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A MSM Photodetector on p-type GaN for UV Image system

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I. Introduction

The market of GaN related UV photodetector is growing for the commercial application to the healthcare, ozone-layer monitoring, and fire alarm. Several types of GaN-based photodetectors have been investigated such as the p-i-n diode [1], [2], the Schottky barrier photo-detector [3], [4], and the metal-semiconductor-metal (MSM) photodetector [5], [6]. Among them, the MSM photodetector is an attractive choice for low cost and general-purpose applications. While its simplicity of fabrication, low noise and high responsivity, the MSM structure on an n-GaN layer has been reported suffering from a leakage current. This is due to the thermionic emission over the Schottky barrier height of typically around 1 eV. It is not simple to achieve a high electron barrier by just selecting high workfunction metals. Instead, the hole barrier in the p-GaN Schottky diode can be increased as high as 3 eV, which is very desirable for low leakage current.

In this paper, we proposed and fabricated a MSM UV photodetector on an auto-doped p-type GaN, which was grown on a silicon substrate. We investigated the effects of deep traps and the silicon substrate with regard to the photoresponsive currents in the MSM photodetector. If the proposed MSM detectors are integrated with the enhancement mode n- MOSFET on the p-GaN substrate, it will prove to be useful for UV image sensing.

II. Fabrication of GaN SB-MISFET

We fabricated the MSM photodetector onto a silicon-auto-doped p-type GaN epitaxial layer. It was grown on an (111)-oriented n-type silicon substrate by metal organic chemical vapor deposition (MOCVD). We did not use any intentional dopant sources for the epitaxy but chose the high temperature AlN buffer layer. The grown 700 nm thick p-GaN layer had a hole concentration of 2.1×10^{17} cm^{-3} and hole mobility of 46 cm^2/Vs. In previous work, the enhancement type MOSFET had been fabricated on the same type of epitaxial layer [7]. Fig. 1 (a) shows the photomicrograph and the schematic structure of the GaN MSM UV photodetectors, which were designed and fabricated in this study. The finger space and width of MSM photodetector are 5 to 10 um. Fig. 1 (b) shows band structures without and with a bias of -5 V, respectively. The fabrication process flows are mentioned below. A 500 Å-thick Si_3N_4 layer was deposited on p-GaN layer for passivation between two electrodes by a plasma enhancement chemical vapor deposition (PECVD) process at 300 °C. Two electrode metal contacts were formed on the p-GaN layer by depositing 500 Å-thick aluminum. The electrical and optical properties of the MSM photodetectors were characterized using HP4155 and an optical set-up with a 150 W Xenon arc lamp.

III. Results and Discussions

Fig. 2 shows the current-voltage characteristics of the fabricated MSM photodetector, according to the bias conditions. Fig. 2(a) shows the statistical distribution of the leakage current density for the fabricated MSM photodetectors, whose finger space and width were from 5 to 10 um. Over 90 percent of the 35 devices show a leakage current density within 3 nA/cm^2, which is significantly low compared to the previously reported MSM or Schottky type GaN photodetectors fabricated on n-GaN layer [3-6].

Fig. 2(b) exhibits the I-V characteristics of the MSM photodetector, which were measured in the dark and under UV and visible illumination, respectively. Under the 340 nm UV, the photo-current was enhanced by nearly five orders of magnitude from the dark current at 5 V bias. The UV photo-current increases sub-linearly with bias over 2V, which implies no gain mechanisms in the bias regime. It increases rapidly near the bias of 0.1-1 V.

Fig. 3(a) shows the spectral responsivity of the fabricated MSM photodetector according to the applied bias conditions. The cutoff wavelength was about 365 nm and the UV/visible rejection ratio was as high as 400 under 4 V bias as shown in the inset of the figure. The ratio was not reasonably high enough when considering the above-mentioned very low leakage current under dark condition. Observing the I-V characteristics in Fig. 2(b), the 500 nm visible photo-current was enhanced as well. But the bias effect was not significant in the visible photo-current.

They may be originated from the defects in the auto-doped p-GaN on silicon substrate during the epitaxy. As shown in Fig. 3(b), the PL spectrum for the p-type GaN layer, which is used for fabrication of the MSM PD in this work, exhibits the broad intensities above the GaN peak wavelength at 365 nm. This means that the response to the visible light is due to the distributed trap levels (E_t) in the bandgap. The conduction mechanism of unintentionally p-doped GaN has been proposed as the nitrogen site silicon atoms, which are out-diffused from the substrate. The defect mechanism is not clearly understood yet [7].

