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Fabrication of p-SnO/n-SnO_2 transparent p-n junction diode by spray pyrolysis and extraction of device's intrinsic parameters

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ABSTRACT

This is the first time report of transparent p-SnO/n-SnO_2 heterojunction diodes fabricated by spray pyrolysis. Intrinsic device's parameters such as ideality factor, parasitic series resistance and reverse saturation current of the fabricated diodes were analyzed by the theoretical model proposed by Gracia et al. Two diodes with SnO layer thicknesses 86 nm and 80 nm were fabricated and observed to have ideality factors of 2.75 and 3.56 along with parasitic series resistances of 8 KΩ and 5 KΩ respectively. The transmission percentage of diode was increased from 70% to 88% on reducing the thickness of the SnO layer.

1. Introduction

p-n junction is the fundamental building block of all kinds of electronic and optoelectronic devices such as solar cells, junction transistors, light emitting diodes etc [1]. A p-n junction consists of consecutively connected n and p type semiconductor layers. The material selection of n and p type semiconductors are very important for the interface quality of the diode. In the present study we chose SnO as p layer of the diode because of its good electrical and optical properties and SnO_2 as n layer because of its wide band gap along with low resistivity, nontoxicity etc. There are only a few reports of SnO thin films by chemical spray pyrolysis method [2,3]. There are reports of fabrication of p-SnO/n-SnO_2 diodes by different methods like sputtering [4], thermal evaporation [5] etc. But this is the first time report of p-SnO/n-SnO_2 diodes fabricated using chemical spray pyrolysis method. A detailed analysis of the diodes is also carried out.

2. Experimental

2.25 g of $SnCl_2{\cdot}2H_2O$ was dissolved in 50 ml distilled water to make 0.2 M precursor solutions for SnO_2 thin films. Also 1.12 and 0.902 g of $SnCl_2{\cdot}2H_2O$ were dissolved in 50 ml [for diode 1] and 40 ml [diode2] distilled water to make 0.1 M precursor solutions for SnO thin films. A few drops of concentrated hydrochloric acid were added to make the solutions transparent. Then the mixture was magnetically stirred at 60 °C for an hour.

A p-n junction was fabricated using n-SnO_2 (1 cm diameter) and p-SnO (0.7 cm diameter) thin films on ITO coated glass substrates by chemical spray pyrolysis method at a substrate temperature 350 °C with spray rate of 10 ml/minute and carrier gas pressure 0.2 Kg/cm^2. The thickness of n- SnO_2 layer was 133 nm and that of p-SnO layer was 86 nm for diode1 whereas for diode 2, p-SnO layer has a thickness 80 nm. In order to take I-V characteristics, a silver electrode was used above the p-SnO layer and copper wires were used for metallic contact formation.

The structural characterization of SnO and SnO_2 thin films on glass substrate as well as different layers of the diode were carried out using X-ray diffraction analysis (XRD) with Rigaku D-Max Geigerflex X-ray diffractometer with CuKα radiation source ($\lambda = 1.5418$ Å) for 2θ values between 20° and 80° at room temperature. The optical characterization of the diode was studied by using Shimadzu UV–Vis spectrophotometer model-UV 2600. The electrical characterization of both SnO_2 and SnO thin films using Hall effect measurements was done using ECOPIA HMS-5000 in Vander Pauw configuration. The thickness of each layer of the diode was measured using Woollam M 2000 Ellipsometer. The I–V characteristics of diodes were done by using Keithley 2450 source measure unit.

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3. Results and discussions

The Fig. 1(A) shows XRD patterns of individual layers of SnO_2 and SnO synthesized on glass substrates. The grown SnO are in agreement with the standard JCPDS file no: 77-2296, having orthorhombic crystal structure (O-SnO). The SnO_2 thin film are in agreement with the standard JCPDS file no: 78-1063, having orthorhombic crystal structure. Fig. 1(B) shows XRD spectra of Glass/ITO/SnO/SnO_2 p-n junction diodes. The XRD pattern shows the peaks corresponding to both SnO and SnO_2 for both diodes. The XRD pattern of the diodes contain diffraction peaks corresponding to orthorhombic phases of SnO_2 and SnO.

The Fig. 1(C) shows the transmission spectra of SnO/SnO_2 p-n junction diodes. The transmission percentage of diode1 is observed as about 70%. The transmission percentage of the diode is improved to about 88% by lowering the thickness of the SnO layer of the diode.

