Visible blind $p^+–\pi–n^––n^+$ ultraviolet photodetectors based on 4H–SiC homoeipilayers

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Abstract

$p^+–\pi–n^––n^+$ ultraviolet photodetectors based on 4H–SiC homoeipilayers have been presented. The growth of the 4H–SiC homoeipilayers was carried out in a LPCVD system. The size of the active area of the photodetectors was $300 \times 300 \mu\text{m}^2$. The dark and illuminated $I–V$ characteristics had been measured at reverse biases form 0 to 20 V at room temperature, and the illuminated current was at least two orders of magnitude than that of dark current below 13 V bias. The peak value zones of the photoresponse were located at 280–310 nm at different reverse biases, and the peak value located at 300 nm was 100 times greater than the cut-off response value in 380 nm at a bias of 10 V, which showed the device had good visible blind performance. A small red-shift about 5 nm on the peak responsivity occurred when reverse bias increased from 5 to 15 V.

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1. Introduction

The ultraviolet photodetector based on silicon carbide [1], group III-nitrides [2] and diamond [3] has numerous applications on medical, military and environmental engineering. 4H–SiC can be used for fabricating photodetectors with high quantum efficiency, low leakage current, and visible blindness or even solar blindness because of its very high breakdown field, outstanding radiation hardness, excellent chemical and mechanical rigidity, thermal conductivity [4] and a wide band gap of 3.26 eV [5]. SiC UV photodetectors with different structures have been fabricated for years. During these types, photodetectors with pn junction [6] usually have been demonstrated, and these with improved scheme such as 4H–SiC $p^+–\pi–n$ [7], 6H–SiC $p–i–n$ [8], 4H–SiC avalanche pn [9,10] were also demonstrated. Although some of these types of photodetectors have achieved good performance, the endeavor of pursuing better device performance by optimizing detector structure will never cease. In this paper, we reported on the fabrication of 4H–SiC $p^+–\pi–n^––n^+$ ultraviolet photodetectors for the first time. The dark $I–V$ characterization and the ultraviolet response of samples were studied, and they showed that the photodetectors had low dark current and high detectivity in the UV range and can operate insensibly in visible/IR background occasion.

2. Device structure and fabricating process

The 4H–SiC homoeipilayers were grown at about 1500 °C by low-pressure hot-wall chemical vapor deposition (LPCVD) on $1 \times 1 \text{cm}^2$ pieces of n$^+$-doped (0 0 0 1) 4H–SiC substrates with 8° off-axis toward (11–20) obtained from Cree Research Inc. SiH$_4$ and C$_2$H$_4$ diluted in H$_2$ were used for silicon and carbon source, respectively, B$_2$H$_6$ was used for in situ p-type dopant. The homoepitaxial growth of 4H–SiC epilayers by LPCVD was previously reported by Sun et al. [11]. Three epilayers were grown in sequence on the substrate including a 2000 nm unintentional n layer, a 200 nm p layer and a 85 nm $p^+$ cap layer. The nominal
The doping levels in the p and p+ layers were $3 \times 10^{16}$ and $2 \times 10^{19}$ cm$^{-3}$, respectively, and that of the unintentional n layer was about $2 \times 10^{17}$ cm$^{-3}$.

The active area of the photodetector was $300 \times 300 \mu$m$^2$. The square mesa was 500 nm deep, and was etched by the inductively coupled plasmas (ICP) with a 1000 nm Al mask. A 500 nm oxide grown by PECVD at 280 °C for 0.5 h was utilized to form a passivation layer after the mesa was cleaned by removing the sacrificial layer which was formed by surface oxidation. The p+ layer ohmic contact was formed by sputtering 50 nm Pt on the mesa after the oxide removed by lithography, and the n+ substrate ohmic contact was formed by sputtering 100 nm Ni on the whole back. Both contacts were then annealed in vacuum at 1000 °C for 1 min. 100 nm Cr and 1000 nm Au were both sputtered on the back and front of the chip to form alloy electrodes. The ultraviolet light path window opened on the Pt layer with a side obliquity of 20° to the mesa was formed by lithography, the sizes of the optical window and the wire bonding were $200 \times 200$ and $100 \times 300 \mu$m$^2$, respectively. The Nomarski view and the mesa structure of the photodetector are shown in Fig. 1.

