Structural and Electrical Characterization of the CdTe/SnO₂ Heterojunction for Solar Cell Application

Nasser Saad Al-Din

Department of Physics, Faculty of Science, University of Al-Baath P.O. Box 77, Homs, Syria

Received: June 04, 2014 / Accepted: July 04, 2014 / Published: August 25, 2014.

Abstract: Thin film heterojunction of the type CdTe/SnO₂ was prepared by spray pyrolysis and electron beam evaporation technique, respectively. The structural and electrical properties of the CdTe/SnO₂ heterojunction are investigated by X-ray diffraction (XRD), Hall and current-voltage (I-V) measurements. The XRD spectrum of SnO₂ film is indicated that it has a rutile tetragonal structure with a preferred orientation along (110) plane. XRD pattern of CdTe thin film is shown that it has a cubic structure with a preferred orientation along (111) plane. Hall measurements demonstrate the firm p-type conductivity of the CdTe film and n-type conductivity of the SnO₂ film. The Hall mobility and carrier density were determined from the combined measurements of resistivity and Hall coefficient at room temperature. The current-voltage curve of the heterojunction demonstrates obvious rectifying diode behavior in the dark and under illumination conditions. The ideality factor of the heterojunction was determined in case of forward bias at low voltages and it was found to be 7.08. The turn-on voltage appears at about 0.6 V under forward-biased voltage, and the reverse breakdown voltage is about 1 V. It was found that the forward current of the heterojunction was 160×10^{-6} A with +1 V applied bias, while the reverse leakage current was 37×10^{-6} A when -1 V was applied.

Key words: Thin film, heterojunction, ideality factor.

1. Introduction

An important application of thin film technology from the point of view of global energy crunch is solar cell, which converts the energy of the solar radiation into useful electrical energy [1]. Economical and stable transparent conductive SnO₂ films are of considerable interest, due to their application in solar cells, optoelectronic devices, thin film resistors, antireflection coatings, photochemical devices and electrically conductive glass [2]. SnO₂ has a tetragonal structure, with a wide energy gap of $E_g = 3.7$ eV, and behaves as an n-type semiconductor [3].

Cadmium telluride (CdTe) is a compound semiconductor comprising of group II-VI elements having a cubic Zincblende (Sphalerite) structure with a lattice constant of 6.481 Å [4]. Cadmium telluride is

one of the most promising semiconductor thin film materials for producing large area solar cells at low cost [5]. Since CdTe has an ideal band gap energy of 1.45 eV and a high absorption coefficient 6×10^4 cm⁻¹ at 0.6 μm, a very thin layer of CdTe is sufficient to absorb most of the incoming sunlight [6]. CdTe homojunctions are difficult to produce as self compensation limits extrinsic p-type doping. Heterojunction systems based upon thin polycrystalline films have thus been developed [7]. Due to the interest that have received both SnO₂ and CdTe semiconductors, I decided to study the properties of CdTe/SnO₂ Heterojunction.

The increasing need for SnO₂ films called for the employment of various deposition techniques such as magnetron sputtering, rf sputtering, chemical vapour deposition, metalorganic chemical vapour deposition, spray pyrolysis, sol-gel dip coating, evaporation, photo-chemical vapour deposition, pulsed laser

Corresponding author: Nasser Saad Al-Din, doctor, professor, research fields: solar cells and heterojunction. E-mail: nsaadaldin@yahoo.com.

deposition, and painting [1]. In this study, tin oxide thin films were prepared by the spray pyrolysis technique. The spray pyrolysis technique is particularly attractive because of its simplicity. It is fast, inexpensive, vacuumless and suitable for mass production [8, 9].

Whereas various techniques such as screen printing, close-spaced sublimation, electro deposition and vacuum evaporation method have been investigated as suitable techniques for the fabrication of CdTe thin films [10]. Thermal evaporation technique was used to obtain CdTe thin film in my work.

In this paper, CdTe/SnO₂ heterojunction was fabricated. The structural and electrical properties of the CdTe and SnO₂ thin films were presented and discussed. I-V measurement of heterojunction was carried out.

