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Ultraviolet photodetector based on sol–gel synthesized MgZnO nanoparticle with photoconductive gain

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ABSTRACT

Ultraviolet photodetectors based on sol–gel synthesized $Mg_{0.18}Zn_{0.82}O$ nanoparticles have been constructed. The device exhibits a maximum responsivity of 0.27 A/W at 13 V bias, and the UV/visible reject ratio up to 2 orders of magnitude. The peak response of the photodetector centers at 322 nm and cutoff wavelength is 363 nm. The above characteristics of device illustrate that sol–gel synthesized MgZnO nanoparticle is suitable to act as the active layer of UV photodetector. The EQE of the photodetector is larger than unity, indicating photoconductive gain exists within the device.

1. Introduction

ZnO, an environmentally friendly semiconductor with a wide band gap of 3.37 eV, is of great interest for ultraviolet (UV) photon detection because of its high saturated drift rate, high breakdown voltage and low growth temperature, etc. [1–6]. Also it has been reported that the irradiation-resistance of ZnO is larger than many other wide bandgap semiconductors such as In_2O_3 and TiO_2 [7,8], which makes it suitable for use in harsh environment. $Mg_{1-x}Zn_xO$, which is realized by alloying MgO with ZnO, exhibits the same material advantages as pure ZnO. By varying the Mg composition, the band gap can be tuned from 3.37 to 7.8 eV, which corresponds to a wavelength range of 160–370 nm [9]. The above fact promises that shorter wavelength UV photodetectors may be realized from MgZnO alloys. Until now, MgZnO thin films have been prepared by many techniques such as molecular beam epitaxy (MBE) [10,11], metal-organic chemical vapor deposition (MOCVD) [12–14], pulsed laser deposition (PLD) [15], radio frequency (RF) sputtering [16], and sol–gel process [17–19]. Among the fabrication methods mentioned above, the sol–gel deposition technique has many advantages over other methods, such as ease of fabrication, large scale production, physical flexibility, excellent compositional control, and most importantly, low cost [17–20]. Besides, the photodetector based on nanocrystalline film prepared by sol–gel method usually exhibits photoconductive gain, which contributes to high sensitivity of photodetector [21,22]. At present, lots of reports about ZnO UV photodetectors prepared by sol–gel methods can be found in the literatures [20–22]. Nevertheless, very few researches have been reported on UV photodetectors using sol–gel synthesized MgZnO films.

In this paper, we constructed UV photodetectors based on MgZnO nanoparticles prepared by sol–gel method. The electrical and optoelectronic characteristics of devices were investigated. At 13 V, the external quantum efficiency (EQE) of the photodetector is larger than unity, indicating photoconductive gain exists within the device.

2. Experimental

The MgZnO thin films employed as the active layer of the UV photodetectors were grown on quartz substrates by a sol–gel method [23]. For synthesis of MgZnO sols, the values of the Mg^{2+} molar fraction was adjusted to 0.2. A mixture of zinc acetate 2-hydrate [$Zn(CH_3COO)_2 \cdot 2H_2O$] and magnesium acetate 4-hydrate [$Mg(CH_3COO)_2 \cdot 4H_2O$] was dissolved in a 2-methoxyethanol ($C_3H_8O_2$) and monoethanolamine (MEA) solution at room temperature. The molar ratio of MEA to metal ions in the sols was maintained at 1, and the concentration of metal ions was controlled at 0.75 mol/L. Then the solution was used for spin-coating MgZnO thin films on quartz substrates. The coated substrate was dried at

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100 °C for half an hour and then placed in a furnace and annealed in air atmosphere at 600 °C for half an hour. This cycle was repeated 13 times to obtain films with a thickness of around 600 nm. After the growth of the MgZnO film, a thin Au layer was evaporated onto the MgZnO film using a vacuum evaporation method. Interdigital electrodes were configured onto the MgZnO films via a photolithography and wet etching process. The structural characterization of the MgZnO films was carried out in a Bruker D8 X-ray diffractometer using Cu Kα (λ = 1.54 Å) as the excitation source. The surface morphology of the MgZnO films was characterized by a Hitachi S4800 scanning electron microscope. The absorption spectrum of the MgZnO films was studied in a Shimadzu UV-3101 PC scanning spectrophotometer. The electrical characteristics of the films and devices were measured using a Lakeshore 7707 Hall measurement system. The photoresponse of the photodetectors was measured in a SPEX scanning monochromator employing a 150 W Xe lamp as the illumination source. The temporal response of the photodetectors was studied by using the 266 nm line of a Nd:YAG laser with a pulse width of 10 ns as the excitation source. Note that all the measurements were performed at room temperature.

3. Results and discussion

Hall measurement reveals that the MgZnO film shows *n*-type conduction with an electron concentration of 4.2×10^{16} cm^{-3} and a Hall mobility of 0.2 cm^2 V^{-1} s^{-1}. The absorption spectrum of the $Mg_{0.18}Zn_{0.82}O$ film is shown in Fig. 1. The film shows the absorption edge at around 360 nm. The inset of Fig. 1 shows plots of $(\alpha h\upsilon)^2$ as a function of $h\upsilon$, where α is the absorption coefficient, and $h\upsilon$ is the photon energy. By using the following formula: $\alpha(h\upsilon) = A(h\upsilon\text{-}Eg)^{1/2}$, the bandgap of the $Mg_{0.18}Zn_{0.82}O$ film is determined to be about 3.53 eV. The EDS measurement shows that the value of Mg content in the MgZnO film is 0.18. It has been demonstrated that the dependence of the bandgap of sol–gel synthesized $Mg_xZn_{1-x}O$ on Mg composition can be expressed by the following formula [17]:

