Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 584-585

P-9-4

Physical characteristic of UV photodetectors based on sol-gel derived ZnO thin film

K. J. Chen[1], F. Y. Hung[2*], S. J. Chang[1], S. J. Young[1]

[1]Institute of Microelectronics & Department of Electrical Engineering; Center for Micro/Nano Science and Technology
National Cheng Kung University, Tainan 701, TAIWAN
[2]Institute of Nanotechnology and Microsystems Engineering; Center for Micro/Nano Science and Technology
National Cheng Kung University, Tainan 701, TAIWAN

[*]Corresponding author Email: fyhung@mail.mse.ncku.edu.tw

1. Introduction

Photodetectors operating in the UV region are important devices that can be used in various commercial and military applications such as ozone layer monitoring, flame detection and missile warning systems [1-2] etc. In recent year, the UV photodetectors were fabricated on wide direct bandgap materials. ZnO is one of attracted much attention material which due to their wide direct band-gap energy of 3.37 eV and large exciton-binding energy of 60 meV. ZnO thin films have been prepared by a various of deposition techniques, such as RF magnetron sputtering, molecular beam epitaxy (MBE), metal organic chemical vapor deposition (MOCVD), pulsed laser deposition (PLD) and sol-gel process [3-7]. Among them, sol-gel method has advantages of preparing large area ZnO thin films with low cost and easy technology. Therefore, a few investigations have been prepared UV photodetectors on sol-gel-synthesized ZnO thin film [8-9]. In addition, photodetectors devices nearly used interdigital (IDT) circular structures as contact electrodes. Xu et al. [10] fabricated UV photodetectors on ZnO:Al thin films with IDT configuration. Also, Young et al. [11] performed the ZnO UV photodiodes with interdigitated of palladium contact electrodes. However, the spiral configuration was not nearly used as contact electrodes.

In this study, we fabricate the UV photodetectors on sol-gel derived ZnO thin films. The spiral structure is used as contact electrodes which enhance the photoiluminated area to improve the quality of devices.

2. Experimental procedure

ZnO thin films were deposited on the quartz substrate by sol-gel method. To prepare the aqueous solution of ZnO, 2M zinc acetate dehydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$) was synthesized with diethanolamine (DEA) in the hydranal methanol (dry $\leq$ 0.01% water), and the molar ratio of DEA to zinc acetate was 1. The aqueous solution was stirred at 140 ºC for 3 hours to yield a homogeneous and transparent solution. Spin coating method with a rotating rate of 3000 rpm was used to coat all substrates. After that, the samples were dried at 200 ºC for 10 minute to evaporate the solvent and remove organic residuals, then naturally cooling to room temperature (non-stop for 10 times). Finally, the samples were performed the annealed at 650 ºC for 1 hour under O_2 atmosphere with flow rate of 50 sccm. The thickness of ZnO thin film was approximately 300 nm which measured by dual-beam focused ion beam (FIB) (not given in this study).

UV photodetectors were designed and fabricated based on circular spiral metal-semiconductor-metal (MSM) structures. The thickness of 30 nm iridium (Ir) film was patterned onto the sol-gel derived ZnO surface by electron beam evaporation to serve as metal contacts. The width of Ir contact electrodes were 300 μm with a spacing of 300 μm. The active area of UV photodetector was 6000 × 4000 μm^2. The schematic structure of the MSM UV photodetectors fabricated in this study was shown in Fig. 1.

The photoluminescence (PL) measurement was used to analyze the optical properties of ZnO crystallization by 325 nm UV light from a He-Cd laser at room temperature. The crystalline structure was analyzed by multipurpose X-ray thin-film diffraction (XRD) and scanning electron microscopy (SEM). Also, current-voltage (I-V) characteristics of the devices were measured by HP 4145 semiconductor parameter analyzer under dark and illumination. The top-illuminated spectral responsively was quantified using a 250 W xenon (Xe) arc lamp as the light source and calibrated a monochromatic covering the range of 300 ~ 450 nm.

3. Results and discussions

Fig. 2 shows the room temperature PL spectrum of sol-gel derived ZnO thin film. In this spectrum, ZnO thin film contained a strong UV emission band at 380 nm (3.26 eV) and a very weak green emission band at 550 nm (2.25 eV). It was found that full-width half-maximum (FWHM) of UV emission band was 108 meV. This result was indicated that the crystallization quality of our ZnO thin film is good and as well as ZnO epitaxial layer by radio frequency (RF) plasma-assisted MBE [12]. The XRD pattern of ZnO thin film is shown in Fig. 3. It was corresponded to the wurzite-type ZnO and highly preferred (002) orientation. In the inset Fig. 3, we also observed a (002) diffraction peak at 2θ = 34.7º with a FWHM of 0.38º. This result was indicated that the ZnO thin film certainly has good quality.