2. Experiments

The glass substrate was cleaned with ethanol and acetone in ultrasonic cleaner. Tin oxide thin films (SnO₂) were deposited on glass substrates at 450 °C by spray pyrolysis technique in air atmosphere. The starting solution for SnO₂ thin films was 0.2 M tin chloride dehydrate SnCl₂·2H₂O prepared by dissolving the equivalent mass of tin chloride in a mixture of deionised water and ethanol. For more solubility, we added some drops of HCl to the base solution [11]. The addition of HCl rendered the solution transparent, mostly, due to the breakdown of the intermediate polymer molecules. The spray solution prepared was 50 mL and the predetermined amount of solution was sprayed so as to achieve approximate uniformity in the film thickness. The SnO₂ formulation can be represented as:

The thickness *d* of the film was around 500 nm.

This film shows intrinsic n-type conductivity.

CdTe thin films was deposited on top of the n-type SnO₂ film by thermal evaporation technique at vacuum about 10⁻⁶ mbar. CdTe powder of 99.999% was used as the source material. The thickness (*d*) of the film was around 300 nm. This film shows intrinsic p-type conductivity.

For the electrical measurements of CdTe/SnO₂ heterojunction, the metal electrodes were formed on both the CdTe layer and the SnO₂ layer in sketch depicted in Fig. 1. The prepared samples was characterized by using X-ray diffraction (XRD), Hall effect measurements and current-voltage (I-V) measurements.

3. Results and Discussion

Fig. 2a shows the XRD spectrum of the SnO₂ film grown on glass substrate. All the diffraction peaks are indexed and are compared with the standard JCPDS data. The peaks in the spectrum indicate that the SnO₂ film has a rutile tetragonal structure with a preferred orientation along (110) plane. The XRD spectra of obtained tin oxide films shows seven peaks at 2θ equal to 26.553°, 33.797°, 37.8°, 51.716°, 54.623°, 61.771° and 65.751° which correspond to (110), (101), (200), (211), (220), (310) and (301) planes, respectively.

XRD pattern of CdTe thin film is shown in Fig. 2b. XRD analysis of the thin film indicated the cubic structure with peaks at 2θ = 23.598°, 39.182°, 46.259° and 56.696° with the orientations (111), (220), (311) and (400), respectively. It was observed that the CdTe film has a preferred orientation along (111) plane. However, the intensities of the (220), (311) and (400) peaks were extremely low in comparison with the (111) one.

To obtain more quantitative information, the XRD

Table 1 The values of FWHM, *D* and δ of SnO₂ and CdTe thin films for (110) and (111) plans, respectively.

Film	(<i>hkl</i>)	FWHM (degree)	<i>D</i> (nm)	$\delta \times 10^{-4} (\text{nm})^{-2}$
SnO ₂	(110)	0.16	57	3.12
CdTe	(111)	0.2	45	4.93

Fig. 1 Sketch of the device structure based on the CdTe/SnO₂ heterojunction.

Fig. 2 XRD spectra of (a) SnO₂ and (b) CdTe thin film.

pattern was analyzed with Gaussian function where full width and half maxima [FWHM] was determined. The grain size of SnO₂ and CdTe thin films was calculated by using the Scherrer formula for (110) and (111) plans, respectively in the XRD patterns [12, 13]:

$$D = \frac{0.9\lambda}{\beta \cos \theta} \quad (1)$$

where, D is the grain size; λ is the X-ray wavelength (0.154056 nm); θ is the Bragg angle, and β is the observed angular width at half maximum intensity (FWHM) of the diffraction peaks. The results for these films are shown in Table 1.

The dislocation density δ which represents the amount of defects in the films was determined using the formula $\delta = 1/D^2$ [14]. These values are given in Table 1. The larger D and smaller FWHM values indicate the better crystallization of the film.

Table 2 The values of d , R_s , ρ , μ and n of SnO₂ and CdTe thin films.

