

PHOTOCONDUCTIVE UV DETECTORS BASED ON ZnO FILMS PREPARED BY R.F. MAGNETRON SPUTTERING METHOD

NGUYEN VIET TUYEN, TA DINH CANH, AND NGUYEN NGOC LONG

Department of Physics,

Hanoi University of Science, Vietnam National University, Hanoi

Abstract. *Highly c-axis oriented zinc oxide (ZnO) thin films were deposited on glass substrates by radio frequency (r.f.) sputtering. The photoconductor UV detector based on ZnO films, having a metal-semiconductor-metal (MSM) structure with interdigitation configuration, were fabricated by using aluminium (Al) as a contact metal. The characteristics of dark and photocurrent of the ultraviolet (UV) detector and the UV photo-response of the detector were investigated. The linear current-voltage (I-V) characteristics under both forward and reverse bias exhibit ohmic metal-semiconductor contacts. Under illumination by monochromatic light at a wavelength of 365 nm, the photo-generated current was measured to be 0.56 μA at a bias of 6 V. The photo-response decay in these devices is slow.*

I. INTRODUCTION

ZnO is a wide and direct band gap (3.3 eV) semiconductor material with hexagonal wurtzite structure and has potential applications for surface acoustic wave devices (SAW), gas sensors, transparent conducting layers, light emitting diodes (LEDs), ultraviolet (UV) lasers and especially the UV detector [1, 2]. The reports of ZnO UV detector mainly focus on metal/semiconductor/metal (MSM) structure which contains ohmic contact based photoconductive type [3, 5] and schottky-barrier-based photovoltage type [4, 6, 7]. The photoconductive detector is easy to achieve higher gain and photoresponsivity, but the photoresponse time is usually longer than other types because of the persistent photoconductivity.

In this paper, we describe the photoconductivity in the UV region of ZnO thin films grown by a sputtering method and show that the ZnO thin films are advantageous and promising materials for use in ultraviolet sensor.

II. EXPERIMENT

ZnO thin films were prepared by a radio frequency (r.f.) sputtering technique which has a base pressure of 5.8×10^{-3} Torr. Glass substrates with the size of $20 \times 20 \text{ cm}^2$ were placed on the sample holder which is parallel to the 75 mm-diameter ZnO target. Before sputtering, the glass substrates were ultra-sonically cleaned sequentially in distilled water, acetone, alcohol, and distilled water. After 5 minutes of sputtering in argon (Ar) plasma, with r.f. power of 200 W at deposition temperature of 150°C , a ZnO film was deposited on the glass (the thickness of the ZnO thin film is about 0.6 μm). Aluminium was used as

a contact metal because of its electron negativity. A 200 nm thick Al film electrode with interdigitation (IDT) configuration was patterned on the sputtered ZnO surface with a shadow mark by thermal evaporation at 250°C.

The crystal structure and growth direction were investigated by using a X-ray diffractometer (D5005, Bruker, Germany), and the surface morphology was studied by using a scanning electron microscope (JSM 5410 LV, Jeol, Japan) and an atomic force microscope (AFM). The optical properties in the visible region were studied by employing an UV/VIS spectroscope (UV 2450 PC, Shimadzu, Japan) and the photoluminescence (PL) spectra were measured at room temperature by a spectrofluorometer (FL 3-22, Jobin Yvon Spex, USA).

III. RESULTS AND DISCUSSION

The ZnO film, prepared with a ZnO target, exhibited columnar grain growth with a strong *c*-axis orientation perpendicular to the substrate surface. Fig. 1 shows a typical X-ray diffraction pattern for the ZnO films.