Fig. 2(a and b) show the cross sectional FESEM images of diode 1 and diode 2 respectively, clearly showing the interface between various layers. The Fig. 2(c and d) show top-view FESEM images of SnO_2 and SnO thin films deposited on glass substrate indicating uniform surface morphology with small granular shaped particles distributed throughout the surface.

The n-SnO_2 film showed a mobility of $5.2 \pm 0.0272\ cm^2/V.s$ and carrier concentration of $2.9 \pm 0.399 \times 10^{19}\ cm^{-3}$ and the corresponding values of p-SnO film were $7.8 \pm 0.065\ cm^2/V.s$ and $6.8 \pm 0.157 \times 10^{18}\ cm^{-3}$ respectively. The schematic diagram of p-n junction fabricated with structure Glass/ITO/n-SnO_2/p-SnO/Ag is shown in Fig. 3(a). There is a chance of Schottky behaviour because of the semiconductor/metal contact [6]. In order to check the ohmicity of the contact used, I-V characteristics of SnO/Ag contact is taken as shown in Fig. 3(b) and we obtained ohmic behavior while using silver as contact. The I-V characteristics of the two diodes are shown in the Fig. 3(c and d). The forward threshold voltage or turn on voltage (V_{on}) is 0.54 V and 0.57 V for diode 1 and 2 respectively.

Ideality factor is conventionally determined by plotting ln(I) Vs V as shown in (Fig. 4a and b) [7,8]. The ideality factors are found to be 2.90 and 3.58 respectively. But this simple method fails when a parasitic series resistance (R_s) is present. In order to circumvent the problem introduced by R_s several alternative methods are proposed over the last few years. In the present work, we used the method reported by Garcia Sanchez et al. [9,10], based on integration of the experimental data instead of differentiation. For the better estimation of ideality factor, reverse saturation current along with parasitic series resistance we use this method.

In the present method, an auxiliary function $G(I_0V_0)$ of the measured current and voltage is defined as [9,10],

$$G(I_0V_0) = \frac{I_0V_0 - 2\int_0^{V0} IdV}{I_0} \approx nV_t\left[\ln\left(\frac{I_0}{I_s}\right) - 2\right] \qquad (2)$$

$G(I_0V_0)$ is obtained by numerical calculation from experimental data, and when plotted against $\ln(I_0)$ we get a straight line. The slope and intercept of the graph allows direct calculation of n and I_s respectively. Fig. 4(c and d) shows variation of auxiliary function $G(I_0V_0)$ as a function of $\ln(I_0)$ for the p-n junction diodes 1 and 2. The ideality factor for the diode1 and 2 are calculated as 2.75 and 3.56 respectively. Thus, both this method and conventional method gives comparable ideality factors. However, the

