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Varying load resistances of zinc oxide ultraviolet photodetectors: A simple method to change responsivity

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ABSTRACT

The metal–semiconductor–metal structured ultraviolet photodetector has been fabricated based on Zinc oxide thin films grown by a radio frequency magnetron sputtering technique, and Au is used as the contact metal. The dark current of the photodetector is as low as 1.17 nA at 3 V bias in the current–voltage measurements. The photoresponse properties are characterized by varying the load resistors (1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ and 22 MΩ), and the corresponding responsivities are 2.69, 1.27, 0.25, 0.02 and 7.20×10^{-4} A/W. It can be found that the responsivity of the photodetector is enhanced with the load resistors decreasing; however, the signal-to-noise ratio decreases. It is demonstrated that the best method to make the ZnO-based photodetector suitable for different application environments is with the appropriate load resistance.

1. Introduction

Zinc oxide (ZnO) is a wurtzite-type semiconductor with a wide band gap of 3.4 eV and a high exciting binding energy of 60 meV, which is an important material for light-emitting diodes, laser diodes and ultraviolet (UV) photodetectors [1,2]. Among these applications, UV photodetectors have been used in satellite-based missile plume detection, air quality monitoring, environment monitoring, space research, and high temperature flame detection [3–6].

Recently, there are some successful techniques on ZnO-based UV photodetectors, such as Liu et al. and Liang et al., who have fabricated UV photodetectors based on ZnO films grown on sapphire by MOCVD [7,8]. Basak et al. investigated the detection properties of ZnO films prepared by the sol–gel technique [9]. Our group reported previously ZnO-based UV photodetector, which was fabricated by using gold as the Schottky metal for a metal–semiconductor–metal (MSM) structure [10]. Meanwhile, Schottky-type photodetectors are more attractive due to their high speed and low noise performance [8]. Although there are many reports on ZnO-based Schottky UV photodetectors and their performances, very few has reported on the effect of the load resistance on the photoresponse performance [4,8,11].

In this letter, we report that the MSM structured UV photodetector has been fabricated based on ZnO films grown on quartz by a radio frequency (RF) magnetron sputtering technique. The photoresponse of the photodetector was characterized, and the responsivity and the signal-to-noise have been something different with different load resistances, which can make the photoresponse properties meet the requirements of different occasions.

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This method is convenient, economical and practical to change the detector responsivity.

2. Experiments

ZnO films have been grown by a RF magnetron sputtering technique on the quartz substrates. Before deposition, the substrates have been cleaned by acetone and ethanol for 10 min in the ultrasonic bath. Then, the deionized water has been used to rinse the substrates. The sputtering target is a highly pure ZnO ceramic, and a turbo-molecular pump and mechanical pump system evacuate the chamber pressure under the 5×10^{-4} Pa (the based pressure). The substrate temperature has been heated to and held at 400 °C. In order to complement oxygen deficiency of the ZnO films, mixed gases were the work gas which contains ultrapure (5N) oxygen and argon (20 sccm:60 sccm, sccm stands for standard cubic centimeters per minute). And the working pressure has been maintained at 3.0 Pa in the chamber during the sputtering process. The RF power has been kept at 120 W.

The vacuum evaporation has been used to deposit metal contacts (Au) on ZnO films. We used UV exposure and wet etching to achieve the MSM structured electrode, whose fingers were 500 μm long and 5 μm wide with an interval spacing of 2 μm, and the sum of finger pairs was 15.

The D/max-RA X-ray spectrometer (Rigaku International Corp., Japan) with Cu Kα radiation of 1.54 Å is used to evaluate the crystalline property of ZnO films. The current–voltage (*I–V*) characteristic under dark is measured by a semiconductor parameter analyzer. And the photodetector is with the load resistors of 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ and 22 MΩ, respectively. The responsivity has been measured with a 3 V bias by the photoresponse testing system with a bromine–tungsten lamp.