3. Device performances

3.1. Dark I–V measurement

The dark and ultraviolet illuminated current–voltage characteristics of samples were measured at room temperature. Fig. 2 shows the obtained I–V characteristics both in the dark current and illuminated current increased along with the increasing reverse voltage. The dark current was around 3.2 pA at the beginning of the instrument running, then it increased slowly from 3.2 pA to 20 pA when the reverse voltage increased from 0 to 13 V, while the applied reverse bias was higher than 13 V, the dark current increased more quickly. The curve of the illuminated current was relatively flat especially when the applied bias was between 5 and 13 V, though the ratio between the illuminated current and the dark current decreased as the applied voltage increased, the illuminated current was at least two orders of magnitude higher than the dark current when the reverse bias was between 0 and 13 V. It could forecast that the photodetector would achieve better performance at certain bias below 13 V.

3.2. Responsivity measurement

The photoelectric experiments were carried out in a common photoreponse set-up with a Xe lamp, a Jobin Yvon H25 (monochrometer integrated with chopper) and a KEITHLEY 617 programmable electrometer for DC mode measurement. A commercial UV-enhanced Si photodiode was used to calibrate the optical system. Response characteristics of the photodetector was investigated by measuring the DC photocurrents as a function of reverse bias using 200–400 nm ultraviolet light from the Xe lamp. Fig. 3 shows the responsivities of the p+–π–n–n+ ultraviolet photodetector under reverse biases of 0, −1, −5, −10, −12, and −15 V, respectively. The responsivity of the whole wavelength (200–400 nm) increased when the applied bias increased. The peak value zones were located at 280–310 nm. 4H–SiC is indirect semiconductor, and does not have a sharp cutoff edge at the band edge, the absorption coefficient increased slowly from 400 nm as the wavelength decreased. While at wavelength shorter than 280 nm, the responsivity decreased as the wavelength decreased. This decrease is most likely due to the influence of the higher surface recombination [12]. At a bias less than 5 V the peak value was located at 295 nm which was less than the previous result [13]. A small red-shift about 5 nm occurred when the reverse bias was higher than 5 V. The red shift is caused by the widening of the depletion width of the p layer of the detector [10]. Generally, the p-type material shows a much higher photoresponse than the n-type material [14], the diffusion length for electrons is much larger than that for holes, which explains the larger
and characterized by the dark $I-V$ characteristics and photoresponse spectra at room temperature. These photodetectors fabricated on 4H–SiC homoepilayers showed low dark current and high detectivity in the UV range. The dark and illuminated $I-V$ characteristics were measured at reverse biases form 0 to 20 V, the obtained dark current was 3.2 pA at tiny bias and was around 20 pA at -13 V, and the illuminated current was at least two orders of magnitude than that of dark current below 13 V bias. The photoresponse spectra at a wavelength range of 200–400 nm were measured under reverse biases of 0, -1, -5, -10, -12, and -15 V, respectively, and it showed that the peak value zones of the photoresponse were located at 280–310 nm, and a small red-shift about 5 nm on the peak responsivity occurred when reverse bias increased from 5 to 15 V. The peak value located at 295 nm was above 100 times greater than the cut-off response value in 380 nm at a bias of 10 V, which showed the photodetector had good visible blind performance.

### References


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**Fig. 2.** $I-V$ characterization of the 4H–SiC $p^+–\pi–n^+–n^+$ ultraviolet photodetector under dark and ultraviolet illuminated situation.

**Fig. 3.** Responsivities of the 4H–SiC $p^+–\pi–n^+–n^+$ ultraviolet photodetector under reverse biases of 0, -1, -5, -10, -12, and -15 V, respectively.

The photoresponse of p-type material at long wavelengths. The red-shift of the peak ceased at -10 V and the peak was finally located at 300 nm. The peak values were above 100 times greater than the cut-off response value in 380 nm at a reverse bias less than 10 V. It suggested that the device had a good visible blindness detectivity. Although the responsivities increased when the reverse bias increased from 12 to 15 V, they became turbulence in the peak value zones, and the ratio between the peak value and the cut-off value dropped, especially at the bias of -15 V. The responsivity characterization became worse when the applied bias was higher than 10 V, it indicated that the photodetector had good visible blind performance at an applied bias of 10 V.

### 4. Conclusions

$p^+–\pi–n^+–n^+$ ultraviolet photodetectors with the size of the active area of 300 × 300 μm² have been demonstrated