Enhanced Performance of MgZnO/ZnO Dual-band UV Photodetectors Depend on depletion region with different electrode width

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Abstract. In this work, visible-blind dual-band UV photodetectors with different interdigital electrode width were fabricated on MgZnO/ZnO bilayer film by the radio frequency (RF) magnetron sputtering technique. The devices exhibit excellent photo-response at 320 nm and 360 nm, respectively. Meanwhile, the PD with larger electrode width possesses higher photo-response and lower dark current (I_d), which proved that the wider electrode is more favourable to enhance the performance of PDs. The result is originate from the stronger electric filed on the depletion region related to the electrode width. This demonstrates a facile way to fabricate dual-band UV PDs with high properties for practice application.

1. Introduction
Dual-band ultraviolet (UV) Photodetectors (PDs) have attracted great attention because of their two detection ranges, which can improve the detection accuracy and efficiency[1-3]. Among variety materials, ZnO is an ideal candidate for UV PDs due to its wide band gap (~3.37 eV), large exciton energy and environmentally friendly, and further alloying MgO into ZnO, the tunable bandgap (3.37~7.8 eV) achieved in MgZnO alloy is preferred to double wavelength detection[4, 5]. Compared with other structures, Mental-Semiconductor-Mental (MSM) is chosen here due to the advantages of small size, intrinsic high speed and simplicity in fabrication process[6].

Recently, the strategies to improve responsivity, one of the key figure-of merit parameters for evaluating the performances of UV PDs, have been extensively studied, such as improving the quality of semiconductor films, quantum dot modification and plasma enhancement[7-9]. However, only a few studies have focused on the physical structure of the electrode on the devices[10, 11], especially the effect of depletion region width affiliated with different electrode width was barely researched.

In this work, we report MgZnO/ZnO MSM dual-band UV PDs with different electrode width (3 μm and 8 μm) prepared by the RF magnetron sputtering deposition on the quartz substrate (SiO₂). Dual-wavelength UV responsivity was observed in visible-blind region. At the same time, according to the relationship between the depletion region and the electrode width, the photoelectric properties of wide electrode and narrow electrode were studied.
2. Experimental Section

2.1. Fabrication of MgZnO/ZnO bilayer films and Photodetectors
First, a ZnO thin film was deposited for 30 minutes at room temperature with a total pressure of 0.5 Pa, a sputtering power of 150 W and an O$_2$/Ar flow ratio of 10:40 from a ZnO ceramic target by RF magnetron sputtering on the prepared SiO$_2$ substrate which was cleaned with acetone, ethanol, and deionized water for 15 min in advanced. Then, the MgZnO thin film was sputtered with Mg$_{0.2}$Zn$_{0.8}$O ceramic target at 573.15 K for 3 hours. The O$_2$/Ar flow ratio is 10:50 with 4 Pa working pressure and 120 W sputtering power. An Au film was sputtered on the MgZnO film surface by direct current (DC) magnetron sputtering technique. The UV exposure photolithography and wet etching was used to achieve the MSM structured interdigital electrodes. The interval spacing and length of the Au fingers were 5 µm and 500 µm, with the widths of 3 and 8 µm, respectively, as shown in Figure 1.

2.2. Characterization and measurement
A Rigaku-Ultima VI X-ray diffractometer (XRD) with Cu Ka radiation was used to measure the crystalline properties of the MgZnO/ZnO film. The absorption and transmittance spectra were performed by PerkinElmer Lambda 950 UV/Vis Spectrometer from 320 to 600 nm. The Zolix DR800-CUST measurement system was used to determined the responsivity of PDs. Current-voltage (I-V) characters were recorded by an Agilent 16442A test fixture. All measurements were carried out at room temperature.