$$Eg(Mg_xZn_{1-x}O) = 3.28 + 1.36x \quad (1)$$

Where x is the Mg composition in the $Mg_xZn_{1-x}O$ film. By inserting the Mg composition of 0.18 into the formula, a bandgap value of 3.52 eV can be derived, which is close to the value of 3.53 eV determined by the absorption spectrum. XRD pattern of the $Mg_{0.18}Zn_{0.82}O$ film is shown in Fig. 2. The diffration pattern presents three main peaks at 31.96°, 34.78° and 36.48°, which are consistent with diffraction peaks from (100), (002) and (101) planes of wurtzite ZnO. The film is well oriented to the c-axis without any peaks related to MgO. This indicates that the ternary compounds of $Mg_{0.18}Zn_{0.82}O$ is formed and it still keep the wurtzite structure. The surface morphology of the $Mg_{0.18}Zn_{0.82}O$ nanoparticle is displayed in the inset of Fig. 2. The shapes of the nanoparticles are clearly spherical, and the average grain size is about 70 nm. These $Mg_{0.18}Zn_{0.82}O$ nanoparticles are in close contact with each other and form a continuous film. The inset of Fig. 3 shows the schematic illustration of the $Mg_{0.18}Zn_{0.82}O$ Metal-Semiconductor-Metal (MSM) structured photodetector. The Au fingers of the interdigital electrodes are 500 μm in length and 5 μm in width, and the inter-electrode spacing is 5 μm. The active area of the device is about 1.0×10^{-3} cm^2. The current–voltage (I–V) characteristics of the photodetector based on $Mg_{0.18}Zn_{0.82}O$ nanoparticles under dark and 322 nm light illumination conditions are illustrated in Fig. 3. The linear I–V curves implies ohmic contact has been obtained at the Au/$Mg_{0.18}Zn_{0.82}O$ interface. Due to the $Mg_{0.18}Zn_{0.82}O$ nanoparticles with surface states, high density of interface states will be formed at the interfaces of Au/$Mg_{0.18}Zn_{0.82}O$ during the electrodes

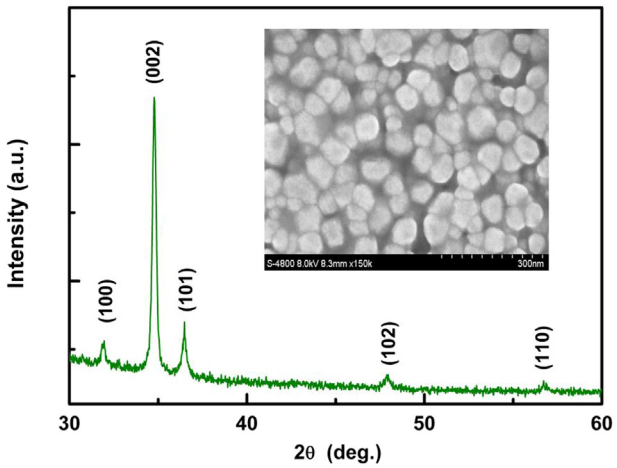

Fig. 2. The XRD pattern of the $Mg_{0.18}Zn_{0.82}O$ film, with the inset showing the surface morphology of the $Mg_{0.18}Zn_{0.82}O$ film.

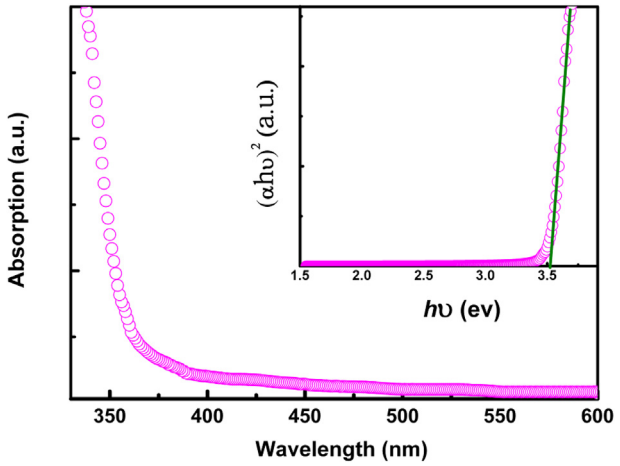

Fig. 1. Room temperature absorption spectrum of the $Mg_{0.18}Zn_{0.82}O$ film, and the inset shows the bandgap of the $Mg_{0.18}Zn_{0.82}O$ film determined from the absorption spectrum.

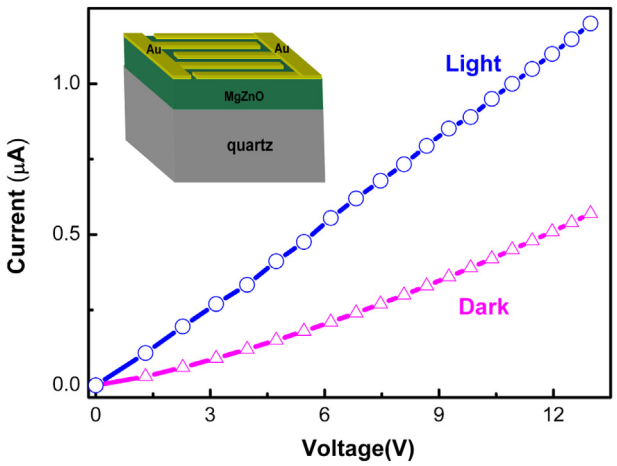

Fig. 3. Current-voltage (I–V) characteristic of the photodetector based on $Mg_{0.18}Zn_{0.82}O$ nanoparticles under dark and 322 nm light illumination conditions, with the inset showing a schematic diagram.