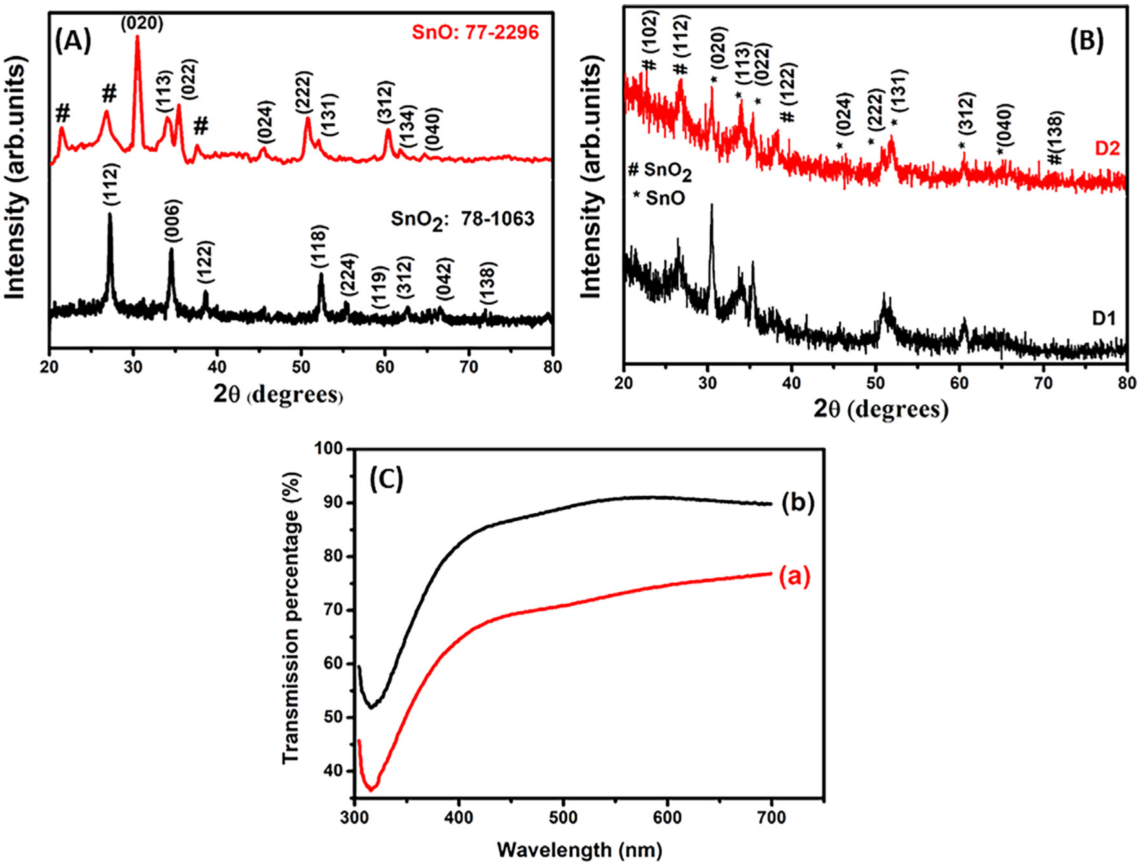

Fig. 1. XRD spectra of (A) Individual layers of SnO_2 and SnO (B) Glass/ITO/SnO/SnO_2 diode1 and 2 [D1 and D2]. Here # denotes SnO2 peaks and * denotes SnO peaks and (C) Transmission spectra of (a) Glass/ITO/SnO/SnO_2 diode1 and (b) Glass/ITO/SnO/SnO_2 diode 2.

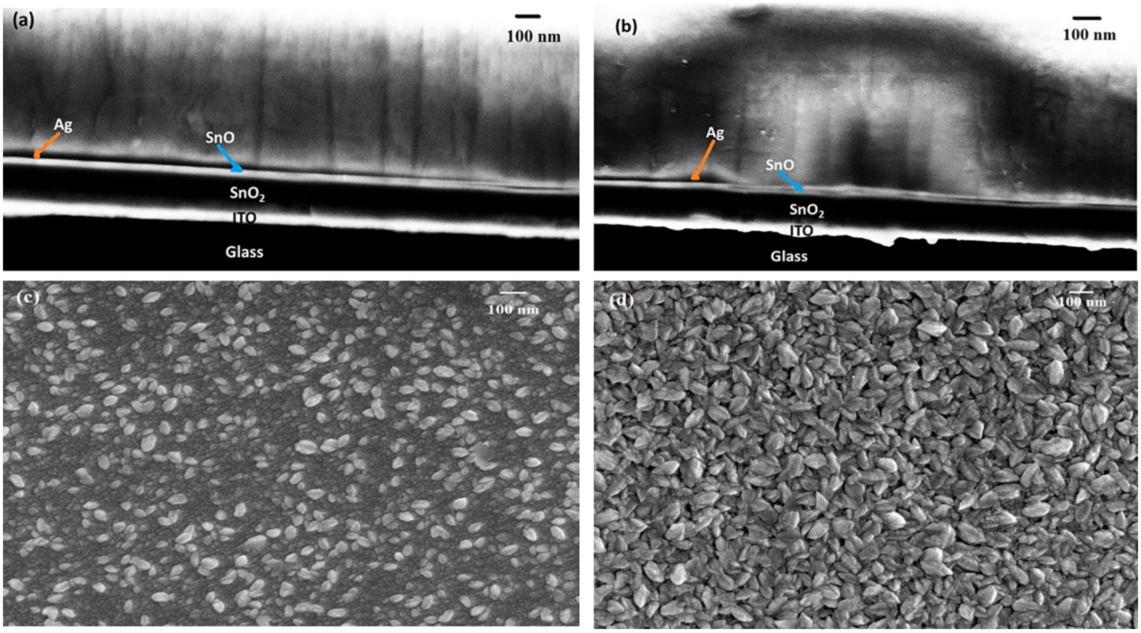

Fig. 2. Cross sectional FESEM images of (a) diode1 and (b) diode2. (c) FESEM images of SnO_2 and (d) SnO thin films on glass substrate.

