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Low-frequency noise properties of MgZnO nanorod ultraviolet photodetectors with and without UV illumination

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ABSTRACT

Low-frequency current noise measurements were performed on Mg-doped ZnO (MZO) nanorod photodetectors (PD), and 1/f noise was observed in both dark and under ultraviolet (UV) illumination. Results show that the average length and diameter of the nanorods were 609 nm and approximately 50 nm, respectively. The X-ray diffraction spectrum showed that the Mg-doped ZnO nanorods had a wurtzite hexagonal sturcture. The photoelectric properties of the nanorods were stable under UV illumination. The resulting Mg-doped ZnO nanorods had excellent potential for UV photodetector applications. Mg-doped ZnO nanorod UV photodetectors had a high UV-to-visible ratio and a fast rise/fall time. The dynamic response of the Mg-doped ZnO nanorod photodetector was stable and reproducible with an on/off current contrast ratio of approximately 4×10^3. The UV-to-visible rejection ratio of the sample was approximately 400 when biased at 1 V, and the fabricated UV photodetector was visible-blind with a sharp cutoff at 350 nm. The low-frequency noise spectra obtained from the UV photodetector were caused by the 1/f noise. The noise-equivalent power (NEP) and normalized detectivity (D^*) of the Mg-doped ZnO nanorod PD were 3.35×10^{-10} W and 1.49×10^8 cm Hz0.5 W^{-1}, respectively. Under UV illumination, the NEP and D^* were 1.8×10^{-6} W and 2.7 × 106 cm Hz0.5 W^{-1}, respectively.

1. Introducion

The worsening destruction of the ozone layer has increased the amount of ultraviolet (UV) radiation on Earth in recent years. This phenomenon seriously affects humans. Thus, issues on the safety of UV radiation have attracted considerable attention. UV radiation is harmful to humans because it can accelerate skin aging, increase skin cancer, damage DNA, and suppress the immune system [1]. Thus, high-performance UV detectors are urgently necessary. Zinc oxide (ZnO) is an interesting oxide semiconductor material that can be used as a component of UV detectors. It exhibits a wide band-gap of 3.37 eV and a high exciton binding energy of 60 meV at room temperature [2–5]. It is a promising photonic material for several technologies, such as light-emitting diodes (LEDs), laser diodes (LDs), and photodetectors (PDs). In addition, ZnO exhibits UV optical sensor features. Common methods of fabricating ZnO nanostructures include the hydrothermal method, physical vapor deposition, and chemical vapor deposition. The hydrothermal method has several advantages, such as its relatively low-temperature growth conditions and low cost. ZnO nanostructures have shown great potential for PDs because they a demonstrate high surface-to-volume ratio, a fast response and recovery, high photoconductive gain, and visible light-blindness [6].

Mg-doped ZnO (MZO) nanostructures are interesting materials because the band gap of the $Mg_xZn_{1-x}O$ nanostructures can be adjusted from 3.3–7.7 eV by modifying the Mg concentration, which covers the following wavelengths: UV-A (320–400 nm), UV-B (280–320 nm), and UV-C (200–280 nm) [7]. Thus, regulating the Mg content allows for modification of the characteristics of the energy gap to levels where the UV detector can be effective. A UV PD with MZO film was developed previously [8,9] but reports on the characteristics of MZO nanorod UV PDs are few. Low-frequency noise measurement is a powerful tool for measuring the distribution of traps and defects in semiconductors [10–13]. This study reports on the fabrication of a MZO nanorod metal-semiconductor-metal (MSM) UV PD on a glass substrate through the hydrothermal method. The optoelectronic and noise properties of the fabricated Mg-doped ZnO UV MSM PD are discussed.

2. Experimental

The glass substrates were cleaned with acetone, isopropyl alcohol, and deionized water in an ultrasonic cleaner. A MgZnO

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seed layer was deposited on the glass substrate using radio frequency (RF) magnetron sputtering. The thickness of the MgZnO film was approximately 80 nm. A thick Au film was then thermally evaporated onto the MgZnO seed layer through an interdigitated shadow mask to form the contact electrodes. An interdigitated shadow mask with a finger width of 5 mm and a finger length of 5 mm was designed. The spacing between the neighboring fingers was 0.1 mm. Finally, in a sealed beaker, the MZO nanorods were hydrothermally grown by immersing the MgZnO/Glass substrate at 80 °C for 3 h in a 100-ml aqueous solution of zinc nitrate hexahydrate ($Zn(NO_3)_2 \cdot 6H_2O$, 23.75 mM), hexamethylenetetramin (HMT, 25 mM), and magnesium nitraten-hexahydrate ($Mg(NO_3)_2 \cdot 6H_2O$, 1.25 mM). This method was similar to the aqueous solution process developed by Fang et al. [14].

The surface morphologies of the synthesized materials were characterized through high-resolution scanning electron microscopy (Hitachi S-4800I), a Philips Technai F20 G^2 FEI–TEM high-resolution transmission electron microscope (HRTEM) operated at 200 kV, and a Bruker D8 X-ray diffractometer (XRD) system with Cu–Kα radiation. The PD characteristics of the fabricated devices were measured by a Keithley 2410 semiconductor parameter analyzer in the dark and in UV illumination at room temperature. The spectral responsivity measurement of the PD was measured by a Jobin Yvon–Spex system using a 300 W xenon arc lamp light source (Perkin Elmer PE300BUV) and a standard synchronous detection scheme measured at 300 Hz. The noise power spectra were then analyzed through a HP35670 Dynamic Signal Analyzer and a BTA 9812 Noise Analyzer.

