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P5-1

Metal-Semiconductor-Metal UV Photodetector Based on AlGaN/GaN Heterostructure

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1. Introduction

AlGaN/GaN heterostructures are now used very extensively for high temperature/high power electronic devices and optoelectronic devices. [1,2] The first UV photodetector based on AlGaN/GaN heterostructure was reported by Khan et al., [3] which used the heterostructure field-effect transistor (HFET) as gated visible blind photoconductor. This photodetector showed advantages of high gain and monolithical integration with FET circuits in one epitaxial step. However, a main drawback of this photoconductivity detector is the relatively high dark current, which limits the minimum detectable irradiation power. Schottky metal-semiconductor-metal (MSM) photodetectors (PDs) are attractive devices because of their low dark current, high response speed, superior responsivity, and simple planar structure, which is compatible with FETs. It is known that piezoelectric and spontaneous polarization fields occurring in AlGaN/GaN heterostructure can generate a high two-dimensional electron gas (2DEG) concentration at the heterojunction interface without doping. For this reason, the undoped AlGaN/GaN structure can also be used for high electron mobility transistor (HEMT) fabrication. It is promising to fabricate the MSM PDs on AlGaN/GaN heterostructures, enabling the monolithical integration of the MSM PDs in HEMT circuits in one epitaxial step, and meanwhile keeping MSM PDs' own superior performance. It is then the purpose of this work to investigate the MSM PDs prepared on AlGaN/GaN heterostructures.

2. Device fabrication

The epilayer structure employed in this work were grown by atmospheric-pressure MOCVD method and consisted of a 30 nm GaN buffer on (0001) sapphire substrate followed by a 800 nm undoped GaN layer, a 20 nm undoped $Al_{0.16}Ga_{0.84}N$ layer and a 6 nm insulating cap layer. From Hall-effect measurement, the electron mobility was found to be 908.7 cm^2/Vs at 300 K and 4207.5 cm^2/Vs at 77 K, respectively, and the sheet carrier density was found to be $3.2\times10^{11}cm^{-2}$ at 300 K. Figure 1 shows the schematic structure of the device with the band diagram. Interdigital patterns with the active area of 105×105 μm^2, finger width of 5 μm, gap spacing of 5 μm were defined by photolithography. The transparent Schottky contacts were formed with 100-Å-thick Pt layer, which was deposited using e-beam evaporation and a standard lift-off process. As contact pads, a Ni/Au (20/300 nm) bilayer was deposited.

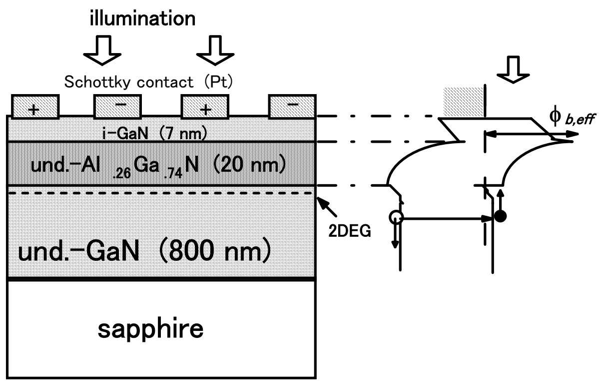

Fig. 1 Schematic diagram of the device and its energy band. The i-GaN cap layer is used to enhance Schottky barrier height by the piezoelectric effect. [4]

3. Results and Discussion

Measurements of the current-voltage (I-V) characteristics of the MSM-PDs were performed with an Agilent 4156C precision semiconductor parameter analyzer. The dark current shows a strong voltage-dependence for low bias and saturation for higher bias values as depicted in Fig. 2. It can be assumed that the dark current is due primarily to thermionic emission over the potential barriers at the AlGaN/GaN heterointerface and at the Schottky contact between the AlGaN barrier layer and the electrode metal. At a bias of 10 V, the current is only 2.4 pA, which corresponds to a current density of 8.5×10^{-8} A/cm^2 using the metal contact area as the effective area. This value is about one order lower than that of the GaN MSM PDs used the same interdigitated pattern. [5] We attribute the low dark current to the i-GaN layer, which enhanced Schottky barrier height.