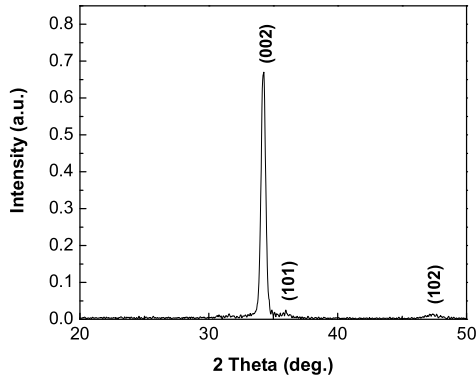


Fig. 1. XRD pattern of ZnO film deposited on glass substrate

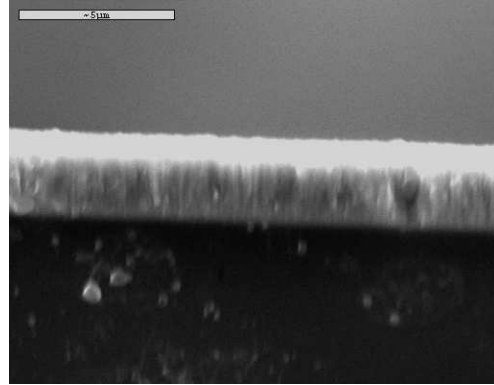


Fig. 2. SEM photograph of ZnO thin films on glass substrate

A strong diffraction line appears at 34.4°, which is assigned to (002) diffraction peak of hexagonal ZnO. The lattice constants were calculated to be $a = 0.3249$ nm and $c = 0.5212$ nm utilizing the observed (002) diffraction peak, which is slightly larger than a reported value of $a = 0.3248$ nm and $c = 0.5206$ nm for bulk ZnO crystal [8]. Consequently, it is obvious that the hexagonal ZnO films obtained in this work are of high crystalline quality. A typical SEM photograph of an obtained ZnO film is shown in Fig. 2. A thickness of the film was typically 0.6 μm.

A representative AFM image of the high-quality ZnO film is shown in Fig. 3. The mean square roughness for $1.5 \times 1.5 \mu\text{m}^2$ of the ZnO film is less than 4 nm, suggesting that the surface is flat and smooth. These results indicate that the sputtered ZnO thin films are appropriate for fabrication of UV detectors.

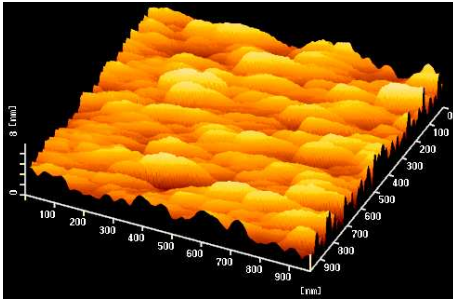


Fig. 3. AFM image of ZnO film

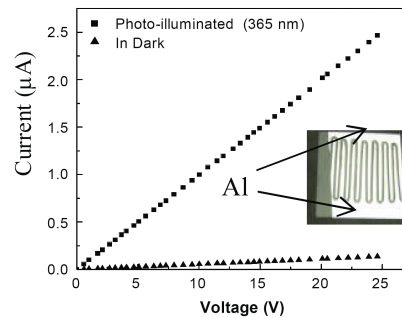


Fig. 4. Dark and photo-illuminated of Al/ZnO/Al photoconductive detector (the inset shows the IDT electrodes of ZnO UV detector)

The Al/ZnO/Al (MSM) structure with interdigitated (IDT) configuration was used to evaluate the UV detector performance. The inset in Fig. 4 is the partial IDT electrodes of ZnO-UV detector. The measured dark and photo-illuminated I-V characteristics are shown in Fig. 4. The linear I-V relation under both forward and reverse bias exhibits ohmic metal-semiconductor contacts. The detector operates in the photoconductive mode. The dark current for bias voltage of 6 V was $0.003 \mu\text{A}$. The low dark current is helpful to enhance the detector's signal to noise (S/N) ratio. Under illumination by monochromatic light with a wavelength of 365 nm, the photocurrent obtains a value of $0.56 \mu\text{A}$ at a bias of 6 V.

The measured results of spectral response of the photocurrent measurements of Al/ZnO/Al structure are shown in Fig. 5. The photocurrent maximum is at around 365 nm (3.40 eV) and at the longer wavelengths it drops roughly by 50 %. This is because when a light with photon energy greater than the band-gap value is absorbed by the semiconductor, the photo-generated carriers are excited through the metal-semiconductor-metal junction giving rise to a change in the electrical conductivity. At the longer wavelength side of the photocurrent maximum a cut-off is observed. This cut-off corresponds to the bandgap of ZnO. Although the cut-off is not sharp, more than two times drop in photocurrent value was observed from 365 to 405 nm. This indicates that sensitivity of sputtered ZnO film in the UV region is high enough for using it as UV detector material.

The photoresponse decay for the device under 6 V bias at room temperature has been measured. Before each experiment, the samples were kept in dark for at least 12 h, and then excitation light was turned on for 2 h. Fig. 6 shows a typical slow photoresponse decay. It takes 30 s for the signal to drop to 50 % of its maximum value. This might be due to the presence of defect states within the band gap of the polycrystalline ZnO films. The photo-generated carriers can be trapped repeatedly by these defect states, therefore, that can lengthen the photoresponse decay.

Fig. 7 shows the transmission spectrum of ZnO thin film. There is a steep absorption edge at 375 nm. The transmission coefficient is more than 90% at the visible light region and is zero at the UV light region. This indicates that the thickness of $0.6 \mu\text{m}$ for ZnO film is enough for the UV light absorption for formatting the photocurrent.