3. Result and discussion

Fig. 1 shows the XRD patterns of ZnO film and ZnO-based UV photodetector. As shown in the XRD pattern, there is a diffraction peak located at about 34.4°, which can be indexed to the (002) plane of ZnO, and it means that ZnO films crystals are typically fabricated along the *c*-axis [10,12]. In addition to the peak (at about 34.4°), there is another peak (at about 38.5°) in the XRD pattern of ZnO-based photodetector, which is the Au diffraction peak from the Au–ZnO–Au MSM interdigital configuration as contact electrode [13].

I–V characteristic under dark is shown in Fig. 2. The nonlinear *I–V* characteristic indicates that the contact electrodes of Au/ZnO are Schottky-type contact. At 3 V bias, the dark current of ZnO-based photodetector is only 1.17×10^{-9} A, which is due to the high material resistivity and the rectifying nature of the contacts. The low dark current has benefit on increasing the signal-to-noise (S/N) ratio of ZnO-based photodetector for hot carrier transporting, which might be due to that ZnO film has few intrinsic donor defects, like oxygen vacancies and zinc interstitials and so on [10]. The dark resistance (R_{dark}) can

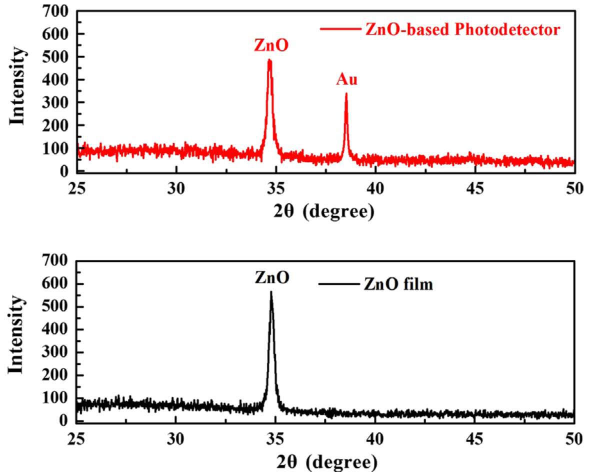

Fig. 1. X-ray diffraction patterns of ZnO film and ZnO-based UV photodetector.

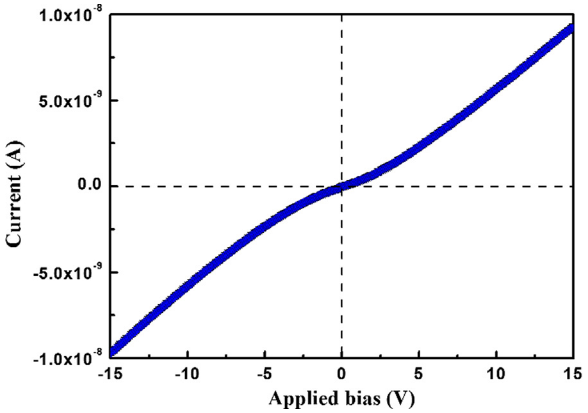

Fig. 2. *I–V* characteristics of the ZnO-based photodetector under dark.

be calculated by

$$R_{dark}=U_{bias}/I_{dark} \tag{1}$$

where I_{dark} is dark current at the bias point, so it can be discovered that R_{dark} is 2.52×10^{9} Ω at a bias of 3 V. And the value of R_{dark} is propitious to calculate the detectivity of the photodetector below.

Fig. 3 shows the responsivity spectra of the ZnO-based MSM UV photodetector with different load resistors, and the device is measured at 3 V bias. As shown in Fig. 3, the responsivity is changed by varying load resistor. The load resistors are 1 kΩ, 10 kΩ, 100 kΩ, 1 MΩ and 22 MΩ, and the corresponding responsivities are 2.69, 1.27, 0.25, 0.02 and 7.20×10^{-4} A/W, respectively. The responsivity decreases with the load resistances increasing, and it can be found that the responsivity with 1 kΩ load resistor is the maximum. Fig. 4(a) shows a simple schematic diagram of the responsivity testing system, and it is clear that the photodetector is in load with a resistor. The ZnO-based photodetector is irradiated by the light at different wavelength ranges, and then the photodetector with the load resistance is measured by phase lock-in amplifier.