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Photocurrent properties of high-sensitivity GaN ultraviolet photodetectors*

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GaN epilayers were grown on sapphire substrates by metal-organic chemical vapour deposition. Metal–semiconductor–metal photoconductive detectors were fabricated using this material. The photocurrent properties of the detectors were measured and analysed. The spectrum response shows a high sensitivity in the wavelength region from 330 to 360nm, with a peak at 358nm and a sharp cutoff near 360nm. The maximum responsivities at 358nm were 700A/W (2V) and 7000A/W (30V). The relationship between responsivity and bias indicates that the responsivity increases linearly with bias until 30V. The influence of the spacing between two electrodes on the detector responsivity was also studied.

Keywords: GaN, photocurrent, photodetectors, responsivity
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1. Introduction

Gallium nitride (GaN) has been considered to be one of the most promising materials for the fabrication of high responsivity and visible-blind ultraviolet (UV) detectors due to its unique properties, such as direct- and wide-band-gap (3.4eV) and high-saturation–electron drift velocity, etc. Visible-blind UV photodetectors have a number of applications including missile detection, flame sensing, and solar UV monitoring. The GaN material exhibits a lot of merits for fabricating photodetectors over traditional materials. For instance, the responsivity is improved greatly due to its direct band gap; the detector can be used in visible and infrared radiation background for it only senses ultraviolet light; the spectrum range can be modulated by doping Al, In and other elements in GaN; its dark-current is quite low, and so on. Reports in these fields have been published in recent years.[1−6] The fabrication of high-performance detectors requires high-quality materials, proper device design and advanced technology. In this paper, high-quality GaN epilayers are grown on sapphire substrates by metal-organic chemical vapour deposition (MOCVD), a low-temperature MOCVD-grown GaN is obtained as the buffer layer. Photoconductive detectors are fabricated using this material. The photocurrent properties of the detectors are measured and analysed, and the influence of the spacing between two electrodes on the detector responsivity is also studied.

2. Experiment

GaN films were grown on sapphire substrate by MOCVD with trimethylgallium (TMG) and ammonia (NH_3) as the gallium and nitrogen sources, respectively. Hydrogen was used as a carrier gas. In order to relax the lattice mismatch between GaN and sapphire and thermal stress, a low-temperature (480°C) MOCVD-grown GaN buffer layer with a thickness of a few nanometres was prepared before the growth of the epitaxial GaN film on the sapphire (0001) substrate. The thickness of the GaN epitaxial layer grown at a high temperature was about 2μm. In the high-resolution x-ray diffraction pattern, the full width at half maximum (FWHM) of the diffraction lines for the GaN sample was 265.3s. A strong band edge emission was observed in the photolumi-

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nescence spectra of GaN at 3.44eV, the FWHM of which is 40meV. Surface morphologies were observed using atomic force microscopy (AFM), showing that the surface was smooth. These measurements indicated that this GaN material has a good quality. The background carrier density and electron mobility measured using Hall effect were $n \sim 4.1 \times 10^{16}\text{cm}^{-3}$ and $\mu \sim 140\text{cm}^2/\text{Vs}$, respectively. A detailed description of the materials will be published elsewhere. Interdigitated finger electrodes were adopted in the design of the photoconductive detector. In order to investigate the influence of the electrode spacing on the sensitivity of the detector, two kinds of samples No.1 and No.2 were fabricated, the spacing between the interdigitated finger electrodes were 10μm and 15μm, respectively. Both the length and width for the electrodes were the same. In order to obtain good ohmic contacts, Ti/Al/Pt/Au (15/100/40/200nm) multilayers metal were evaporated on the surface of the GaN epilayers by electron beams, and the electrode patterns were made by using lift-off technology. Then the samples were annealed in a rapid thermal annealing furnace in nitrogen atmosphere. The current-voltage (I-V) characteristics of the electrodes in the device were measured to be linear, indicating that the electrodes were of good ohmic contacts. Figure 1 shows the schematic diagram of the GaN ultraviolet photoconductive detector.

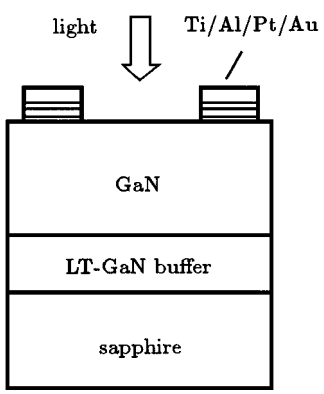


Fig.1. Schematic structure of a GaN ultraviolet photoconductive detector.