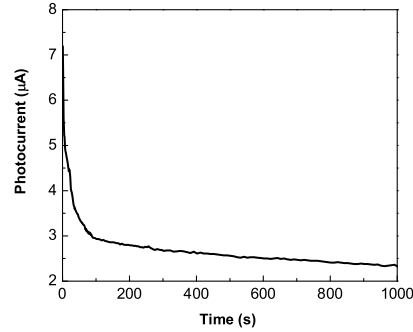
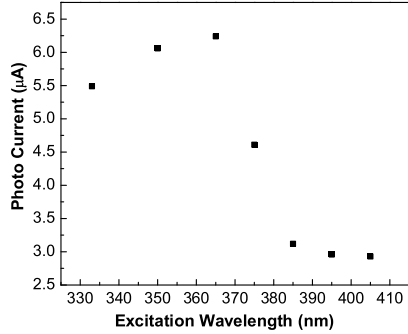


Fig. 5. Photocurrent spectrum of **Fig. 6.** Photoresponse decay of ZnO photoconductive device Al/ZnO/Al photoconductive detector

In order to elucidate the behavior of photo-generated carriers at different excitation wavelength, we have examined the absorption and photoluminescence spectra of ZnO film at room temperature (Fig. 8). An exciton peak is observed at approximately 367 nm (3.38 eV) in the absorption spectrum. In the PL spectrum, two emission bands are observed, one is at 379 nm (3.27 eV) near the band edge and a broad one is at 535 nm (2.32 eV).

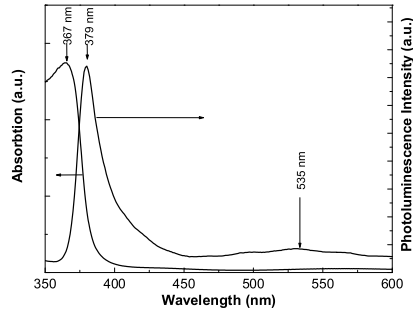
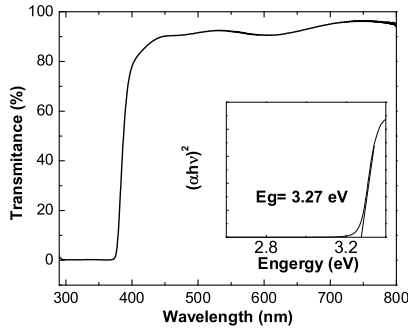


Fig. 7. Transmission spectrum of ZnO thin film **Fig. 8.** Absorption and PL spectra of ZnO thin film at room temperature

The near band edge emission is due to free exciton recombination, although it exhibits slightly red shift from the absorption peak. The broad PL band is usually related to the defects formatting deep-levels in the band gap, which are frequently observed in ZnO thin films. It can be noticed that the wavelength of 365 nm at which the photocurrent obtains maximum value is approximate to the wavelength of 367 nm at which the absorbance is strongest. This indicates that photocarriers are generated by the absorption process near the band edge.

IV. CONCLUSION

Highly *c*-axis oriented ZnO films were deposited on glass substrates by r.f. magnetron sputtering technique. The MSM photoconductive UV detectors based on ZnO thin films were fabricated by using Al as contact metal. The I-V characteristic of the detector is linear under dark or 365 nm UV light illumination. Under illumination by monochromatic light with a wavelength of 365 nm, the photocurrent was 0.56 μ A at a bias of 6 V. Photoresponse decay for such film is very slow. The results of the photoresponse, absorption and photoluminescence measurements of the ZnO films allow to affirm that photocarriers are generated by the absorption process near the band edge.

ACKNOWLEDGMENT

The authors wish to thank the Vietnam National University (Project No QT 08-16) for financial support.

REFERENCES

- [1] Z. Q. Xu, H. Deng, J. Xie, Y. Li, X. T. Zu, *App. Surface Science*, **253** (2006) 476.
- [2] Q.A. Xu, J.W. Zhang, K.R. Ju, X.D. Yang, X. Hou, *J. Crystal Growth*, **289** (2006) 44.
- [3] S. Mridha and D. Basak, *J. App. Phys.*, **101** 083102 (2007) 1.
- [4] Z. Q. Xu, H. Deng, J. Xie, Y. Li, Y. Li, X. T. Zu and S. Xue, *J. of Sol-gel Scie. and Tech.*, **36** (2005) 223.
- [5] Jichen and T. Fujita, *Jpn. J. App. Phys.*, **41** (2002) 203.
- [6] D. Balsak, G. Amin, B. Mallik, G.K. Paul, S.K. Sen, *J. Crystal Growth.*, **256** (2003) 73.
- [7] K. Omichi, K. Kaiya, N. Takahashi, T. Nakamura, S. Okamoto and H. Yamamoto, *J. Mater. Chem.*, **11** (2001) 262.
- [8] F. Masuoka, K. Ooba, H. Sasaki, H. Endo, S. Chiba, K. Maeda, H. Yoneyama, I. Niikura, and Y. Kashiwaba, *Phys. Stat. Sol.*, **4** (c) 3 (2006) 1238.

Received 05 May 2009.