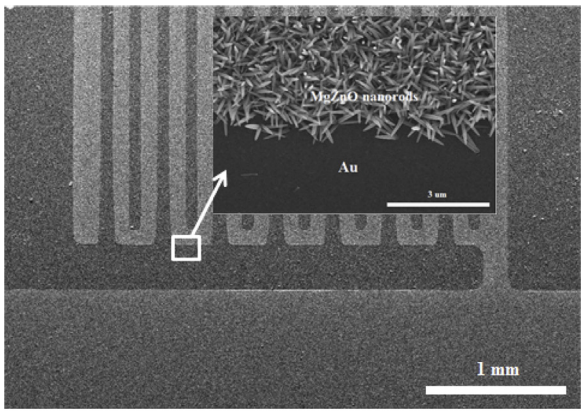
3. Results and discussion

Fig. 1(a) and (b) show the top-view and cross-sectional FESEM images, respectively, of the as-synthesized MZO nanorods prepared on a seeded layer glass substrate. The density of the MZO nanorods with uniform diameter and uniform length were 50 and 609 nm, respectively. The inset shows the energy dispersive spectrum of MZO nanorods and indicates that these nanorods are composed of Zn, Mg, and O.

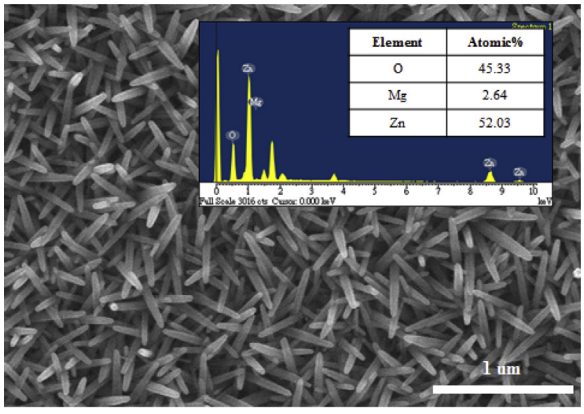
The results of the XRD analysis of the arrays conducted on a Bragg Brentano-focusing geometry diffractometer showed a strong texture effect corresponding to the c-axis-elongated and side-direction nanorods. Fig. 2 shows the XRD spectrum of the MZO nanorods prepared on the MgZnO/Glass substrate. The (002) diffraction peak was stronger than the other peaks, such as (100), (101), (102), and (103), indicating that the ZnO crystals preferred to grow along the c-axis. A sharp XRD peak appearing in the nanorods can be indexed to wurtzite ZnO (JCPDS Card No. 3601451).

Fig. 3(a) shows the low-magnification transmission electron microscope (TEM) image of the MZO nanorod, whereas Fig. 3(b) shows the HRTEM image of the lattice spacing for the middle part of a single MZO nanorod in Fig. 3(a). The observed HRTEM images of the c-axis correspond to the d[0002] 0.521 nm lattice spacing of the wurtzite MZO. The inset of Fig. 3(b) shows a selected area electron diffraction (SAED) pattern obtained from a single MZO nanorod. This diffraction pattern indicates that the nanorod is a single crystal with a wurtzite structure.

Fig. 4(a) shows the typical I–V characteristics of the MZO nanorod PD in the dark and under 365-nm UV light exposure. The sample was illuminated during the photocurrent measurement with a UV light generated by a compact UV lamp (UVGL-25). This figure also plots the I–V characteristics of the MZO nanorod PD for comparison. Under an applied bias of 1 V, the dark current and photocurrent of the MZO nanorod PD were 1.1×10^{-9} and 4.44×10^{-6} A, respectively. The photocurrent-to-dark current contrast ratio of the fabricated PD exceeded 4036.



(a)



(b)

Fig. 1. FESEM image of the MZO nanorods at (a) a tilt angle and (b) top view. The inset is EDS spectrum of the nanorods.

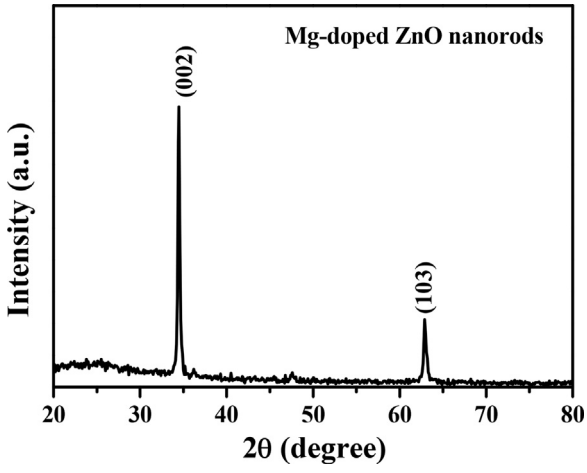


Fig. 2. XRD spectrum for MZO nanorods.

Fig. 4(b) shows the transient response of the fabricated MZO nanorod PD as the UV illumination was switched on and off. The rise time and decay time represent the time for the current to rise to 90% of the peak value and the time for the current to decay to 10% of the peak value, respectively. The turn-on and turn-off transients can be closely fitted by the following exponential curves [15]:

$$\text{Turn on}: I(t) = I_0(t)\left[1 - \exp\left(\frac{-t}{\tau_r}\right)^{\beta}\right] \quad (1)$$