If we improve the p-GaN quality and optimize the process conditions, the UV/visible rejection ratio can be enhanced greatly. Since the MSM structure is fully compatible with the source and drain of Schottky barrier MOSFET [8], it will be easy to integrate the MOSFET circuit and accomplish the UV image sensors.

IV. Conclusions

We fabricated an MSM UV photodetector on a p-type GaN epitaxial layer grown on an n-type silicon substrate. Electrical and optical characteristics of the photodetector were investigated. The dark current density was 2 nA/cm^2, the cutoff wavelength was 365 nm, and the UV/visible rejection ratio was several hundreds. The possible mechanisms of low wavelength selectivity are distributed trap levels in the bandgap of the GaN epitaxial layer and/or the photo carriers by the visible light in the n-type silicon substrate. By optimizing the growth and process conditions, the wavelength selectivity of the p-GaN MSM photodetector will be greatly improved. By being integrated with the Schottky barrier MOSFET devices, the p-GaN MSM photodetector can be applied to UV-image sensor systems.

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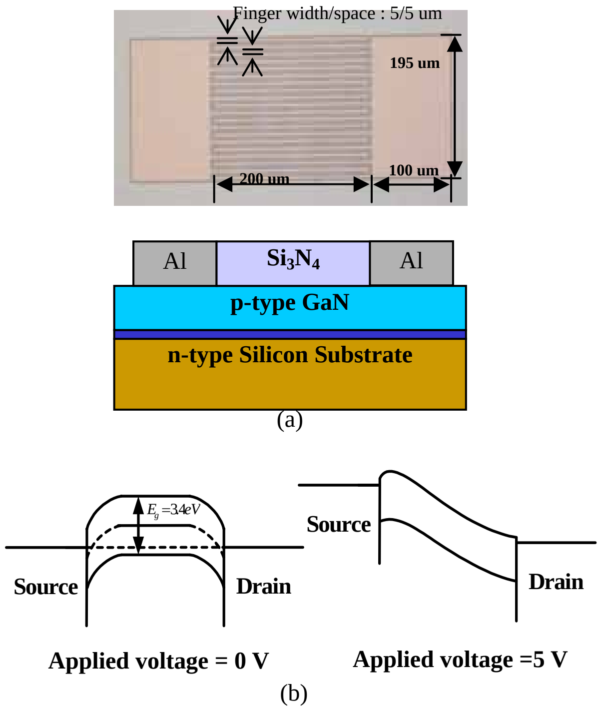

Fig. 1. Photomicrograph and schematic diagram (a) of the GaN MSM UV photodetector, and band structures of the MSM detector under 0 V and 5 V bias (b).

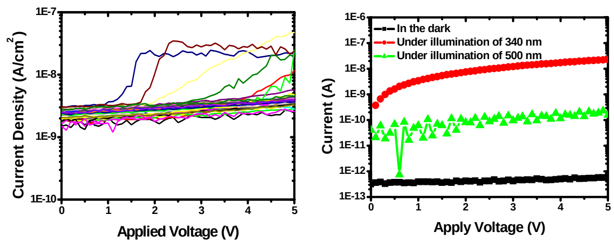

Fig. 2. Leakage current density distribution of the fabricated MSM photodetectors (a), I-V characteristics of fabricated MSM photodetector in the dark and under visible and UV illumination conditions (b).

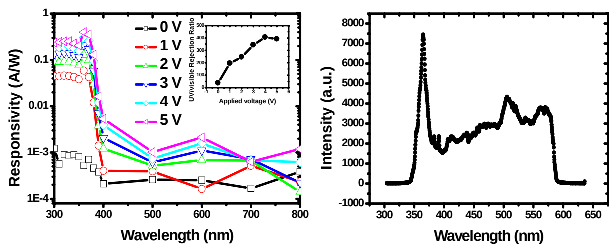

Fig. 3. Spectral responsivity variation according to the applied bias condition (a), (inset is the bias dependent UV-to-visible rejection ratio), photoluminescence spectrum of the p-type GaN epitaxial layer (b).