Technology and Performance of Metal-Semiconductor-Metal AlGaN/GaN Heterostructure Ultraviolet Photodetector

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Abstract AlGaN/GaN heterostructure metal-semiconductor-metal (MSM) structure ultraviolet (UV) photodetector with Ni/Au electrodes is fabricated. Opto-electrical characteristics and current-voltage characteristics of the detector are investigated. It is found that the detector has two spectral response ranges. The peak response is 0.717 A/W at 288 nm and 0.641 A/W at 366 nm. The quantum efficiency is 308% at 288 nm and 217% at 366 nm.

Key words detectors; ultraviolet; AlGaN/GaN; metal-semiconductor-metal; photodetector

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金属-半导体-金属结构 AlGaN/GaN 异质结紫外探测器技术及特性

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摘要 制备了金属-半导体-金属(MSM)结构的 AlGaN/GaN 异质结紫外探测器，探测器采用 Ni/Au 金属作为电极。实验研究了探测器的光电响应特性和 *I-V* 特性。此探测器具有两个光谱响应范围，光谱响应的峰值响应率分别为 288 nm 处 0.717 A/W 和 366 nm 处 0.641 A/W，峰值处的量子效率分别为 288 nm 处 308% 和 366 nm 处 217%。

关键词 探测器；紫外；AlGaN/GaN；金属-半导体-金属；光电探测器

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1 Introduction

In the last few years, ultraviolet (UV) photodetectors have drawn much attention because of military and civil applications in solar UV monitoring, UV astronomy, engine control, biology, flame sensors, chemistry and communication[1-4]. In the past, a lot of semiconductor UV detectors based on GaN, SiC, ZnO or diamond doped were prepared due to their wide bandgap[5-8]. The development of GaN-based UV photodetector has been driven by numerous applications in defense, commercial and scientific areas. Among them, technological and scientific advances based on high Al composition AlGaN semiconductor materials have led to a renewed interest in ultraviolet photodetectors, especially in solar-blind photodetectors.

Metal-semiconductor-metal (MSM) type photodetectors simplify the growth and fabrication processes as the necessity for Ohmic contacts on high doped layers is eliminated. The interest in MSM photodetectors has grown up due to their unique properties in high-speed

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UV detection. AlGaN/GaN MSM structure UV photodetectors have potential to develop the high speed optoelectronic integrated circuit because of their low dark current, high gain, fast response and large bandwidth.

2 Experiment

All the epitaxial layer structures used for the photodetectors in this study are grown on c-plane (0 0 0 1) sapphire substrate by metal organic chemical vapor deposition (MOCVD). Prior to the growth, the sapphire substrates are firstly cleaned *in situ* with pure hydrogen at 1100 ℃. Trimethylgallium, trimethylaluminum and ammonia are used as the source materials of Ga, Al and N, respectively. Silane and biscyclopentadienyl-magnesium are used as the n- and p-type dopant sources, respectively. The heterostructure consisted of a 2 μm thick undoped GaN layer, and a 200 nm thick AlGaN layer. Aluminum composition of the AlGaN layer was determined to be about 30% by X-ray diffraction measurements.

The AlGaN/GaN heterostructure is fabricated into an MSM structure device consisting of two fork-shaped interdigitated Schottky contacts on the AlGaN surface, as shown schematically in Fig. 1(a). MSM detector samples are fabricated by using four mask levels. The Schottky contact fingers with a Ni/Au (50 nm/200 nm) bilayers are defined by optical lithography and then formed by e-beam evaporation. Ni/Au alloy is evaporated and after lift-off process, thermal annealing at 450 ℃ is applied for 15 min a rapid thermal annealing system. The device active area is 500 μm × 500 μm with 10 μm/10 μm finger width/spacing, as shown schematically in Fig. 1(b).

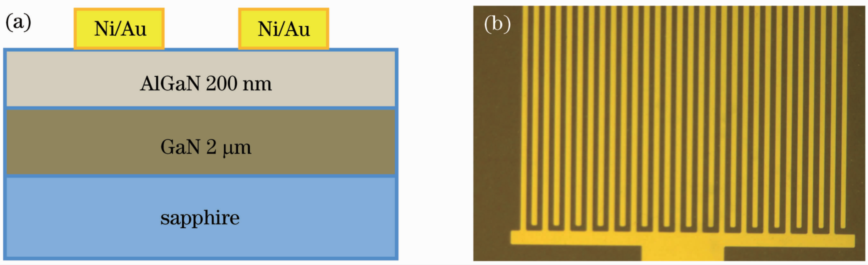

Fig. 1 (a) Schematic diagram of the AlGaN/GaN MSM structure device; (b) top view of the AlGaN/GaN MSM structure device

3 Results and discussion

Room temperature current-voltage (I-V) characteristics of the prepared photodetector are measured using high resistance Keithley 4200 parameter analyzer, direct current (DC) probes with triax output and low-noise triax cables. DC current is measured as voltage is applied to the detector.

