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Influence of illumination intensity on the electrical characteristics and photoresponsivity of the Ag/ZnO Schottky diodes

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ABSTRACT

In this article, the ZnO thin films were grown by RF-magnetron sputtering on ITO glass substrates. The Schottky diodes with the configuration of Ag/ZnO/ITO have been fabricated and it has been observed that the diodes exhibit a good rectification. The structural and optical properties of the ZnO films were investigated by X-ray diffractometry and spectrophotometry. The current–voltage (I–V) characteristics of the Ag/ZnO diode were measured under various illuminations. We use the forward bias current–voltage measurements to determine the electrical parameters such as ideality factor, barrier height and series resistance of the diode. The Ag/ZnO Schottky diode exhibits a non-ideal behavior due to the interfacial layer, the interface states and the series resistance. It is found that the barrier height and ideality factor values are strong functions of illumination intensity. The results show that the ideality factor and the barrier height decrease with increasing illumination intensity. The values of R_s obtained from Cheung and Norde methods are decreased with increasing illumination intensity. Photoresponse characteristics of the diode have been analyzed and it is clear that the diode shows a fast response. It is evaluated that the prepared diodes can be used as optoelectronic devices.

1. Introduction

In the past years, there has been great interest in the development of transparent conducting oxides. Transparent conductive oxide (TCO) thin films have been extensively used in a variety of electronic and opto-electronic applications such as display, solar cells, electrochromic devices, and optoelectronic devices due to its high visible light transparency and high electrical conductivity [1,2]. More attentions have been paid to zinc oxide (ZnO) because of its remarkable optical and electrical properties. ZnO is a II–VI compound semiconductor with a wide direct band gap of 3.37 eV at room temperature. It has an exciton binding energy of 60 meV [3,4]. In general, ZnO thin film is n-type semiconductor material and its electrons come from intrinsic defects, such as oxygen vacancies and zinc interstitials, which move as charge carriers in the conduction band. ZnO thin film can be prepared by many techniques including magnetron sputtering, pulsed laser deposition, the sol–gel techniques and so on [5]. In this work, we manufacture the Ag/ZnO Schottky diodes by the RF-magnetron sputtering method. Compared with other deposition techniques, RF-magnetron sputtering has the advantages of lowing processing temperature, simple fabrication step and high reproducibility [6]. We investigate the electrical characterization of Ag/ZnO Schottky diodes through current–voltage (I–V) measurements under various illumination intensities.

2. Experiment

The ZnO thin films were grown by RF-magnetron sputtering on commercially available indium tin oxide (ITO) coated glass substrates. The ITO film with a thickness of 150 nm served as the bottom electrode. Before deposition, the ITO glass was cleaned ultrasonically in acetone and alcohol for 15 min to remove contamination and then rinsed successively in deionized water. The ZnO thin films were deposited by using a ceramic ZnO target (99.99%). The distance between target and substrate was about 7 cm. The sputtering chamber was evacuated to a base pressure of 4.7×10^{-4} Pa. The sputtering power was 100 W and the working pressure of the deposition was set at 5 Pa. The flow rate of Ar and O_2 were 2 and 40 sccm. Presputtering for 10 min was performed to clean the surface of the target. During deposition, the substrate was set to a temperature of 500 °C and the sputtering time was 60 min. The thickness of ZnO film measured by surface profilometer was about 300 nm. After deposition, silver oxide film with a thickness of about 30 nm was deposited by reactive RF sputtering of an Ag target (99.99%) using an Ar/O_2 atmosphere. Finally, 100-nm-thick Ag was deposited in pure argon using the same metal through a shadow mask.

The crystalline structure of the ZnO thin film was characterized by the X-ray diffraction (XRD) technique. The optical transmittance was recorded with a UV–VIS–NIR double beam spectrophotometer in the wavelength range of 300–800 nm. The current–voltage characteristic of the Schottky diode was measured by Keithley 4200 semiconductor parameter analyzer at room temperature.

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3. Results and discussion

Fig. 1 shows the XRD pattern of ZnO thin film prepared by RF magnetron sputtering. It is obvious that the thin film has a preferential *c*-axis orientation. This indicates that the *c*-axis of the grains becomes uniformly perpendicular to the substrate surface. A strong peak centered at 34.4° is associated with the ZnO (002) plane. It is found that the full-width at half-maximum (FWHM) of XRD is about 0.427°. In order to attain the detailed structural information, the grain size was calculated using Scherrer' formula [7] from the full width at half-maximum:

$$D = \frac{k\lambda}{\beta \cos\theta} \tag{1}$$

where D is the average grain size, the constant k is the shape factor = 0.9, λ is the X-ray wavelength, β is the FWHM of diffraction peak measured in radians and θ is the Bragg diffraction angle. The calculated grain size is about 19.5 nm.

Fig. 2 displays the transmittance spectra of the ZnO thin film. Within the visible region, the average transmittance is more than 70%. The transmission decreases sharply near the ultraviolet region due to the band gap absorption. The optical band gap of the films can be derived from the plot shown in the inset of Fig. 1. We use the relation: $\alpha(h\nu) = C(h\nu - E_g)^{1/2}$, where α is optical absorption coefficient and C is a constant for a direct transition. The optical band gap can be obtained from the intercept of $(\alpha h\nu)^2$ vs $h\nu$ for directly allowed transitions [8]. The ZnO optical band gap obtained from the absorption spectrum is about 3.24 eV at room temperature.