The photocurrents were measured under the illumination with a wavelength of λ=350 nm. When the incident photon energy is equal to or larger than the GaN bandgap (E_g^{GaN}) but less than the AlGaN bandgap (E_g^{AlGaN}), the 20-nm-thick AlGaN layer is transparent to the incident

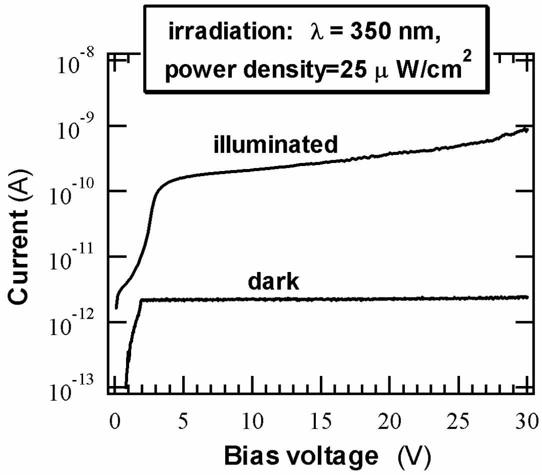

Fig. 2. Dark and illuminated current-voltage characteristics of the AlGaN/GaN heterostructure MSM PD.

photon, and the dominant photoeffect is the generation of electron-hole pairs in the undoped GaN layer. Photoelectrons generated in this layer experience a vertical electric field associated with the band bending at the heterostructure interface as shown in Fig. 1, and a lateral electric field associated with the applied voltage. By the vertical electric field, these electrons are forced into the 2DEG channel, contributing to an increase in the charge density of 2DEG. The result is a self-consistent increase in electric field of the channel region, which leads to an enhanced band-bending. Photogenerated holes are swept away from the interface and eventually collected by the cathode, while the photogenerated electrons are collected by the anode. In Fig. 2. , it is shown that the photogenerated carriers tunneling through the potential barriers at the heterointerface and Schottky contact contribute to the photocurrent, especially at higher bias (>20 V).

The device spectral responsivity of the photocurrent is shown in Fig. 3. A UV-visible spectrophotometer with a xenon-arc lamp source and a monochromator were used for these measurements in the range of 500~300 nm. The constant irradiation power density was corrected with a thermopile unit, while the absolute values of responsivity were determined using a calibrated Si detector. As shown in Fig. 4, the sharp cutoff was observed at the band edge of GaN. The UV-visible rejection is more than three orders of magnitude by λ=400 nm. At a bias of 15 V, the photoresponse is 114.4 mA/W under an irradiation density of 10 $\mu W/cm^2$ with a wavelength of 350 nm, corresponding to the external quantum efficiency (QE) of 40.5%. This is comparable to the GaN *p-i-n* photodiodes reported by Carrano *et al.* [6] (QE~35%) and Hove *et al.* [7] (QE~48%).

Figure 3 also shows a photoresponse arising from AlGaN layer. For λ>325 nm the light is increasingly absorbed in the AlGaN layer as the photon energy increases and the responsivity becomes much larger than for λ<325 nm, since most of the photocarriers don't have to surmount the AlGaN/GaN discontinuity to be collected. This is coinciding with the result of our reflection measurement, which shows the bandedge of the AlGaN is at 325 nm. [8] In

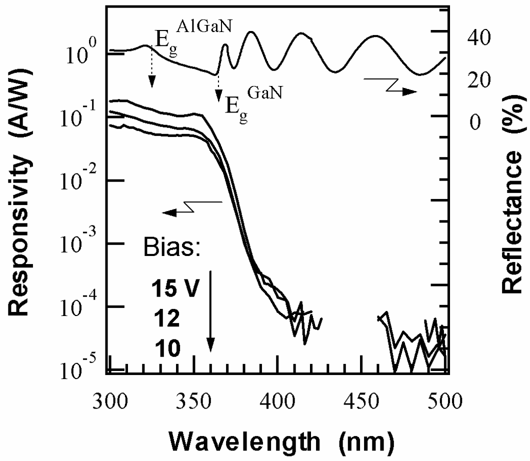

Fig. 3. Responsivities of the low dimensional AlGaN/GaN heterostructure MSM PD bias at 15, 12, 10 V, respectively, under the irradiation power density of 10 $\mu W/cm^2$. The reflectance spectrum of the heterostructure wafer is also shown for identifying the bandedges of AlGaN and GaN.

this condition, the photocurrent relies on emission processes from either the Schottky or the 2DEG channel.

4. Conclusions

The MSM-PDs based on AlGaN/GaN heterostructure operating in the UV region were fabricated and characterized. These photodetectors exhibited low dark current and high responsivity in the UV region. The photodetectors that are fabricated in this structure provide the possibility to combine light detection, signal amplification and processing into a single structure.

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