Film	d (nm)	R_s (Ω/sq) $\times 10^4$	ρ ($\Omega\cdot\text{cm}$)	μ ($\text{m}^2/\text{V}\cdot\text{sec}$)	$n \times 10^{20}$ (m^{-3})
SnO ₂	500	0.0124	0.0062	0.2739	3680
CdTe	300	53.7	16.11	0.0693	5.6

The sheet resistance R_s of SnO₂ and CdTe thin films was measured by using the 2-probe method. The result is reported in Table 2. The electrical resistivity ρ can be calculated using the relation [15]:

$$\rho = R_s \cdot d \quad (2)$$

where, d is the thickness of the film. The results are shown in Table 2.

The Hall measurements were carried out. The negative sign of the Hall coefficient for SnO₂ confirmed the carriers to be n-type, whereas the positive sign of the Hall coefficient, in the Hall effect experiment, confirmed the p-type conductivity of the CdTe thin film. The Hall mobility and carrier density were determined from the combined measurements of resistivity and Hall coefficient at room temperature. The values of μ and n are shown in Table 2.

The I-V characteristics of the CdTe/SnO₂ heterojunction were measured at room temperature in the dark and under illumination. The results are shown in Fig. 3. As this figure indicates, the heterojunction exhibits a rectifying characteristic both in the dark and under illumination. This rectification behavior confirms the p-type conductivity of CdTe film.

Fig. 3 Room temperature I-V characteristics of CdTe/SnO₂ heterojunction measured in the dark and under illumination.

In Fig. 3, one can see the turn-on voltage appears at about 0.6 V under forward-biased voltage while the reverse breakdown voltage is about 1-V. A low leakage current can also be observed under reverse-biased voltage. It could be found that the current under reverse bias conditions is affected by illumination. Although the dark reverse current of the heterojunction is very small, an illumination generated a rather large photocurrent.

The I-V characteristics of the heterojunction can be analyzed by the following relation [16] :

$$I = I_s \left[\exp\left(\frac{qV}{nkT}\right) - 1 \right] \quad (3)$$

where, q is the electronic charge; V is the applied voltage; n is the ideality factor; k is the Boltzmann constant; T is the temperature and I_s is the reverse saturation current. In case of the forward bias $V > 3 \text{ kT}/q$ then the equation may be approximated to as [17]:

$$I \approx I_s \exp\left(\frac{qV}{nkT}\right) \quad (4)$$

The ideality factor of the heterojunction was determined from the slope of the linear region in low forward bias condition as illustrated in Fig. 3 to be 7.08. This large n value can be explained in terms of the interface states and series resistance. The obtained n value suggests that the charge transport mechanism is controlled by recombination in the space charge region [16].

It can be found in Fig. 3 that with +1 V applied bias, the forward current of the heterojunction was $160 \times 10^{-6} \text{ A}$ while the reverse leakage current was $37 \times 10^{-6} \text{ A}$ when -1 V was applied.

4. Conclusions

In conclusion, we have investigated some physical properties of CdTe/SnO₂ heterojunction. The SnO₂ film has a rutile tetragonal structure with a preferred orientation along (110) plane, whereas The CdTe film has a cubic structure with a preferred orientation along (111) plane. Hall measurements demonstrate the firm p-type conductivity of the CdTe film and n-type

conductivity of the SnO₂ film. The Hall mobility and carrier density were determined from the combined measurements of resistivity and Hall coefficient at room temperature. The junctions exhibit diode-like behavior. The turn-on voltage appears at about 0.6 V under forward-biased voltage, and the reverse breakdown voltage is about 1 V. The ideality factor of the detector was determined in case of forward bias at low voltages and it was found to be 7.08. The obtained n value suggests that the charge transport mechanism is controlled by recombination in the space charge region. It was found that with +1 V applied bias, the forward current of the device was $160 \times 10^{-6} \text{ A}$ while the reverse leakage current was $37 \times 10^{-6} \text{ A}$ when -1 V was applied.

