OPTICAL AND ELECTRICAL PROPERTIES OF (Cu, Al, In) DOPED SnO_2 THIN FILMS ON GLASS SUBSTRATE

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Abstract

The undoped SnO_2, Cu, Al and In (5mol%) doped SnO_2 thin films were deposited on glass substrates by sol-gel and spin coating technique. The effect of Cu, Al and In doping on the optical and electrical properties of the SnO_2 thin films were studied. The optical transmittance of thin films was measured and the optical band gap E_g values of the films were obtained in the range of 3.4 - 4.00 eV using the Tauc relation. The electrical transport properties of undoped, Cu, Al and In doped SnO_2 thin films were investigated by mean of current-voltage (I-V) measurement using simple diode model. The important diode parameters such as ideality factor, saturation current, and barrier height are also calculated.

Keywords: Cu, Al and In doped SnO_2, optical band gap E_g, current-voltage (I-V)

Introduction

Tin dioxide (SnO_2) has been intensively investigated because of its rich physical properties and large applications in commercial devices. The SnO_2 with a wide-band-gap (E_g = 3.6-4.0eV) is one of the excellent semiconductors which can be applied to solid state gas sensors, sensing arrays, solar cells, photovoltaic cells, organic light emitting diodes, touch sensitive screens and thin film transistors. [Bagheri Mohaghegi M M et al (2008), Bagheri Mohagheghi MM et al 2008, Khan AF et al (2010), Khan Af et al 2010, Moharrami F et al (2012)]. The SnO_2 thin films can be fabricated by a number of techniques such as chemical vapour deposition (CVD), metalorganic deposition, rf sputtering, sol-gel dip coating, spin coating and spray pyrolysis. [Maekava T et al (2001), Yin LT et al (2000), Yin LT et al (2000), Ouerfelli J et al (2008).] It was clearly established spin coating that structural, electronic transport and optical properties of SnO_2 films are very sensitive to preparation method, deposition conditions, dopant atoms and amount of dopant atoms.

Experimental

The glass substrates were ultrasonically cleaned by keeping in ethanol and in the distilled water, for ten minutes, respectively. Then the glass substrates were dried. The films were deposited on the glass substrates by spin coating technique. In order to prepare the coating solution, firstly, Cu, Al and In (5 mol%) doped SnO_2 powder mixed by conventional stoichiometric composition. The mixture powder is ground by agate mortor to obtain the homogeneous and uniform grain size of powder. This powder is heat treated at 500° C for 1 hr. The crystalline powder, were mixed with 2-methoxgethanol solution by using sol-gel method. And then these pastes were coated on glass substrates and annealed at 400°C for 1 hr, respectively.

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Results and Discussion

Figure 1 (a ~ d) shows the optical transmittance spectra of the SnO_2 films for various dopant atoms (Cu, Al, In). The transmittances of all the films were increased in an apparent way with wavelength near the IR region. It was seen that the transmittance has the lowest value for the film doped with Cu.

The absorption coefficients (α) were determined by means of the optical transmittance spectra using the relation, $\alpha = (1/d)\ln(1/T)$ where d is the thickness and T is the transmittance of the film at a particular wavelength. The optical band gap E_g of the film was calculated using the Tauc relation, which is given as $\alpha h\nu = \alpha_o (h\nu - E_g)^n$, where hν, α_o and n = 0.5, 1.5, 2.0 and 3.0 are the photon energy, a constant and for allowed direct, forbidden direct, allowed indirect and forbidden indirect electronic transitions, respectively. The plot of $(\alpha h\nu)^2$ versus hν is shown in Figure 2 (a ~ d). It was seen that the band gap energy E_g obey to the allowed direct transition (1/2) model. The optical energy band gap was obtained by extrapolating the linear portion of $(\alpha h\nu)^2$ versus hν plot to $(\alpha h\nu)^2 = 0$ as 3.4eV for undoped SnO_2, 4eV for Cu-doped SnO_2, 3.89eV for Al-doped SnO_2 and 3.8eV for In-doped SnO_2. The similar values for the optical energy band gaps were also reported by many researches.