Spectral responsivity measurements were done using a 150 W xenon light source, 1/4 m Digikrom DK240 monochromator, multi-mode UV fiber, SR830 digital signal processor (DSP) lock-in amplifier and DC voltage source. Xenon lamp output fed into the monochromator. The monochromator output is chopped and coupled to a multimode multimode UV fiber using a UV-enhanced focusing lens. The detectors are illuminated by the optical output coming out from the fiber which is calibrated using the calibrated photodetector. The detectors are biased with a DC voltage source up to 10 V, and the resulting photocurrent is measured using the lock-in amplifier.

The spectral response measured at a chopper frequency of 70 Hz and under a bias voltage of 10 V is shown in Fig. 2. The spectrum exhibits two obvious response steps, a AlGaN bandpass spectral response ranging from 240 nm to 300 nm in solar-blind region, and a GaN bandpass spectral response at about 366 nm in visible-blind region. This detector can work efficiently at two frequency regions, with the peak response are 0.717 A/W at 288 nm and 0.641 A/W at 366 nm, respectively.

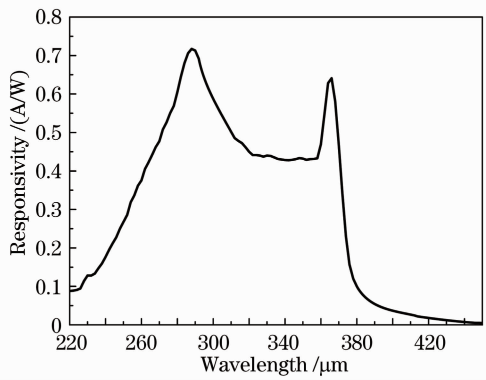

Fig. 2 Spectral response of the AlGaN/GaN MSM structure device at a bias voltage of 10 V

It has been firmly shown that the AlGaN thin films can work as an efficient photo response layer, especially it shows a photoresponse in deep UV range, i. e., below 290 nm. Below 290 nm almost no light reaches the earth's surface due to atmospheric absorption by ozone in the upper atmosphere. This creates a universal low background window called the solar-blind window. For 366 nm, it is possible to create a spectral fingerprint which can be used to identify the presence of specific biological-agent in real-time. A more civilian application of this photodetector is the monitoring of high voltage electrical transmission equipment.

The characteristic of quantum efficiency with 10 V bias voltage is presented in Fig. 3. The quantum efficiency is 308% at 288 nm and 217% at 366 nm. The high quantum efficiency has been attributed to the carrier-trapping process occurred in the metal-semiconductor interface. For MSM structure with Schottky contacts, the electric field is concentrated in the vicinity of the Schottky contact and decay rapidly in the vertical direction. While the Schottky contact is located at the AlGaN surface in the detector, the depletion region is mainly concentrated in the AlGaN layer. Therefore, the responsivity at 288 nm is larger than that at 366 nm.

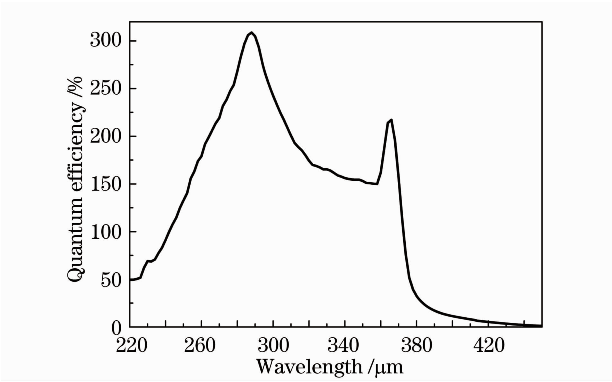

Fig. 3 Quantum efficiency of the AlGaN/GaN MSM structure device at a bias of 10 V

The measured *I*-*V* characteristics of the detector are shown in Fig. 4. Under the light illumination, photo absorption excited excess carriers in the active layer region will move toward the electrodes under the action of applied electric field and thus make extra contribution to the current. So, the current of devices under the illumination of light is larger than the dark current. It is also observed that the detector photocurrent at 288 nm is larger than that at 366 nm. This indicates that the absorption quantum efficiency is a function of the excitation wavelength.

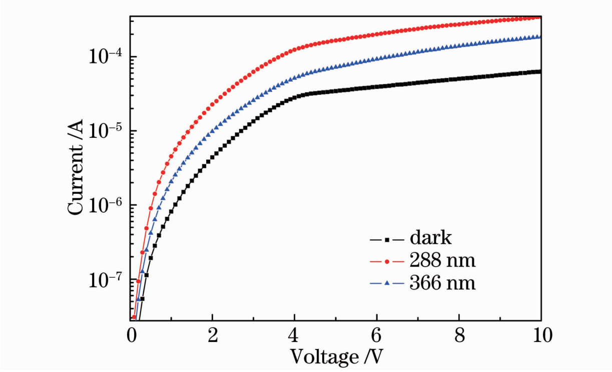

Fig. 4 Current-voltage characteristics of the detector under dark and different light illuminations

4 Conclusion

The AlGaN/GaN heterostructureis fabricated and tested as a MSM photodetector. The opto-electrical characteristics and current-voltage characteristics of the detector are investigated. The peak response is 0.717 A/W at 288 nm and 0.641 A/W at 366 nm at the bias voltage of 10 V. The detector can work efficiently at two frequencies scope.

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