Solid-State Electronics 55 (2011) 59–63

Contents lists available at ScienceDirect

Solid-State Electronics

journal homepage: www.elsevier.com/locate/sse

Investigation on UV photodetector behavior of RF-sputtered ZnO by impedance spectroscopy

N.H. Al-Hardan *, M.J. Abdullah, H. Ahmad, A. Abdul Aziz, L.Y. Low

School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia

ARTICLE INFO

Article history:
Received 5 June 2010
Received in revised form 29 July 2010
Accepted 5 September 2010

The review of this paper was arranged by Prof. E. Calleja

Keywords:
Impedance spectroscopy
UV photodetector
Zinc oxide

ABSTRACT

Ag/ZnO/Ag thin films representing metal/semiconductor/metal ultraviolet (UV) photodetectors were successfully prepared by RF magnetron sputtering. A UV light emitting diode was used as an illuminating source at 365 nm. The current–voltage characteristics of the device under UV illumination showed an enhancement in the forward current. Device modeling was carried out using impedance spectroscopy. The resistance of the device decreased as the light was switched from dark to UV. Moreover, the device showed further decrease in resistance at a bias voltage of up to 2 V.

1. Introduction

Zinc oxide (ZnO) is a good candidate for different applications, such as in transparent conducting oxide layers (TCO) used in solar cell and display panels, because of its direct wide band gap of ~3.37 eV at room temperature [1]. Its large exciton binding energy (60 meV) makes it a good substitute material for gallium nitride in optoelectronic applications, especially in the UV region [2,3]. Advanced applications, such as UV light emitting diodes (LED) and laser diodes, have been reported for ZnO at room, as well as in high, temperatures [4]. Moreover, different sensing applications have been reported for ZnO, including sensors for different gases [2], surface acoustic waves (SAWs) [3], and photodetectors [5–7]. One of the advantages of ZnO thin films is that they can be prepared by different methods, such as chemical vapor phase deposition, pulsed laser deposition, sputtering, and molecular beam epitaxy [1,8].

Impedance spectroscopy is considered a powerful method for analyzing polycrystalline material structures in which different contributions of electrodes, grain boundaries, and individual grains can be distinguished by changing the applied frequency of the system [9–11].

The complex impedance as a function of angular frequency (ω) can be written as [9]:

$$Z^*(\omega) = Z'(\omega) - iZ''(\omega) \quad (1)$$

where $Z'(\omega)$ and $Z''(\omega)$ are the real and imaginary components of the complex impedance, respectively. For a device with a polycrystalline material, the total impedance Z_T can be written as [10]:

$$Z_T = Z_g + Z_{gb} + Z_c \quad (2)$$

where Z_g, Z_{gb}, and Z_c represent the complex impedance contribution of the grains, grain boundaries, and electrode contacts, respectively. Each contribution can be represented in the form of parallel resistance (R) and capacitance (C).

UV photodetector applications of ZnO have been explored, in which the effect of preparation conditions, as well as post-deposition treatment has been studied extensively [12–14]. It was shown that the oxygen molecules absorbed at the surface of the ZnO play the main role. In dark the oxygen molecules captured the electrons from the ZnO surface and creating a depletion layer which may explain the high resistance of the ZnO. The UV light with energy higher than that of the energy band gap creates an electron–hole pairs. The holes are readily trapped at the surface and compensate the charges of the oxygen molecules. The electrons are released back to the surface of the ZnO which result in the increase of the conductivity of the ZnO [5].

In this work, we report the fabrication and characterization of a metal/semiconductor/metal (MSM) UV photodetector of RF-sputtered ZnO. The impedance characteristics of ZnO photodetectors under the exposure of 365 nm UV light, and the effect of a DC bias voltage on detector behavior are investigated.

* Corresponding author. Tel.: +60 17 4961778; fax: +60 4 6579150.
E-mail address: naif.zd06@student.usm.my (N.H. Al-Hardan).

0038-1101/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.sse.2010.09.003

2. Experimental details

Prior to the growth of ZnO, n-type silicon wafers of (1 0 0) orientation were thermally oxidized to form a 1.2 μm layer of SiO_2. Thin films of ZnO with a thickness of approximately 1.20 ± 0.10 μm and total area of $6 \times 6\ mm^2$ were coated on the Si/SiO_2 substrate by RF magnetron sputtering at a power of 200 W and ambient substrate temperature. The process utilized an Edwards A500 magnetron RF sputtering unit, where the ZnO ceramic target was initially exposed to plasma for surface cleaning prior to the coating process. The sample was fixed on a rotating substrate holder at a distance of 100 mm above the target. The initial pressure of the system was 1×10^{-6} mbar, after which it was raised to 2×10^{-2} mbar by purging the chamber with high purity Ar through gas flow controllers. The film thickness and the sputtering rate were controlled using a calibrated film thickness monitor (type FTM-7). The films were then heat treated in air for 1 h at 900 °C and atmospheric pressure. The UV detector was fabricated to an MSM configuration using thin films of silver (Ag) as the metal electrodes. The electrodes were thermally coated through a metal mask and the distance between the two electrodes was 0.7 mm. The structure of the photodetector is shown in Fig. 1.

A UV LED with a wavelength of 365 nm and power of 3 mW (Nichia Corp., Japan) was used as the illuminating source. The impedance response of the photodetector was measured by an Agilent impedance analyzer (model 4294A) in the frequency range 40 Hz–2 MHz. The unit was first calibrated to eliminate the effect of the leads. A Keithley 237 source meter unit was employed to measure the current–voltage (*I–V*) characteristics of the system. Both units were controlled by a PC using LABVIEW 8.5 via a GPIB interface. The measurements were performed at ambient conditions (temperature, 25 °C; humidity, 62%).