References

- [1] E. Elangovan, K. Ramamurthi, Optoelectronic properties of spray deposited SnO₂: F thin films for window materials in solar cells, *Journal of Optoelectronics and Advanced Materials* 5 (2003) 45-54.
- [2] E. Elangovan, K. Ramamurthi, Effect of substrate temperature on electrical and optical properties of spray deposited SnO₂: Sb thin films, *Journal of Optoelectronics and Advanced Materials* 5 (2003) 415-420.
- [3] K.A. Mishjil, S.S. Chiad, H.L. Mansour, N.F. Habubi, Influence of copper doping on the structural and optical properties of sprayed SnO₂ thin film, *Journal of Electron Devices* 14 (2012) 1170-1177.
- [4] R.K. Sharma, K. Jain, A.C. Rastogi, Growth of CdS and CdTe thin films for the fabrication of n-CdS/p-CdTe solar cell, *Current Applied Physics* 3 (2003) 199-204.
- [5] O. Vigil-Galan, A. Arias-Carbajal, R. Mendoza-Perez, G. Santana-Rodriguez, J. Sastre-Hernandez, J.C. Alonso, et al., Improving the efficiency of CdS/CdTe solar cells by varying the thiourea/CdCl₂ ratio in the CdS chemical bath, *Semicond. Sci. Technol.* 20 (2005) 819-822.
- [6] M.A.F. Mendoza, R.C. Perez, G.T. Delgado, J.M. Marin, A.C. Orea, O.Z. Angel, Structural, morphological, optical and electrical properties of CdTe films deposited by CSS under an argon-oxygen mixture and vacuum, *Solar Energy Materials & Solar Cells* 95 (2011) 2023-2027.
- [7] K.D. Rogers, D.A. Wood, J.D. Painter, D.W. Lane, M.E. Ozsan, Novel depth profiling in Cds-CdTe thin film, *Thin Solid Films* 361-362 (2000) 234-238.

- [8] G.E. Patil, D.D. Kajale, D.N. Chavan, N.K. Pawar, P.T. Ahire, S.D. Shinde, et al., Synthesis, characterization and gas sensing performance of SnO₂ thin films prepared by spray pyrolysis, *Bull. Mater. Sci.* 34 (2011) 1-9.
- [9] R.L. Mishra, S.K. Mishra, S.G. Prakash, Optical and gas sensing characteristics of tin oxide: Nano-crystalline thin film, *Journal of Ovonic Research* 5 (2009) 77-85.
- [10] S. Lalitha, R. Sathyamoorthy, S. Senthilarasu, A. Subbarayan, K. Natarajan, Characterization of CdTe thin film-dependence of structural and optical properties on temperature and thickness, *Solar Energy Materials & Solar Cells* 82 (2004) 187-199.
- [11] S.M. Rozati, E. Shadmani, Effect of Zn concentration on physical properties of nanostructure tin oxide films prepared by spray pyrolysis technique, *Digest Journal of Nanomaterials and Biostructures* 6 (2011) 365-372.
- [12] N. Memarian, S.M. Rozati, Characterization and gas-sensing performance of spray pyrolysed In₂O₃ thin films: Substrate temperature effect, *Acta Physica Polonica A* 122 (2012) 202-206.
- [13] M.M. Abdullah, M.H. Suhail, S.I. Abbas, Fabrication and testing of SnO₂ thin films as a gas sensor, *Archives of Applied Science Research* 4 (3) (2012) 1279-1288.
- [14] H.S. Patel, J.R. Rathod, K.D. Patel, V.M. Pathak, Structural and surface studies of vacuum evaporated cadmium telluride, *American Journal of Materials Science and Technology* 1 (2012) 11-21.
- [15] N. Jebbari, N.K. Turki, R. Bennaceur, Effect of SnCl₄ concentration on F: SnO₂, in: *Chemical Spray Pyrolysis International Renewable Energy Congress*, 2010, pp. 276-279.
- [16] S. Darwish, DC electric and photoelectric measurements of CdTe thin films in Schottky-barrier cells, *Physica B* 349 (2004) 296-303.
- [17] G. Wary, T. Kachary, A. Rahman, Thermal and doping effect on photovoltaic behaviour of H-treated (n) ZnO/(p) CdTe heterojunctions, *Indian Journal of Pure & Applied Physics* 44 (2006) 754-758.