Current-voltage (I-V) data of undoped SnO_2, (Cu, Al, In) doped SnO_2 thin films were measured in the forward and reverse directions using a DC power supply. Figure 3 (a ~ d) show the current – voltage characteristics of undoped SnO_2, (Cu, Al, In) doped SnO_2 thin films. From the ln I-V characteristics, the ideality factor (η) and the saturation current (I_s) are carried out. The saturation current (I_s) obtained from the ln I versus V characteristics. The diode ideality factor (η) is calculated by equation (1).

$$I = I_s \exp\left[\frac{V_a}{\eta V_T}\right] \qquad (1)$$

where, I_s is the saturation current, V_a is the applied voltage, V_T is the threshold voltage (0.02586V) for room temperature. The zero-bias barrier height (ϕ_{bo}) can be obtained by using the area "A" (0.03 cm^2) and the Richardson constant R* (8.16 $AK^{-2}cm^{-2}$) from the equation (2),

$$I_s = AR^*T^2 \exp\left[-\frac{q\phi_{bo}}{KT}\right] \qquad (2)$$

The values of ideality factor, saturation current and zero bias barrier height of undoped SnO_2, (Cu, Al, In) doped SnO_2 thin films are described in Table (1).

Table 1 Ideality factor (η), saturation current (I_s) and zero bias barrier height for undoped SnO_2, (Cu, Al, In) doped SnO_2 thin films

Samples	Saturation current I_s (A)	Zero bias barrier height Φ_{bo} (eV)	Ideality factor (η)
Undoped SnO_2	2.02×10^{-03}	0.4190	1.124
Cu doped SnO_2	4.04×10^{-03}	0.4011	1.118
Al doped SnO_2	4.08×10^{-03}	0.3832	1.112
In doped SnO_2	4.21×10^{-03}	0.3727	1.109

From the current-voltage characteristics, it was observed that the current flow through the samples exponentially increased with an increase in potential in forward bias region, it shows an exponential growth of the current that is main characteristics of a diode. In the reverse bias, the reverse breakdown voltage increase with increasing reverse-biasing voltage.

Conclusion

The undoped SnO_2, Cu, Al and In doped SnO_2 thin films on glass substrates were successfully investigated. The transmittances of all the films were apparently increased with increasing wavelength near the IR region and the transmittance has the lowest value for the film doped with Cu. The forbidden band-gap energy value for Cu doped SnO_2 was found as 4eV. The E_g was determined as 3.8eV and 3.89eV, having the nearly same result for In and Al-doped SnO_2 films. The electrical transport mechanism of the undoped, Cu, Al and In doped SnO_2 films was determined by means of the simple diode model. The zero bias barrier height and the ideality factor was determined the range of 0.37 – 0.42 eV and 1.109-1.124, respectively.