Fig. 4 shows I-V characteristics of the ZnO photodetector measured in dark and photoilluminated. The I-V relations under both forward and reverse bias exhibited a linear which corresponded to the ohmic metal-semiconductor contacts (not given here). With 5 V applied bias, it was found that measured dark current and photocurrent were 5.11×10^{-7} and 4.32×10^{-9}, respectively. In other words, the magnitude of photocurrent to dark current could be achieving about two orders. The similar results were observed in previous reports [10, 13]. Notably, both of magnitudes of photocurrent to dark current were less than one order. Fig. 5 shows the spectral response of the photocurrent measurement of ZnO MSM photodetector. It was found that the cutoff occurred at 370 nm. With incident light wavelength of 360 nm and 5 V applied bias, the responsivity was 0.011 A/W. Although the cutoff was not sharp, more than two orders magnitude in photocurrent value was observed from 370 to 420 nm. This result was indicated that the sensitivity of sol-gel derived ZnO thin film in the UV region was good enough for applying it as UV photodetector material.

4. Conclusion

Comparing to previous reports, the crystallization and optical properties of our sol-gel derived ZnO thin films has good quality. The UV photodetector based on ZnO thin films with spiral structure of Ir contact electrodes were fabricated. The linear I-V relation was corresponded to the ohmic metal-semiconductor contacts. Under illumination using Xe lamp, photo-generated current arrived at 5.11×10^{-7} at 5V. In addition, the magnitude of photocurrent to dark current could be achieving more than two orders.

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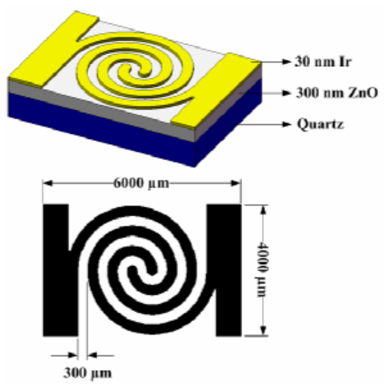

Fig. 1 The schematic structure of ZnO MSM photodetector.

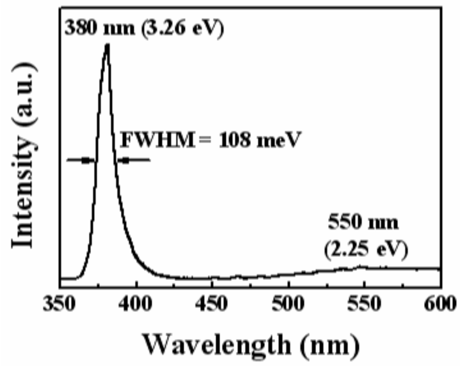

Fig. 2 The PL spectrum of ZnO thin film at room temperature.

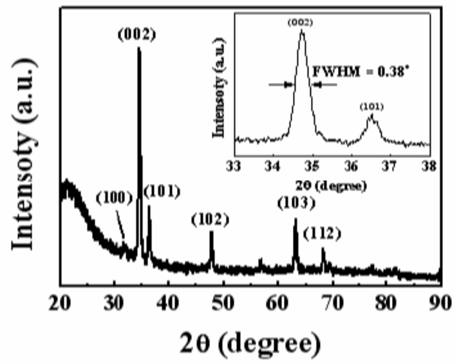

Fig. 3 XRD pattern of ZnO thin film.

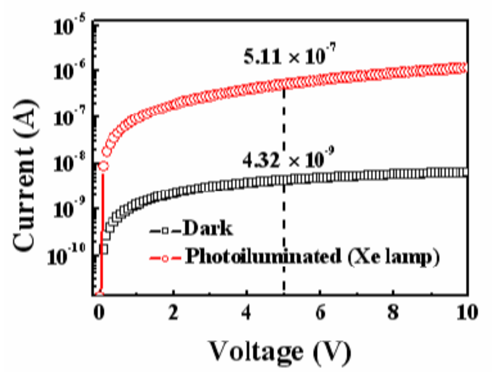

Fig. 4 I-V characteristics of ZnO photodetector measured in dark and under Xe illumination.

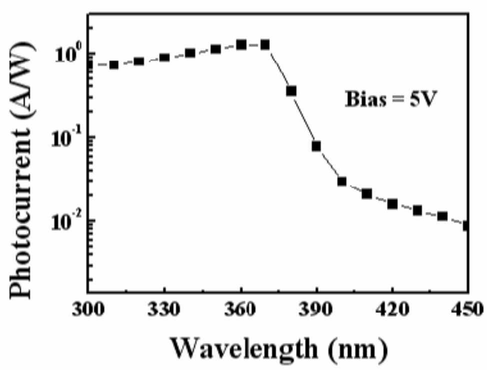

Fig. 5 The spectral response of the photocurrent measurement of ZnO MSM photodetecto