The prepared ZnO films were also investigated using a high resolution PANalytical X-ray diffractometer (HR-XRD) for phase identification, whereas the cross-sectional morphology of the film was determined using a SUPRA 50 VP field emission scanning electron microscope. The photoluminescence (PL) spectra were obtained at room temperature using a Jobin Yvon Horiba HR800UV system with a 325 nm line HeCd laser at a power of 20 mW.

3. Results and discussion

3.1. Structure of the films

The ZnO film thickness was about 1.20 ± 0.10 μm, as measured by a calibrated crystal quartz thickness monitor (FTM-7). The XRD diffraction pattern (Fig. 2) shows that the prepared ZnO on thermally oxidized Si substrates was highly oriented along the *c*-axis, with peaks at Bragg angles of 34.20° and 72.37°, attributed to the (0 0 2) and (0 0 4) phases of the hexagonal ZnO, respectively, with reference to JCPDS No. 36-1451. Generally, the *c*-axis orientation is frequently observed in ZnO films prepared by RF sputtering because the (0 0 2) orientation has the lowest surface energy among the other orientations [15].

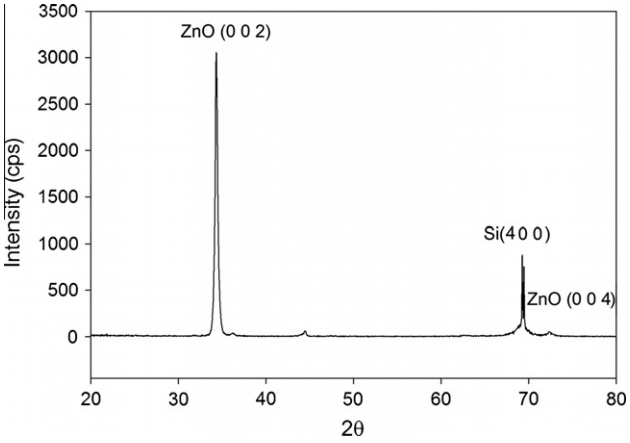

Fig. 2. HR-XRD of RF-sputtered ZnO thin films on thermally oxidized n-Si (1 0 0).

Fig. 3 shows the cross-section of the prepared films, clearly demonstrating that the prepared ZnO films exhibit columnar structures, oriented perpendicularly to the substrate.

The PL characteristics of the ZnO thin films grown on a n type Si wafer were obtained at room temperature in the wavelength range of 300–1000 nm (4.1–1.24 eV) (Fig. 4). The spectra showed a strong UV emission of 379 nm (3.27 eV), which could be attributed to the recombination of free excitons [16]. Two low emissions were also observed at 510 nm (2.43 eV) and 760 nm (1.6 eV). It is suggested that the appearance of the 510 nm band could be related to defects such as oxygen vacancies, zinc interstitials, zinc vacancies, and oxygen interstitials, while the origin of the second band at 760 nm is related to the excess of oxygen or zinc interstitial [16]. The PL results coupled with the XRD characteristics indicate that the prepared ZnO thin films have a good crystal quality of the wurtzite hexagonal crystal structure.

3.2. UV sensing properties

The *I–V* characteristics of the ZnO MSM photodetector in dark and ambient light are shown in Fig. 5a. The MSM shows back-to-back Schottky contacts. However, UV illumination at 365 nm changed the type of contact behavior from Schottky to ohmic, as can be seen clearly in Fig. 5b. Such linearity may arise from the increase in

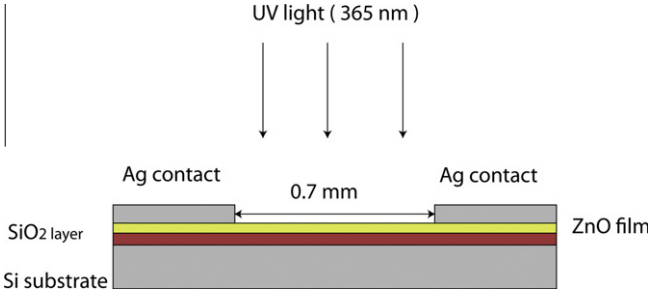

Fig. 1. Cross-section diagram of the ZnO MSM photodetector.

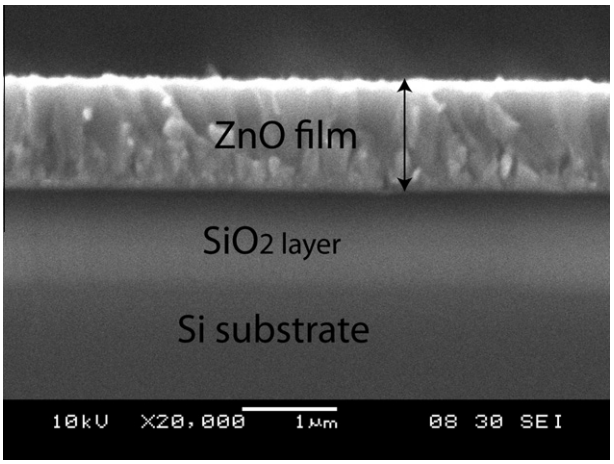

Fig. 3. SEM cross-section image of the prepared ZnO films. The bar length is 1 μm.