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Surface treatment to improve responsivity of MgZnO UV detectors

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ABSTRACT

MgZnO films were grown on quartz substrates by radio frequency (RF) magnetron sputtering technique with a combinatorial target. The structural and optical properties of the sputtering films were characterized. Based on the MgZnO films, planar geometry metal–semiconductor–metal (MSM) structured ultraviolet (UV) detectors were fabricated. At 30 V bias, a peak responsivity of 3.5 mA/W was achieved at 285 nm, and the visible rejection was about one order of magnitude with 25 pairs of electrodes. Afterward, in order to improve the responsivity, the surface of the MgZnO-based detector was sputtered ZnO within 20 s. The responsivity was improved significantly from 3.5 to 15.8 mA/W after surface treatment, and the corresponding visible rejection increased to three orders of magnitude. It revealed ZnO particles play a key role in enhancing the responsivity of detector, and the physical mechanism has been explained by a straightforward model.

1. Introduction

The ZnO materials have attracted much attention for applications to UV light emitters, transparent electronics, surface acoustic wave devices, gas sensors, electronic spark detection, fire alarms and medical diagnostics [1–5]. ZnO have many fascinating properties such as the band-gap tuning from 3.4 to 7.8 eV by doping Mg, extending the cutoff wavelength from UVA (320–400 nm) to UVB (280–320 nm), or even UVC (200–280 nm) regions [6]. Therefore, MgZnO alloy become a promising material to make UVB and UVC detectors. Recently, Zheng et al. have reported that the peak responsivity of MgZnO film based detector is 31.1 A/W at 70 V bias, which is due to its high quality films [7]. Wang et al. and Zheng et al. have obtained single-phase MgZnO film on ZnO and sapphire substrates to fabricate MgZnO detectors, which maximum responsivity is 0.4 A/W at 10 V bias [8,9]. Obviously, most researchers focused on improving the crystal quality for high performance UV detectors. However, it is falling short of innovative method to improve the responsivity starting from the detector itself up to now.

Differing from the conventional methods, the surface treatment of the device may be an effective approach. In our study, we succeeded in the growth of MgZnO films on quartz substrates by RF magnetron sputtering technique. The MSM MgZnO detectors were obtained by UV lithography and wet etching. Afterward, the surface of the detector was sputtered an ultra-thin layer of ZnO cluster. In the existing reports, few researches have explored the surface treatment of MgZnO UV detectors. Fortunately, a satisfaction result has obtained, and the growth of ZnO particles on the surface of MgZnO detector is favorable for improving responsivity of MgZnO detectors. In addition, this conclusion was also demonstrated by the MgZnO UV detectors with different pairs of electrodes. We believe that our developed method, surface treatment, has the potential to enhance responsivity on the other UV detectors dramatically. Moreover, ZnO maintains lattice-matching to MgZnO film without doping other impurities, and improves the film surface quality [10]. ZnO has high exciton binding energy (60 meV) [11], so it can improve absorption of the film.

2. Experimental

The MgZnO thin films were prepared on quartz substrates by RF magnetron sputtering technique. Differing from the conventional single target, the combinatorial targets with stromatolitic structure was employed in our experiment, as shown in Fig. 1. Clearly, the MgZnO beam flow will be enclosed by Zn beam flow, reducing the losing of Zn atoms caused by its high vapor pressure, and the composition of the $Mg_xZn_{1-x}O$ film can be controlled easily, even at high substrate temperature. The sputtering chamber was pumped down to 5×10^{-4} Pa before introducing Ar and O_2 gases

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with the rate of 50 and 15 sccm (standard cubic centimeter per minute). The working pressure was kept at 4 Pa with RF power of 120 W. The growth time is about 1.5 h and the substrate temperature was controlled at about 673 K during the sputtering process. In order to improve the crystal quality, the films were annealed at 773 K for 30 min under atmosphere after sputtering. Au was selected as the contact metal and the clear-cut MSM structure with interdigitated configuration was obtained by lithography and wet etching. After that, the surface of the MgZnO UV detectors were sputtered ZnO within 20 s. The structural characterizations of MgZnO were carried out by XRD using a D/max-RA X-ray spectrometer (Rigaku) with Cu Kα radiation of 0.1543 nm. The optical properties were recorded using a PC PerkinElmer Lambda 950 scanning spectrophotometer. Linear *I–V* characteristic was measured by semiconductor parameter analyzer. The spectral responsivities were measured using a Zolix DR800-CUST testing system. And the surface morphology was detected by using a Pacific Nanotechnology Nano-R2 AFM.