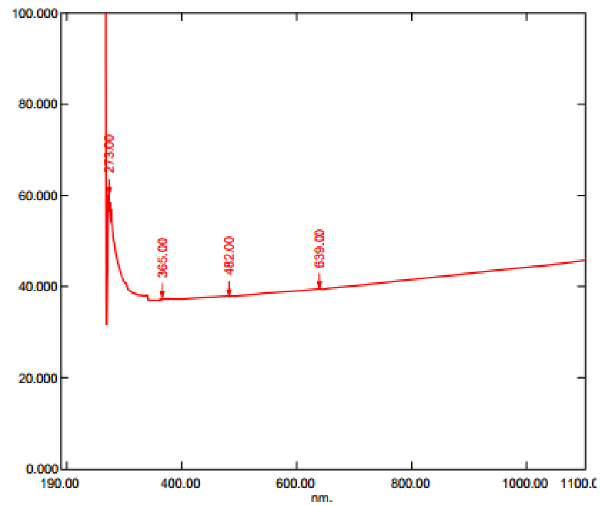

Figure 1 (a) Transmittance (T%) spectra for undoped SnO_2 thin film on glass

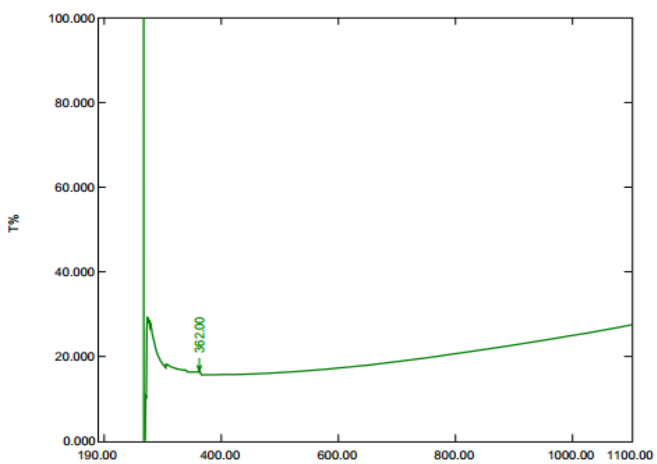

Figure 1 (b) Transmittance (T%) spectra for Cu doped SnO_2 thin film on glass

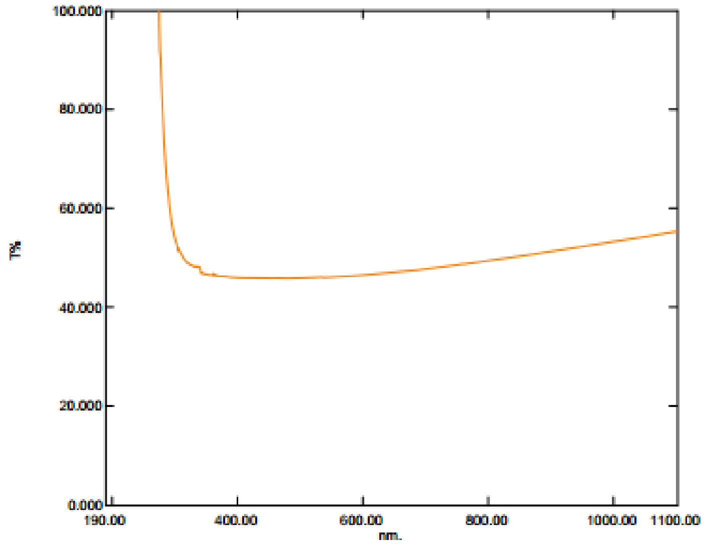

Figure 1 (c) Transmittance (T%) spectra for Al doped SnO_2 thin film on glass