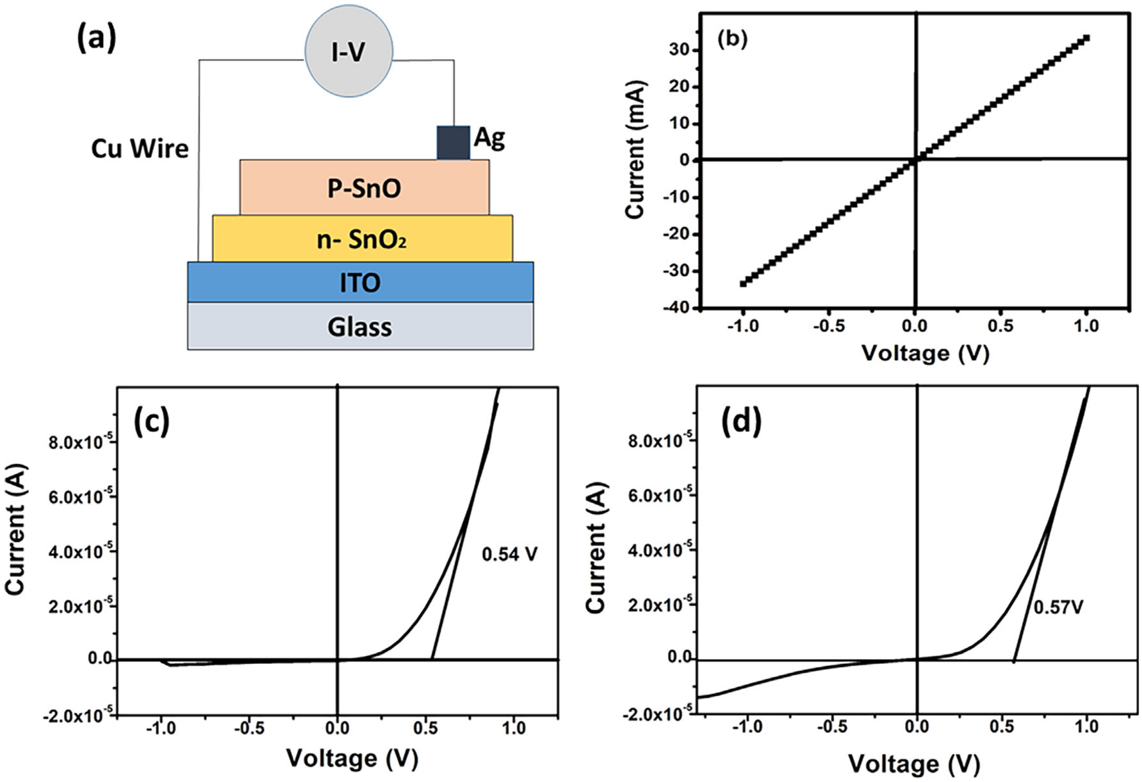

Fig. 3. (a) The schematic diagram of p-SnO/n-SnO_2 p-n junction diode (b) I-V characteristics of SnO/Ag contact (c) I-V characteristics of p-n junction diode for diode1 (d) I-V characteristics of diode2.

use of G function enables us to get an additional estimate on series resistance. The departure from the ideal behavior ($n = 1$) is because of [11] (1) the generation and recombination of carriers in the depletion layer, (2) the tunneling of carriers between states in the band gap, (3) the high-injection situation that may occur even at comparatively small forward bias, (4) inhomogeneity in barrier height, (5) Influence of parasitic series resistance and (6) existence of interfacial layer at Ag and the tin oxide interface. The reverse saturation current (I_s) for the diodes calculated by theoretical model are 2.44×10^{-7} A and 1.61×10^{-7} A whereas that obtained from conventional method are 1.37×10^{-7} A and 1.64×10^{-7} A respectively. The Forward to reverse current ratio (I_f/I_r) for diode 1 and diode 2 are 1.9×10^5 and 10.2 respectively at 1 V bias.

