoemission of GaN and Au and describe the responsivity spectra of UV detectors between VUV and visible (VIS) light regions ($\lambda$ = 50–563 nm, $h\nu$ = 2–25 eV).

**Experimental Procedure** The UV detectors used in this study adopt the Schottky contacts with a transparent electrode. They consist of a 3 μm thick n-GaN layer ($n = 2.0 \times 10^{18}$ cm$^{-3}$) and a 1.5 μm thick i-GaN layer ($n = 1.0 \times 10^{16}$ cm$^{-3}$) on a (0001) sapphire substrate. These layers are grown by metalorganic vapor phase epitaxy (MOVPE). The Au/Ni Schottky contact is deposited on i-GaN. The thickness of Au and Ni are 10 and 1 nm, respectively. The diameter of detectors is 6.5 mm.

The responsivity of UV detectors is estimated by measuring the photocurrent illuminating SR at the beam line 7B (BL7B) of the UVSOR Facility, Institute for Molecular Science [11, 12]. UV detectors are illuminated with the monochromatic light, which is between $h\nu$ = 2.2 eV ($\lambda$ = 564 nm) and $h\nu$ = 25 eV ($\lambda$ = 50 nm). There are three gratings and two cut-off filters for second order light [12]. For this reason, several lines were found in the spectra of Figs. 1 and 2. The measurements of photocurrent are performed at room temperature in the vacuum chamber under the vacuum of $10^{-9}$ Torr. To calculate the responsivity of detectors, the number of photons is needed. It is estimated by measuring photocurrent using silicon photodiode (AXUV-100). The number of incident photons is from $1 \times 10^{10}$ to $4 \times 10^{11}$ photons/s in the measurement range. The photocurrent is measured as reverse current of the Schottky diode at 0 V bias or by applying reverse bias during the illumination of SR. $I$–$V$ characteristics taken in dark and under illumination with 3.8 eV was also carried out in order to characterize the dependence of responsivity on reverse bias.

**Results and Discussion** Prior to the characterization of responsivity, the transmittance of Au in VUV region is estimated by counting the number of transmitted photons into Au membrane. Figure 1 shows the transmittance spectrum. The transmittance of a 10 nm thick Au is about 0.4–0.5 in UV and VUV region and almost agreed with calculation. Thus, the 10 nm thick Au is enough thickness to transmit VUV light into Au electrode.