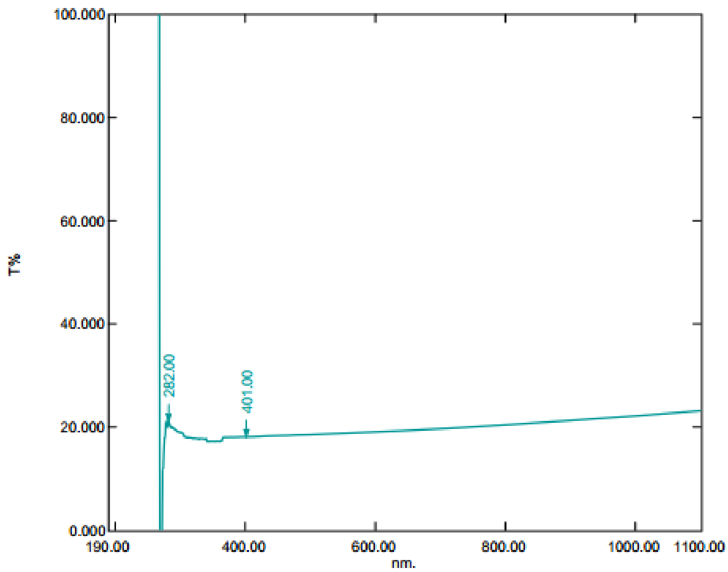

Figure 1 (d) Transmittance (T%) spectra for In doped SnO_2 thin film on glass

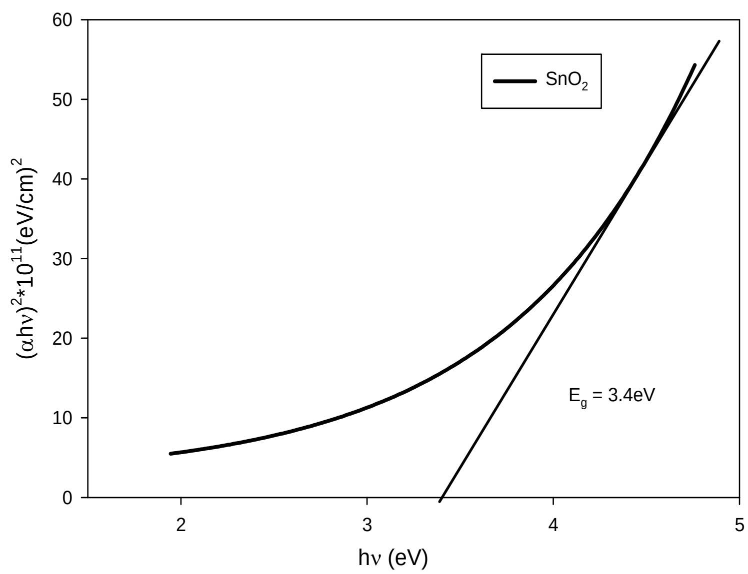

Figure 2 (a) Plot of $(\alpha h\nu)^2$ versus hν (undoped SnO_2)

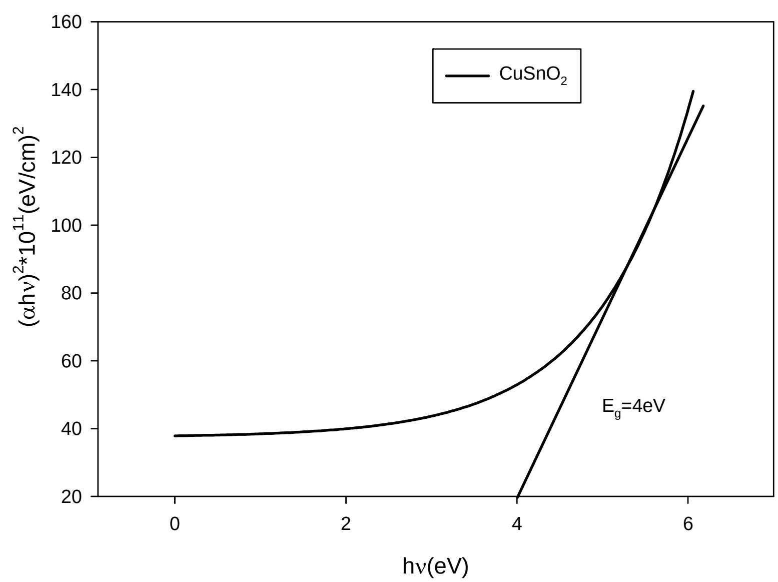

Figure 2 (b) Plot of $(\alpha h\nu)^2$ versus hν (Cu doped SnO_2)

