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Transparent metal oxide films based sensors for solar tracking applications

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ABSTRACT

Titanium dioxide:zinc oxide (TiO_2:ZnO) composite thin films were prepared onto glass and p-type silicon substrates by the sol–gel spin coating technique. The composite metal oxide films indicate a high transmittance more than 90% in visible region. Optical constants such as optical band gap and refractive index of the films were determined using transmittance and reflectance spectra. TiO_2:ZnO/p-Si diodes exhibited a high photocurrent responsivity under various solar illuminations. Electronic parameters like ideality factor, series resistance and barrier height were determined from *I–V* characteristic curves, Cheung model and Norde equations. The capacitance–voltage and conductance–voltage of the diodes were measured in the range from 10 kHz to 1 MHz. The capacitance of the diodes exhibited a decrease in capacitance and increase in conductance with increasing frequency. The obtained results suggest that TiO_2:ZnO/p-Si diodes can be used as a sensor in optic communications and optoelectronic applications.
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1. Introduction

Titanium dioxide has been extensively investigated due its interesting optical, electrical and photocatalytic properties. It is a promising material for various applications and is used in destruction of pollutants from contaminated water and air and killing of harmful bacteria and cancer cells [1–6]. Also, it is a potential material for high temperature gas sensor applications [7]. It has three mineral forms viz: anatase, rutile, and brookite [8]. Anatase phase corresponds to a crystalline structure with the tetragonal system and the application of this phase is photocatalysts under UV irradiation. Rutile type of TiO_2 is a tetragonal crystal structure which is used as a white pigment in paint. Brookite type of TiO_2 is an orthorhombic crystalline structure. These phases of TiO_2 indicate that it is a versatile material for various applications such as paint pigments, electrochemical electrodes, capacitors, solar cells and sunscreen lotions [9].

The physical and chemical properties of this material can be improved using various dopants such as transition metals. Absorption region of this material can be controlled by surface modification and this modification can enhance the photocatalytic properties [10].

On the other hand, zinc oxide is another promising material among the metal oxide semiconductors and it is a main semiconductor for the synthesis of visible-light-active application [11]. TiO_2 has been doped with Zn^{2+} ions and the dopant effects were investigated [12,13]. Thus, in the present study, we prepared TiO_2:ZnO composite films to improve the optical and photosensitive properties of TiO_2 with ZnO contents for photosensor applications. With this aim, TiO_2 based composites were prepared for various molar ratios of ZnO by the sol gel method to prepare new photodiodes. Electrical and photoresponse properties of the photodiodes were investigated by current–voltage and capacitance–voltage measurements and analyzed in detail.

2. Experimental techniques

TiO_2:ZnO composites films were synthesized using titanium (IV) n-butoxide, zinc acetate precursors. Firstly, the nominal value of titanium (IV) n-butoxide was dissolved in ethanol under a stirring for 2 h and then, distilled water was added to solution. Afterwards, the pH of the solution was kept at 1.5 using HNO_3 and a clear solution was obtained. Secondly, zinc oxide solution was prepared. For this, the nominal value of zinc acetate was dissolved in

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ethylene-glycol and then, stirred and was heated for 45 min to obtain a gel. Then, the gel was dissolved in glycerol and absolute ethanol while it was heated. The TiO_2/ZnO composites were prepared for various molar ratios of TiO_2:ZnO 1:1, 1:2 and 1:3. TiO_2/ZnO films were coated on p-type silicon substrates having ohmic contact using a spin coater under 1000 rpm for 30 s and dried at 150 °C on a hot plate and annealed at 450 °C for 1 h in air atmosphere. The ohmic contact was prepared by thermal evaporating of aluminum to back side of silicon wafer and it was annealed at 570 °C for 5 min in nitrogen atmosphere. The contacts of the diodes were prepared by evaporating of Al metal. The diode contact area was found to be 7.85×10^{-3} cm^2. The electrical and photoelectrical measurements were performed using a Keithley 4200 semiconductor characterization system. The optical characterization of the films was done using a Shimadzu UV–VIS–NIR spectrophotometer. Surface morphology and chemical compositions of the films were analyzed using a JEOL electron microscope attached X-ray energy dispersive spectroscopy attachment.