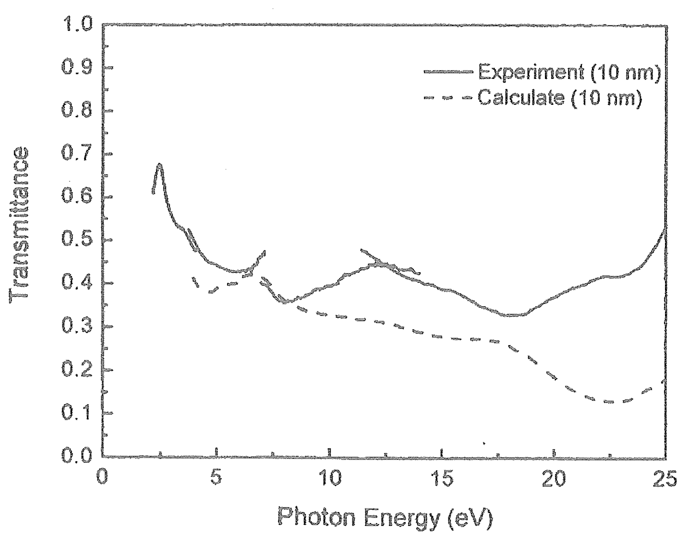


Fig. 1. Transmittance spectrum of 10 nm thick Au electrode

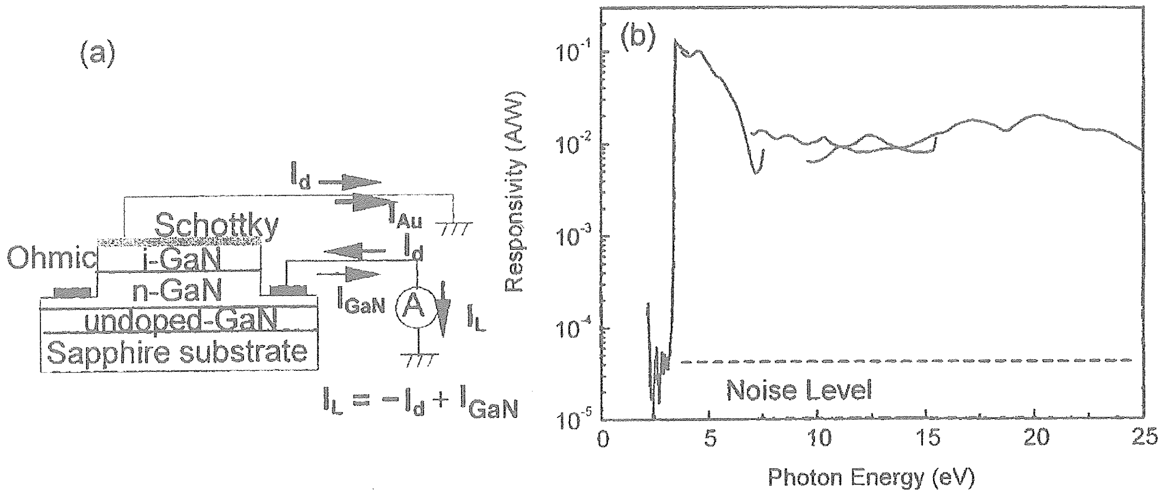


Fig. 2. a) Measurement circuit and b) responsivity spectrum of UV detector

The responsivity spectrum of detectors for photon energy is measured. Figures 2a and b show the measurement circuit and the responsivity spectrum at 0 V bias, respectively. In this measurement, the ampere-meter is connected between Ohmic contact (Al/Ti) and ground as shown in Fig. 2a. The electrons emitted from the surface of Au run from ground to Au electrode directly. So the photoemission current of Au ($I_{Au}$) generates between Au and ground. Thus, it is not measured by the ampere-meter. Dark current is about 1–2 pA. It is corresponding to about the order of $10^{-5}$ A/W in Fig. 2b). N responsivity at the energy lower than 3.4 eV (the absorption edge of GaN) can be observed. This indicates that these detectors can be used only in the UV or VUV region. The ratio of responsivity between UV and VIS regions is about $5 \times 10^3$. The maximum responsivity of this detector is 0.15 A/W at $h\nu = 3.5$ eV ($\lambda = 354$ nm). This value is close to the results of Refs. [3] and [4]. Furthermore, the surface of GaN is not illuminated by VUV light directly because the area of Au transparent electrode is larger than the beam size. So the photoemission current of GaN ($I_{GaN}$) is not detected. It is considered that the total current ($I_L$) is equal to the diode current ($-I_d$). There-

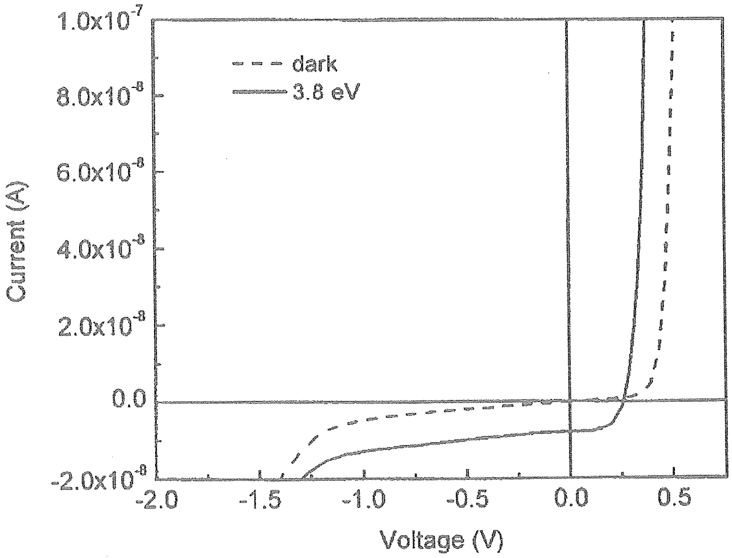


Fig. 3. $I$–$V$ characteristic of UV detector taken in dark and under illumination with $h\nu = 3.8$ eV ($\lambda = 326$ nm)

fore, both the photoemission current of GaN and Au are not observed in this measurement and the higher responsivity is realized in this structure.

Following the measurement at 0 V bias, the current-voltage ($I-V$) characteristics and the dependence of responsivity spectra on reverse bias are characterized. Figure 3 shows the $I-V$ characteristics of the sample. The Schottky characteristic is maintained at $-1$ V of the reverse bias. Between 0 and $-1$ V, The responsivity is not changed by applying the reverse bias.

**Conclusions** Characterization of Schottky barrier UV detectors with a transparent electrode on i/n-GaN epitaxial layers over sapphire substrates in the VUV region using synchrotron radiation is described. A higher responsivity (0.15 A/W at 3.5 eV) and no photoemission of Au and GaN was realized. Therefore, these Schottky type detectors with transparent electrode structures are effective to operate in UV and VUV light ($50 \text{ nm} < \lambda < 360 \text{ nm}$).

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