3. Results and discussion

The GaN detector's spectrum is given by the relationship between the responsivity R and wavelength λ of the detector. The spectral responses of the samples were measured using a xenon light source. Light was first changed into pulse-modulated light by a frequency-controllable chopper, and the pulse-modulated light was then changed into a monochromatic light by a monochromator. The monochromatic light irradiated vertically on the sample and generated the photoelectric current I_0. A lock-in amplifier was used to measure the weak photoelectric current signals. System control, data acquisition and photoelectric current I_0-wavelength λ curve were all completed by a computer. Light power P_0 was measured by a GG3001B light power meter. Then the responsivity R can be calculated. The photoelectric response curves of samples No.1 and No.2 under a 2V bias are shown in Fig.2. These curves indicate that the responsivity of the detector is high at wavelengths from 330 to 360nm, while the peak wavelengths of samples No.1 and No.2 are both at 358nm; the peak responsivities of them are 700A/W and 290A/W, respectively. Samples No.1 and No.2 both show a sharp cut-off edge near 360nm. The responsivity of the sample is very weak when the wavelength is larger than 375nm. This shows that the GaN detectors are insensitive to the visible and infrared radiation. The responsivity of the sample is reduced at short wavelengths. The primary reason is that the short-wavelength light could be completely absorbed by a very thin film of the detector surface, making the photo-induced carriers concentrated, so the carrier recombination rate is enlarged. Due to this reason, the responsivity of a sample at a short-wavelength is lower than that at a long wavelength. Because the light intensity of the xenon lamp is already very weak at 330nm, so the responsivity has been measured at wavelengths larger than 330nm. The responsivity of the GaN detector grown on a sapphire is much larger than the GaN detectors of the same structure grown on a silicon substrate which we fabricated earlier.[6] The explanation for this is mainly that the film quality of the former is better than the latter. Because the impurity and defects will influence the life-time of carriers, when there are few impurity and defects in the GaN material, the life-time of carriers will be longer. So the responsivity of the detectors is improved. Figure 2 also shows the different responsivities of samples No.1 and No.2 under the same bias. The difference can be explained in terms of the responsivity of photodetectors, expressed as[8]:

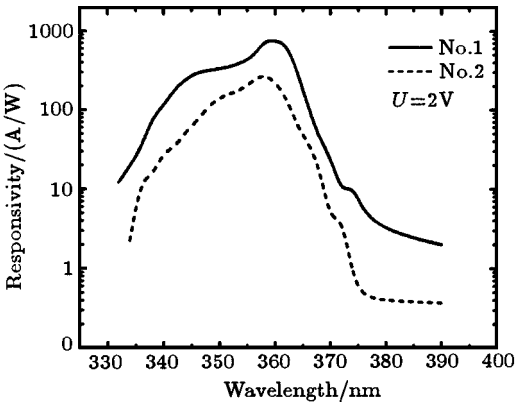


Fig.2. Spectral response curves of samples No.1 and No.2 under a 2V bias.

$$R = g\frac{\eta q}{h\nu} = \frac{\eta q \tau \mu_{\mathrm{e}} V}{l^2}(1+b),$$

where g is the photocurrent gain, q is the electron charge, h is Planck's constant, ν is the light frequency, l is the distance between the two electrodes, τ is average life-time of the light-induced carriers, η is the quantum efficiency, μ_{e} is the electron mobility, μ_{p} is the hole mobility, and $b = \dfrac{\mu_{\mathrm{e}}}{\mu_{\mathrm{p}}}$. In this equation, η, τ, μ and b are all related to the material property. If the detectors are fabricated using the same material, the spacing l between the two electrodes will influence the responsivity greatly. The calculated responsivity is close to the measured result at 358 nm. Thus it can be seen that how to choose a proper electrode spacing in the electrode pattern design is very important to the detector responsivity.

The relationship between the responsivity and bias was measured. This relationship for sample No.1 at 358nm is shown in Fig.3. It shows that the responsivity increases linearly with the bias and no saturation phenomenon is observed until 30V. The analysis we made is that for the photoconductive detectors, the relationship between the responsivity and bias can be explained by the above equation. The responsivity increases linearly with increasing bias; however, the responsivity tends to saturate under several voltage bias (e.g. in GaN detectors grown on silicon).[6] This phenomenon is possibly related to the saturation of the electron drift velocity. It means that in high electric field the drift velocity of carriers will depart from the ohmic law $\nu = \mu E$,[8] where v is the carrier average drift velocity, and E is the electric field. According to previous reports, the maximum saturated drift velocity is $\sim 3 \times 10^7 \mathrm{cm/s}$,[8] while the electron mobility measured in our material is $\sim 140 \mathrm{cm}^2/\mathrm{Vs}$. The carrier average drift velocity, estimated under 30V by using the ratio between electrode distance and mobility, does not reach the saturated electron drift velocity, so the responsivity saturation phenomenon was not observed. Results indicate that if the quality of the GaN material is higher, the transported carriers scattered by impurity and defects will be fewer, the saturated drift velocity will be higher, and thus the linear working voltage range of the detector will be wider.

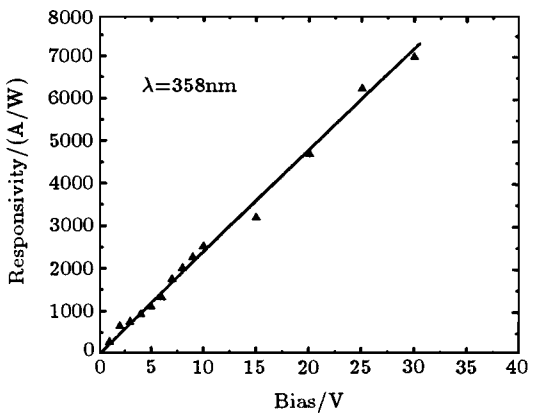


Fig.3. The relationship between responsivity and bias of sample No.1 at 358nm.

4. Conclusion

GaN ultraviolet photoconductive detectors have been fabricated on high-quality GaN layers grown by MOCVD. The spectrum response shows a high responsivity in a narrow range of wavelengths from 330nm to 360nm. A sharp cut-off edge near 360nm was observed. The maximum responsivity measured under 30V at 358nm is about 7000A/W. The relationship between responsivity and bias shows that the change of responsivity with bias increases linearly until 30V. The influence of the spacing between the two electrodes on the detector responsivity was investigated, and the relation between saturated drift velocity and bias was also discussed. The result shows that the responsivity will be improved if the spacing between the two electrodes is properly reduced. The higher the GaN material quality, the higher the detector responsivity and the wider the working voltage range.

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