3. Results and discussion

3.1. Optical characterization of ZnO:TiO_2 composite thin films

The surface morphologies of ZnO:TiO_2 composite films were analyzed using SEM images. SEM images of the composite oxide films are shown in Fig. 1. As seen in Fig. 1, the films are formed from a smooth surface and distribution of some particles on surface. The chemical compositions of the films were confirmed using an EDS spectra. For this, EDS spectra of ZnO:TiO_2 composite films are shown in Fig. 2. The observed elements in the structure of the films are Ti, Zn and O elements. The presence of these elements confirms the chemical composition, i.e., the prepared composite oxide films are formed from TiO_2 and ZnO materials.

Fig. 3 shows the transmittance spectra of TiO_2:ZnO composite films with various molar ratios of TiO_2:ZnO 1:1, 1:2 and 1:3 in the wavelength range of 200–1400 nm. It is seen that the absorption edges of these films have no significant change because of very similar band edges of ZnO and TiO_2 [14]. The films exhibited a high transparency in the visible region and this transparency is significant for photodetector applications.

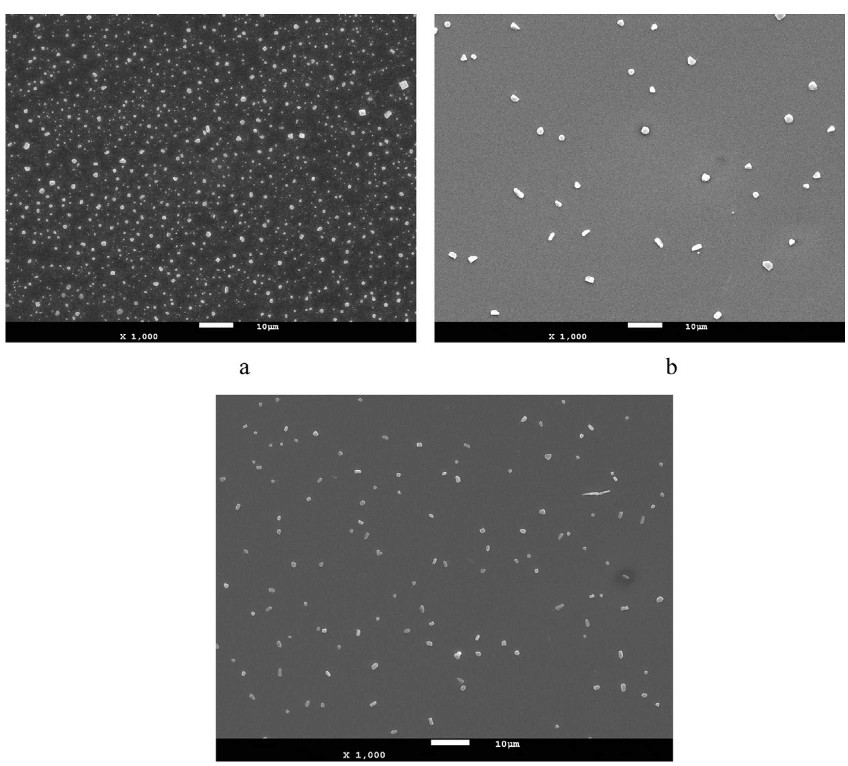
In addition, a strong absorption edge can be observed at $\lambda = 340$ nm. All the spectrums exhibit interference fringes in the visible region due to the multiple reflections resulting from the film/substrate interface [15]. This suggests that the films have a high uniformity [16].

The reflectance spectra of the films are shown in Fig. 4. It can be observed that the reflectance spectra change slightly dependent on the wavelength and ZnO contents. The reflectance for all the films is low and this low reflectance value makes TiO_2:ZnO composite films an important material for anti-reflection coating [17]. It is interesting to note from these results that doped ZnO has weak influence on light absorption performance of TiO_2 films.

For a direct band gap semiconductor, the optical absorption edge can be analyzed by the following relation [18,19],

$$(\alpha h\nu) = C\left(h\nu - E_g\right)^n \quad (1)$$

where C is a constant, E_g the optical band gap, α is the optical absorption coefficient, $h\nu$ is the photon energy, h the Plank's constant and n is an exponent which determine type of optical band gap transitions between valence and conduction bands. It is evaluated that ZnO is a direct band gap semiconductor. Thus, the relation between optical band gap energy and absorption coefficient can be expressed by the following [19–21],



c

Fig. 1. SEM images of the films a) TiO_2:ZnO = 1:1, b) TiO_2:ZnO = 1:2, c) TiO_2:ZnO = 1:3.

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