According to the thermionic emission (TE) theory for a Schottky diode with a series resistance and an interfacial insulator layer, the dependence of the forward current I on the applied voltage V is given as follows [9]:

$$I = I_0 \exp\left(\frac{q(V - IR_S)}{nkT}\right)\left[1 - \exp\left(-\frac{q(V - IR_S)}{kT}\right)\right] \tag{2}$$

where V is the applied voltage across to rectifier contact, T is the temperature in Kelvin, k is the Boltzmann constant, q is the electronic charge, n is the ideality factor introduced in order to calculate the deviation of the experimental I–V data from the ideal thermionic model, and I0 is the reverse saturation current derived from the $\ln(I)$–V plot as the straight line intercept of the $\ln(I)$ axis at zero bias and is given by:

$$I_0 = AA^*T^2 \exp\left(-\frac{q\phi_b}{kT}\right) \tag{3}$$

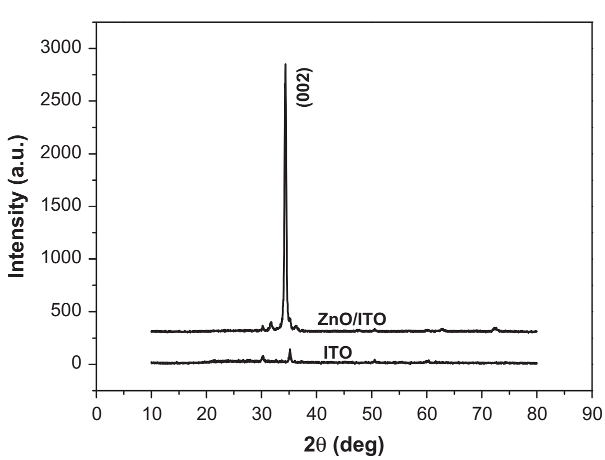

Fig. 1. The XRD pattern of ZnO thin film.

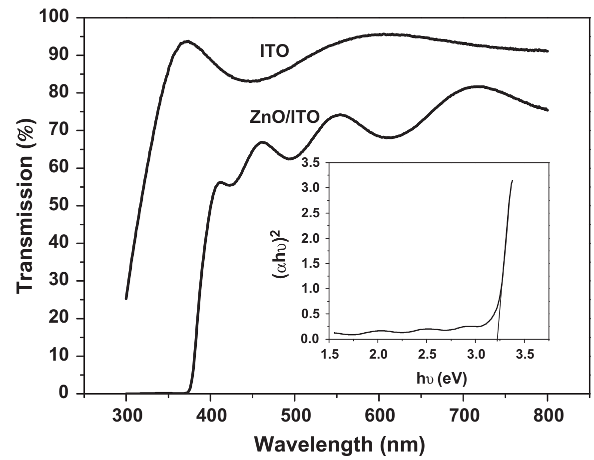

Fig. 2. The transmittance spectra of the ZnO thin film.

where A is the effective diode area, A^* is effective Richardson constant of 32 A/cm^2 K^2 for n-type ZnO [10], Φ_b is the effective barrier height at zero bias defined by Eq. (3). The diode ideality factor (n) can be determined from the slope of semi-logarithmic forward bias I–V plot for 0.25 > V > 3 kT/q according to Eq. (2) and the n were given by:

$$n = \frac{q}{kT}\frac{dV}{d\ln(I)} \tag{4}$$

Φ_b can be obtained from the following equation:

$$\phi_b = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_0}\right) \tag{5}$$

The I_0 was obtained by extrapolation of the linear region of the semi-logarithmic forward I–V curves to zero applied voltage and was used to calculate the barrier height. Fig. 3 shows the I–V characteristics of the diode under dark and various illumination intensities. The wavelength of the illuminated light is 365 nm. As can be seen in these figures, the diode exhibits a good rectification behavior especially at low illumination levels. It is found that the forward current at high bias region is increased with the increasing illumination intensity. The reason is that photons can generate electron–hole pairs in the depletion layer of the semiconductor. This indicates that the light illumination increases the generation of

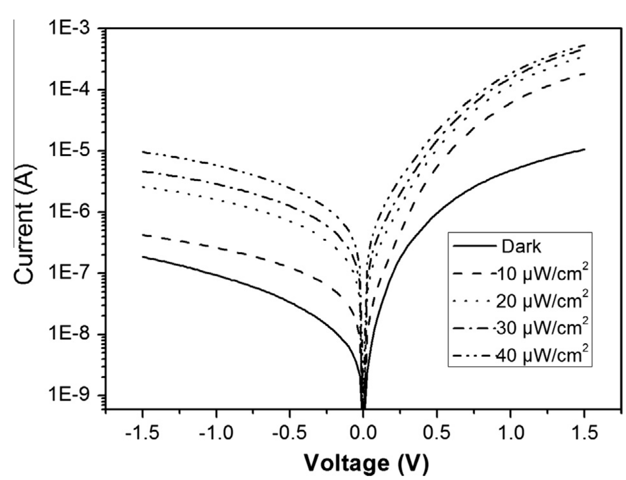

Fig. 3. The experimental current–voltage plots of the Ag/ZnO diode in dark and under various illumination at room temperature.