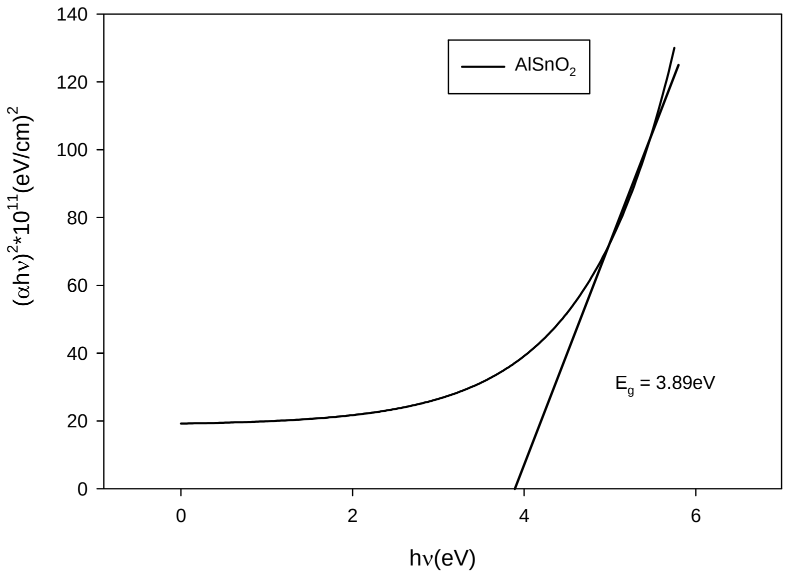

Figure 2 (c) Plot of $(\alpha h\nu)^2$ versus hν (Al doped SnO_2)

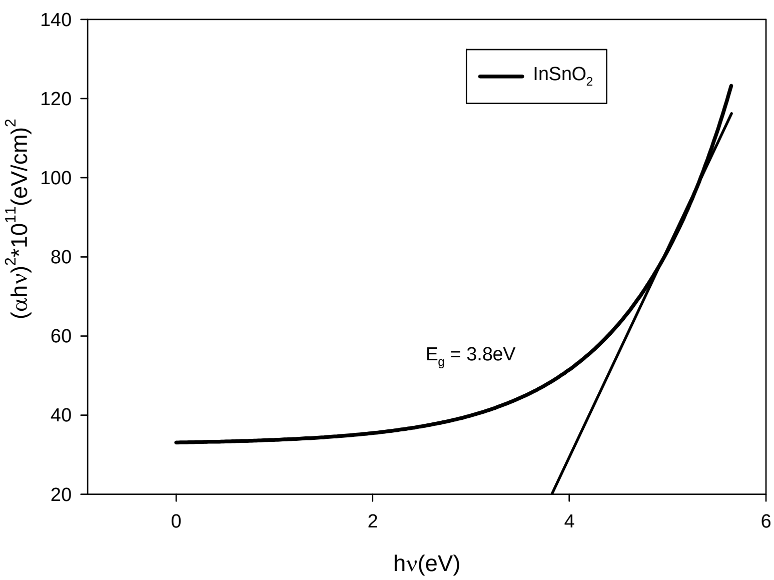

Figure 2 (d) Plot of $(\alpha h\nu)^2$ versus hν (In doped SnO_2)

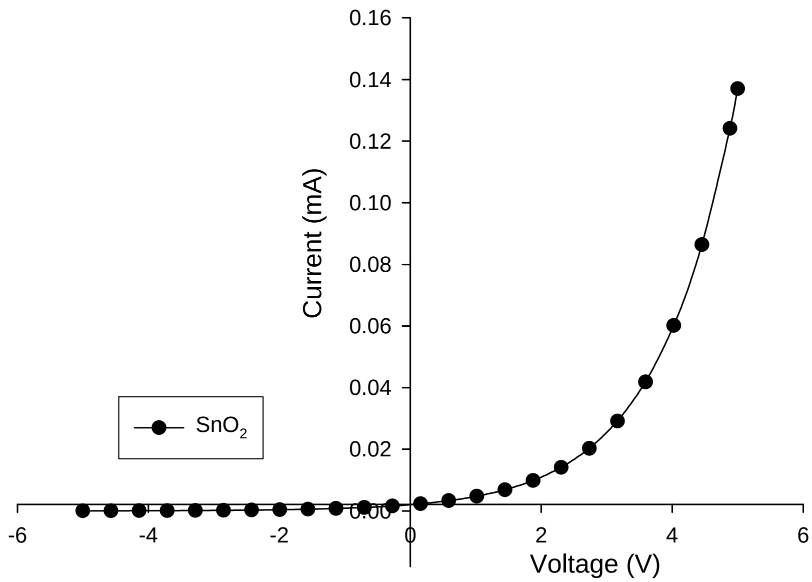

Figure 3 (a) I-V characteristics of (Undoped SnO_2)