3. Results and discussion

Fig. 2 shows the XRD patterns of the as-grown film, annealed film and the detectors. Only (002) peak observed in XRD patterns of the as-grown film and annealed MgZnO films, which indicates the wurtzite structure of the films [12]. Compared to the as-grown film, the annealed film shows larger peak intensity and smaller full width at half maximum (FWHM) [13]. In the XRD spectrum of the detectors, it can be seen that there is one peak in the (002) beside the peaks from In and Au, which are used as the contact metal. Furthermore, the UV detectors based on MgZnO films were sputtering ZnO, but the XRD pattern of detector did not change significantly. It means that surface treatment did not influence the film crystallinity. And the Mg composition in the film is measured by energy dispersive spectroscopy (EDS) and found to be about 30%.

Fig. 1. A schematic of the combinatorial targets.

It is the transmission spectrum of the as-grown, annealed MgZnO films and the UV detector which was sputtered ZnO within 20 s, as shown in Fig. 3, and the substrate contribution is excluded. All of the spectra exhibit sharp absorption edges at about 330 nm, and the transmission in the visible region of the as-grown and

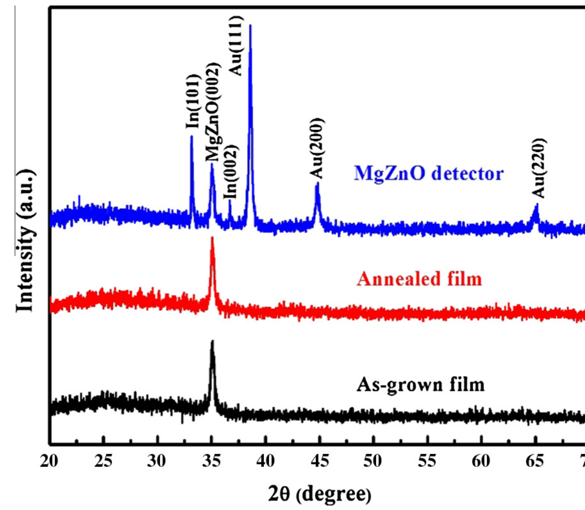

Fig. 2. XRD patterns of the MgZnO detector and films grown on quartz substrate.

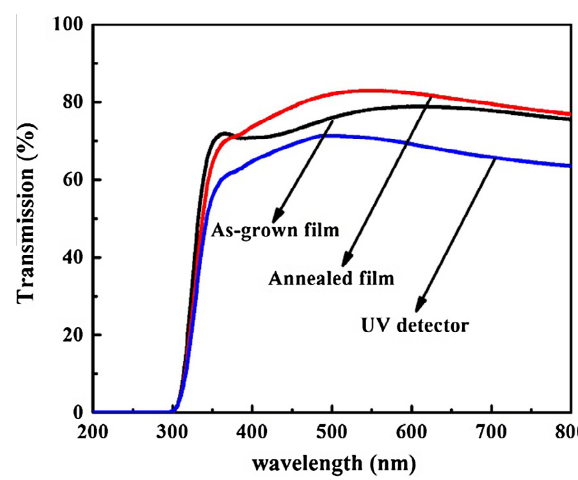

Fig. 3. Transmission spectra of the MgZnO detector, as-grown and annealed films.

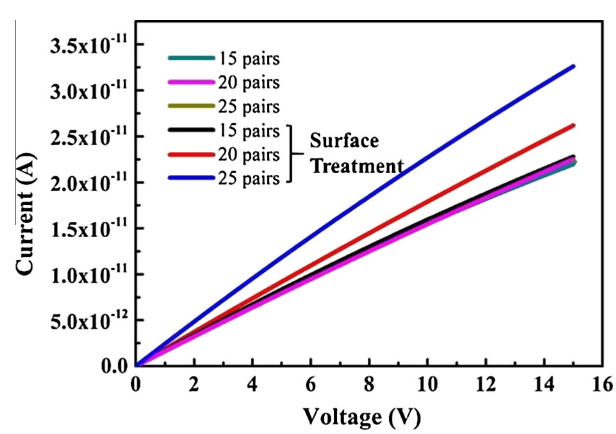

Fig. 4. Dark current of the MgZnO MSM detectors as a function of the bias voltage with and without surface treatment, respectively.