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GaN based ultraviolet narrowband photodetectors

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Abstract. In this work ultraviolet metal-semiconductor-metal photodetectors with semi-transparent Ni/Au interdigitated electrodes based on GaN/*i*-GaN/c-Al_2O_3 heterostructure were fabricated. The current-voltage, transient photoresponse on-off and spectral characteristics of the formed photodetectors were studied. It was found that the devices have a maximum responsivity at a wavelength of 364 nm with full width at half maximum of 11 nm, thus the presented PDs are narrowband.

Keywords: GaN, ultraviolet photodetector, narrowband photodetector, metal-semiconductor-metal

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Узкополосные ультрафиолетовые фотодетекторы на основе GaN

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Аннотация. В данной работе были изготовлены ультрафиолетовые фотодетекторы типа металл-полупроводник-металл с полупрозрачными Ni/Au встречно-штыревыми электродами на основе гетероструктуры GaN/*i*-GaN/c-Al_2O_3. Исследованы их вольтамперные характеристики, быстродействие и спектральные характеристики. Было обнаружено, что устройства имеют максимальную чувствительность на длине волны 364 нм с полной шириной на уровне половины высоты 11 нм, таким образом, представленные ФД являются узкополосными.

Ключевые слова: GaN, ультрафиолетовый фотодетектор, узкополосный фотодетектор, металл-полупроводник-металл

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Introduction

At present, ultraviolet (UV) photodetectors (PD) play a critical role in numerous technological applications, ranging from environmental monitoring and control of ultraviolet emitters to various alarm systems [1]. In recent years, there has been a growing demand for high-performance UV PDs with enhanced sensitivity, speed, reliability and high selective spectral responsivity. The latter characteristic is especially important for PDs used in optical communication and biophotonics applications [2].

The quest for efficient and reliable narrowband PDs has prompted significant research efforts aimed at exploring new materials and device architectures. In this context, GaN epitaxial layers have emerged as promising candidates owing to their unique properties, including a wide bandgap (3.4 eV), high electron mobility and excellent thermal and chemical stability [3].

Currently, there are various types of PDs designs. However, among them, the most attractive are the metal-semiconductor-metal (MSM) PDs, the advantages of which are fast operating speed, high sensitivity and simplicity of fabrication [1]. In this article narrowband UV MSM PDs fabricated on the GaN epitaxial layers are presented.

Materials and Methods

The 210 nm thick GaN epitaxial layers were grown by plasma-assisted molecular beam epitaxy (PA MBE) using Veeco GEN 200 industrial type MBE setup on *i*-GaN/c-Al_2O_3 templates pre-grown by metalorganic chemical vapour deposition. The synthesis occurred under conditions near unity ratio of gallium to nitrogen fluxes (slightly nitrogen-rich growth conditions). The surface morphology of the grown samples was examined using a scanning electron microscope (SEM). The conductivity type, concentration and mobility of charge carriers in the GaN epitaxial layers were assessed using Hall effect measurements based on the Van der Pauw four-point probe method.

Subsequently, MSM PDs with semitransparent Ni/Au (15 nm) interdigitated electrodes were fabricated using standard laser lithography technique, e-beam and thermal vacuum evaporation. Current-voltage (*I-V*), transient photoresponse on-off and spectral characteristics of the formed PDs were obtained.

Results and Discussion

SEM images (see Fig. 1, *a*, *b*) show that the obtained layers have a rough surface morphology, which may be due to slightly nitrogen-rich growth conditions. The rough surface morphology of epitaxial layers provides a large area of interaction between the active material and radiation, which can help increase the sensitivity of photodetectors based on them compared to detectors based on smooth epitaxial layers. As a result of Hall measurements, it was discovered that undoped synthesized layers have *n*-type conductivity, which is typical for III-N materials [4], with a carrier concentration of $n \sim 1.1\times10^{18}$ cm^{-3} and mobility of $\mu \sim 95$ cm^2/(V×s). This value of the charge carrier concentration can be associated with the 3-dimensional MBE growth of GaN layers (as can be seen from the surface morphology) and with a large number of defects in them. A photomicrograph of the formed PDs with semitransparent Ni/Au interdigitated electrodes is presented in Fig. 1, *c*.