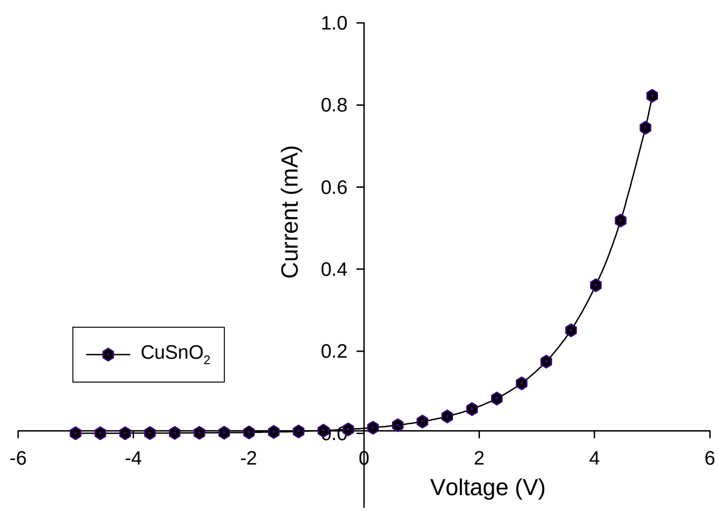

Figure 3 (b) I-V characteristics of (Cu doped SnO_2)

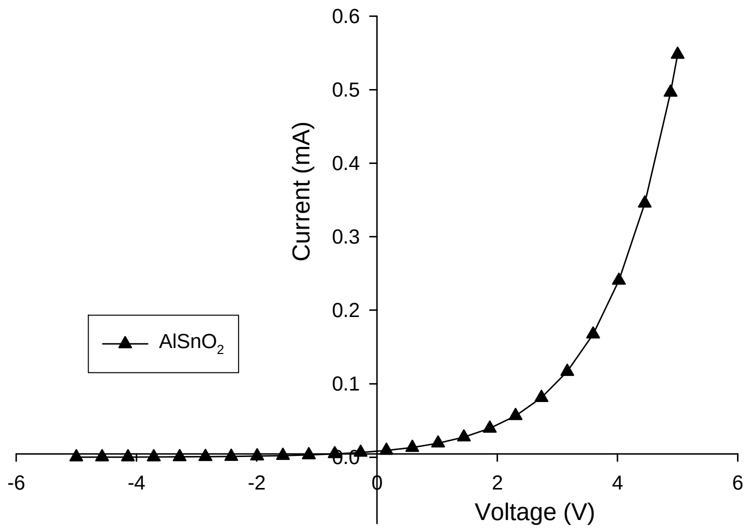

Figure 3 (c) I-V characteristics of (Al doped SnO_2)

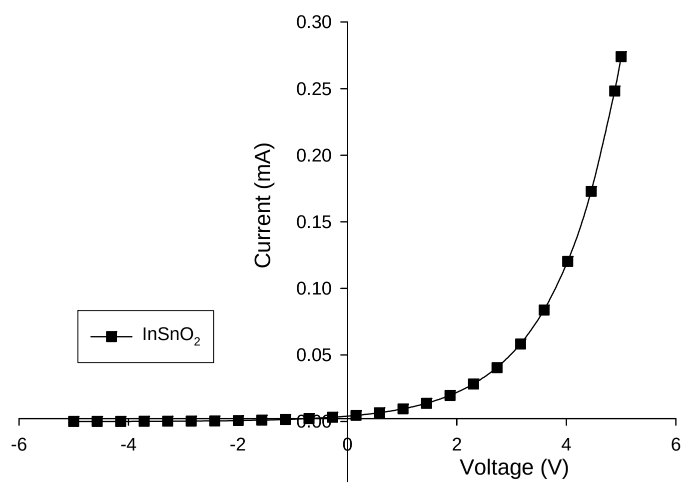

Figure 3 (d) I-V characteristics of (In doped SnO_2)

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