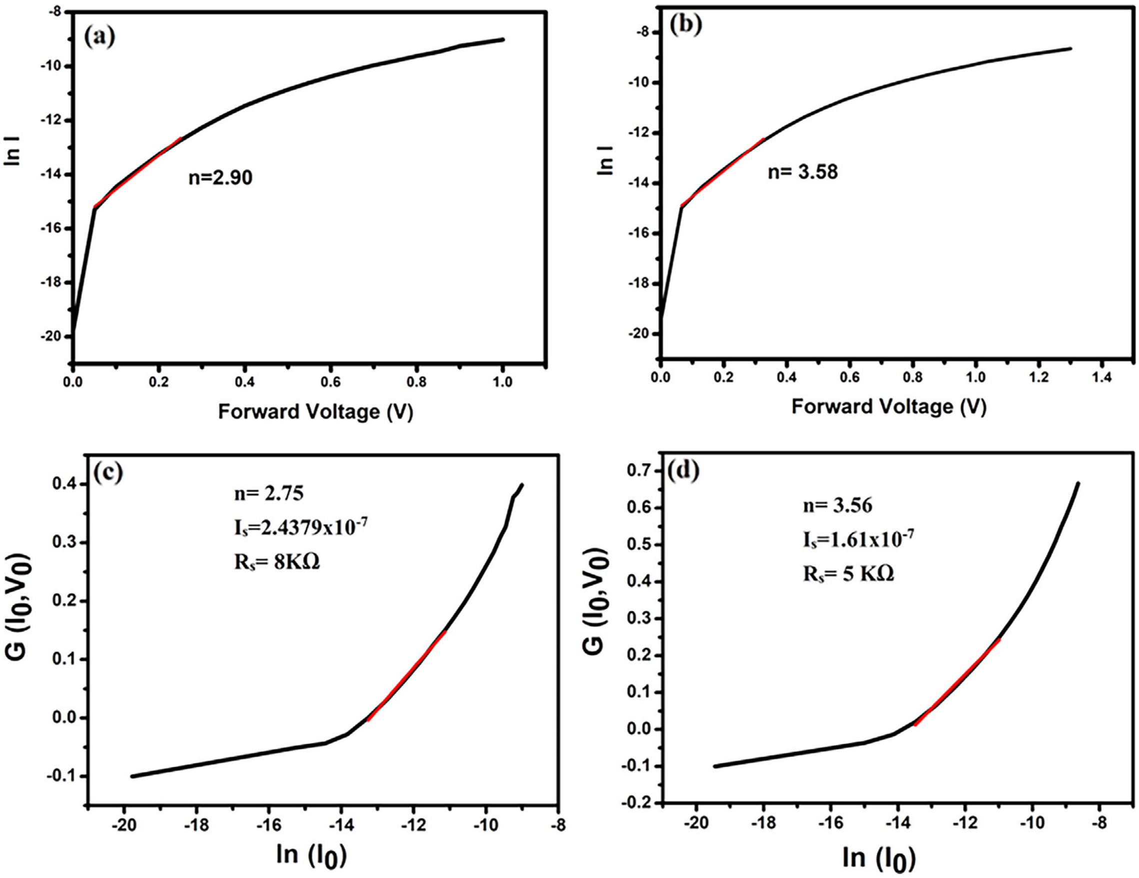

Fig. 4. Variation lnI Vs V graph to determine ideality factor for (a) diode1 (b) diode2 and variation of auxiliary function G(I_0V_0) as a function of ln(I_0) for (c) diode1 (d) diode 2.

The value of parasitic series resistance can be determined by taking the difference between the junction voltage and measured terminal voltage, and dividing it by the measured current. For the terminal voltage 0.6 V, calculated intrinsic voltage across diodes 1 and 2 are found out as 0.346 V and 0.46 V respectively. The values of parasitic series resistance obtained for the diodes 1 and 2 are 8 KΩ and 5 KΩ respectively. This large value of parasitic series resistance might be due to contact resistance and also from the interface problem between the layers during deposition time since we are using chemical spray pyrolysis method.

4. Conclusions

The SnO/SnO_2 p-n junction diodes were fabricated by chemical spray pyrolysis method. The ideality factor, reverse saturation current and parasitic series resistance of the diodes were evaluated. An ideality factor of 2.75 and knee voltage of 0.54 V were obtained for the diode with higher thickness for SnO layer. It also showed rectifying behaviour with high forward to reverse current ratio.

Conflicts of interest

None.

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