3. Results and discussion
Figure 2 shows the XRD patterns of MgZnO/ZnO bilayer films. The strong (002) and weak (004) diffraction peaks with no other peaks occurred indicating that the MgZnO/ZnO films are single hexagonal wurtzite with a c-axis orientation. The inset of Figure 2 exhibits the absorption and transmission spectra of the films. The two absorption edges at 330 nm and 360 nm correspond to the Mg$_{0.2}$Zn$_{0.8}$O and ZnO films, respectively. In addition, the high transmittance (more than 80%) in the visible (Vis) region illustrates that the films is suitable for the application in UV sensitive PDs.

Figure 1. Schematic of PD with different electrode width.

Figure 2. XRD spectrum of the MgZnO/ZnO films. The inset is UV–Vis absorption and transmission spectra of the films.
Figure 3 depicts the $I$–$V$ curve of the Mg$_{0.2}$Zn$_{0.8}$O/ZnO PDs measured in a dark environment. The inset is logarithm curves. Clearly nonlinear curves indicate that the classic Schottky metal-semiconductor (M-S) contact has been formed. The relatively low dark current (30.29 nA at 5 V) is equivalent to less defects in the device, which is beneficial to improve the signal-to-noise (S/N) ratio of the PDs. What’s more, the dark current ($I_d$) increases as the electrode width increases. This may result from the lower resistance of films and the wider depletion width ($W$), which will be explained in detail below.

![Figure 3. $I$–$V$ curves of the PDs. The inset is logarithm curves.](image)

The responsivities of PDs under series bias voltages are plotted in Figure 4(a) and (b). Both devices showed dual-band response around 330 nm and 360 nm in visible-blind region, which is consistent with the absorption edges. Additionally, similar to the $I$–$V$ curves, with the increase of electrode width, the responsivity increases accordingly. To be more intuitive, the peak responsivity curves of two electrode width versus bias are shown in Figure 4(c) and (d). Apparently, the device with wider electrode has higher photo-response in both bands. The effect of depletion width was employed to interpret the phenomena.

![Figure 4. (a) (b) Photo-response spectra of the PDs with different electrode width of 3 and 8 µm. (c) (d) Peak responses of ZnO (360 nm) and MgZnO (320 nm) as a function of the bias voltages.](image)

The M-S contact leads to the formation of depletion region, whose width depends on the width of metal electrode, can be expressed as[12]:

$$W = \left[ 2 \varepsilon_0 \varepsilon_r (\varphi_0 + V - K T / q) / q N_d \right]$$

(1)
where $\varepsilon_0$ and $\varepsilon_1$ are the absolute and relative dielectric constant, respectively, $\psi_0$ is the built-in potential, $q$ is the electron charge, $N_d$ is the donor concentration. (about $10^{16}$ cm$^{-3}$) and $V$ is the applied bias, which is inversely proportional to the film resistance ($R$) known as:

$$R = \rho L / S$$  \hfill (2)

where $\rho$, $L$, $S$ are the resistivity, length of the films, and cross-section area, respectively. When the totally voltage is constant, the wider the electrode width, the larger the cross-section area ($S$), the smaller the film resistance ($R$) and the greater the voltage ($V$) it bears, which results in the broadening of the depletion layer width, increase of carrier concentration and the acceleration of electron-hole separation speed, thus further improving the responsivity of the device.

4. Conclusion

In summary, the MgZnO/ZnO MSM dual-band UV PDs with different electrode width have been fabricated by RF magnetron sputtering method. Both PDs show excellent dual-band response in the visible-blind region. More importantly, the device with wider electrode has superior properties of responsivity and dark current, which provides a facile method to improve the performance of dual-band UV PDs in the future.

Acknowledgments

This work is supported by National Natural Science Foundation of China (Grant No. 61774023), Scientific and Technological “13th Five-Year Plan” Project of Jilin Provincial Department of Education (Grant No. JJKH20190587KJ), Scientific and Technological Development Project of Jilin Province, China (Grant No. 20190101008JH), Scientific and Technological Development Project of Jilin Province, China (Grant No. 20200403048SF).

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