The *I-V* characteristics of the UV PDs were measured both in the dark and under UV LED illumination (with a wavelength and power density of 365 nm and 12 mW/cm^2, respectively). It was noted that exposure to UV radiation resulted in an increase in current. However, it is evident from Fig. 2, *a*, that the PDs exhibit a very high dark current (6 mA at a bias of 1 V),

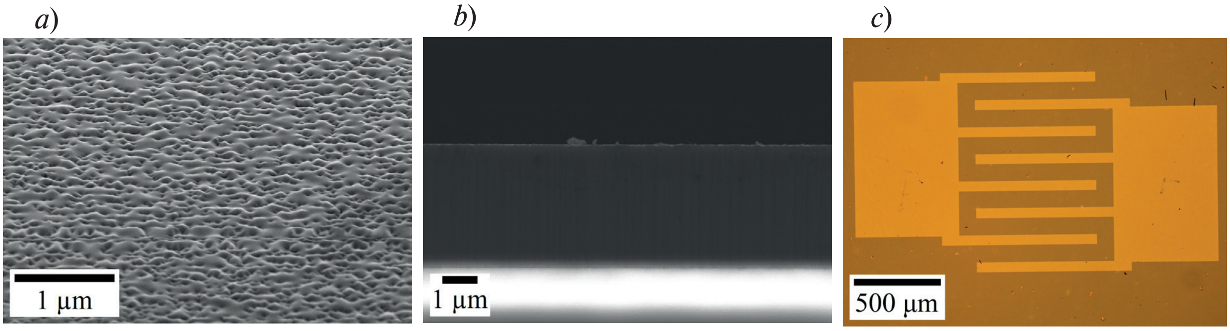

Fig. 1. SEM images of the GaN/*i*-GaN/c-Al_2O_3 epitaxial structure: isometry (*a*) and cross-section (*b*), photomicrograph of metal electrodes (*c*)

which may be attributed to the elevated defect density in the epitaxial GaN layers causing leakage channels [5]. The sensitivity of these photodetectors at a wavelength of 365 nm at a bias voltage of 1 V was 13.5 A/W.

The transient photoresponse on-off characteristics of the PDs were investigated at bias voltage of 1 V, under 365 nm rectangular light pulses with frequency 3 Hz and duty cycle 20% (see Fig. 2, *b*). The 10%–90% rise and fall times of the PDs were 1.4 and 84 ms, respectively. The PDs presented in this work demonstrate a faster response than the GaN-based PDs reviewed in other works [6]. The extended fall time primarily arises from the persistent photocurrent, where electrons have to pass through various trap states existing due to dislocations in order to recombine [7].

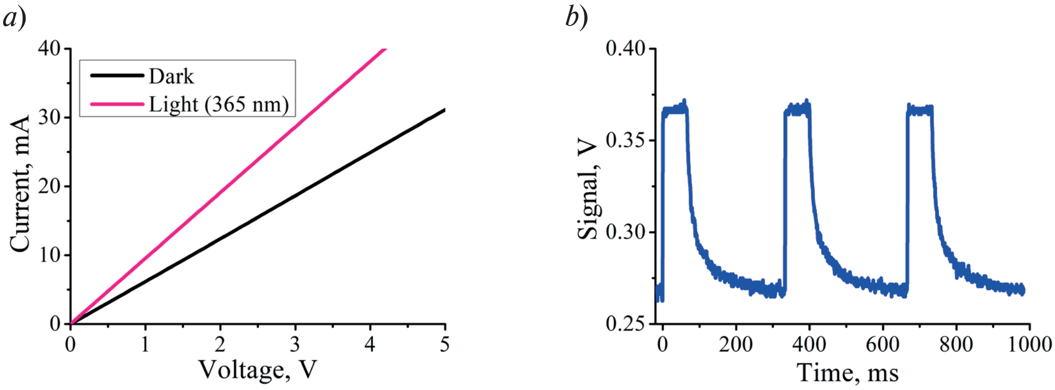

Fig. 2. *I-V* (*a*) and transient photoresponse on-off (*b*) characteristics of the formed PDs

The spectral response of the device over the wavelength range of 300–450 nm at 0.025 V bias is presented in Fig. 3. It can also be seen that the presented PDs have a narrowband detection configuration with a maximum at 364 nm and full width at half maximum (FWHM) of 11 nm. The observed characteristic could be linked to surface charges trapped at surface states or transitions associated with defect levels in GaN [8], but this requires further study.

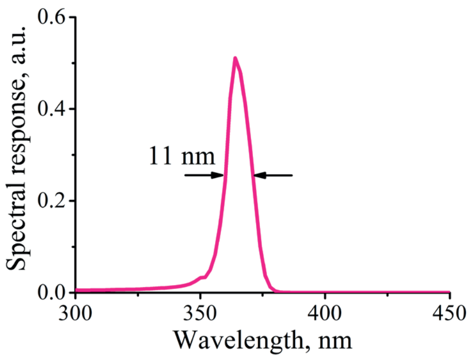

Fig. 3. Spectral response of the formed PDs

Conclusion

This report presents UV narrowband photodetectors based on GaN/*i*-GaN/c-Al_2O_3 heterostructures. These devices exhibit rapid response times of 1.4 ms. Furthermore, the fabricated devices achieve peak responsivity at a wavelength of 364 nm with a FWHM of 11 nm. Thus, PDs based on such GaN heterostructures, due to their high spectral selectivity, can be promising for use in communication systems and biophotonics.

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