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The Effects of Annealing on SnSe Thin Films for Solar Cells Applications

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Abstract:
The structure, optical, and electrical properties of SnSe and its application as photovoltaic device has been reported widely. The reasons for interest in SnSe due to the magnificent optoelectronic properties with other encouraging properties. The most applications that in this area are PV devices and batteries. In this study tin selenide structure, optical properties and surface morphology were investigated and studies. Thin-film of SnSe were deposit on p-Si substrates to establish a junction as solar cells. Different annealing temperatures (as prepared, 125,200, 275) °C effects on SnSe thin films were investigated. The structure properties of SnSe was studied through X-ray diffraction, and the results appears the increasing of the peaks intensity when annealing temperature increased and the grain size will be increased through the rang (19.78- 59.64) nm. The optimum annealing temperatures gained from this study is (200) °C. the enhancements of the solar cell efficiency were slightly upgraded to reach 0.35% with respect to the annealing temperature.

***Keywords:** n-SnSe /p-Si, Structure properties, optical properties, I-V characteristics, surface morphology.*

Introduction

Semiconductors at binary IV-VI superimposed have distinct absorbing electrical and optical properties due to their pleasing characteristics [1]. The mono selenide (SnSe) have the least investigations compared to other chalcogenides. SnSe has orthorhombic crystal structure with forbidding gap near to 1eV [2]. The interest in TE thin membrane study is also increasing, especially when the mound-dimensional materials (such as 2D materials) are being extensively intent cosmopolitan [3].

The structural arrangement leads to a pronounced anisotropy for the physical properties of it, which will be a good material for solar cells industries, for their chemical stability and not negativity with respect to other semiconductors, like Si, GaAs, InP, and CdSe [4-6]. The orthorhombic structure of SnSe gives high Grüneisen parameters, by a harmonic and anisotropic bonding [7-8].

There is an investigation done by (Cullity, 1987) about annealing effect on the SnSe thin films prepared by thermal evaporation method using the source material synthesized from chemical route [9]

In order to study the crystal structure of alloy and thin films using tests X-ray diffraction (XRD) (λ = 1.5418) Å).

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Scherrer's formula used to calculate the average crystallite size (C_S) of thin film:

$$C_S = \frac{0.94\lambda}{B\cos\theta_B} \quad (1)$$

Where the full-width at half-maximum of the main peak is β and the reflection angle is θ [9].

Solar cells are currently the most promising candidate for providing the next generation of secure, sustainable and affordable energy source. Besides the obvious advantages solar cells bring on the table, such as energy independence and pollutant reduction, they also come with very interesting physics as a package deal. In the basic physics of solar cells one can find basic quantum mechanical concepts such as black body theory and basic semi-conductor physics along with material design such as thin film solar cells.

In my presentation I will focus mainly on the basic principles behind the function of solar cells starting with the photovoltaic effect, the effect that is the basis for the generation of charge carriers. Those charge carriers, which are basically electron-hole pairs, are separated by a built-in asymmetry in the solar cell and electrons are fed into a circuit generating current [10]

The electronic behavior of a solar cell is understood by modeling it with an equivalent electronic circuit, which is useful to extract the basic relations for voltage and current generated from a solar cell under illumination. The power losses that exist in real solar cells are modeled as resistances in series and parallel to the solar cell, I will talk about the electron-hole recombination in solar cells, which limits the efficiency of the cell, and the theoretical thermodynamic limit of a single junction solar cell as set by Shockley and Queisser [11].

The efficiency limit is set by the so called detailed balance principle which simply has to do with the fact that the solar cell exchanges thermal radiation with its surroundings, reducing the efficiency. Along with that and other considerations having to do with the band gap of the material

The measurements of I-V determined by using the equation for standardized illumination ($100 mW/cm^2$) and dark [9].

$$I = I_S\left(\exp\left(\frac{qV}{\beta K_B T}\right) - 1\right) - I_L \quad (2)$$

The photovoltaic efficiency η and Fill Factor FF is given by [10]:

$$\eta = \frac{P_m}{P_{in}} x100\% = \frac{I_m V_m}{P_{in}} x100\% \quad (3)$$

$$F.F = \frac{J_m V_m}{J_{sc} V_{oc}} \quad (4)$$

Experimental

The preparation of alloy tin selenide thin films were done by thermal evaporation technique. The purity of SnSe pellet (Alfa 99.999%) was used as a target for manufacturing the thin films. The environment of the preparation process was done under (10^{-5}torr) vacuum pressure. The thicknesses of the prepared films were about 350 nm, which they monitored using in -situ quartz crystal thickness monitor. The Shimadzu (XRD-6000) X-ray Diffractometer were utilized to investigate the structural properties of SnSe films and investigate the optical properties by (Jasco-570 UV/VIS/ NIR Spectrophotometer) at visible range. Xenon lamp was used to illuminate the devices. [10-12]

Results and Discussion

a- X-Ray Diffraction

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The XRD outline of SnSe films which deposited on glass substrate with different annealing temperature (as prepared, 125, 200, and 275) °C illustrated in figure 1. The range of the horizontal axis (angle 2θ) between 20º- 50º, and the vertical axis illustrated the intensity. The samples show orthorhombic phase of SnSe accordance to [(011), (111), (411)] planes. The grain size value of the lattice parameters of all SnSe samples was assessment by Scherrer's equation and offered in Table 1. The increasing of annealing temperature (Ta) affects the crystallite size which appears as direct relation. Thus, the increasing of the annealing temperatures reveals an enhancement in crystallization, and this result agrees with [13-15].

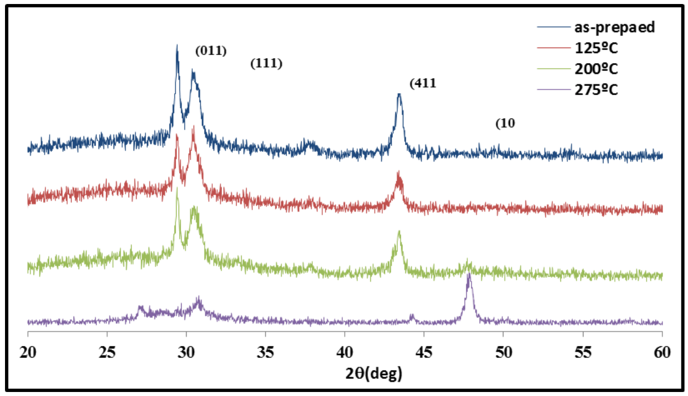

Figure 1. X-Ray curves at different annealing temperature for SnSe.

Table 1. SnSe structure parameters.

SnSe	2 Theta (deg)	2 Theta (deg)	hkl	d-obesved (Å)	d-standard (Å)	D (nm)	δ x10^{14} (lines.m^{-2})
As-prepared	**29.47**	29.42	**011**	3.028	3.033	19.78	25.53
	30.44	30.46	**111**	2.933	2.932	14.35	48.56
	43.43	43.34	**411**	2.081	2.086	16.15	38.312
125 Cº	**29.46**	29.42	**011**	3.029	3.033	12.14	67.83
	30.58	30.46	**111**	2.927	2.932	8.83	128.19
	43.38	43.34	**411**	2.084	2.086	10.95	83.35
200 Cº	**29.46**	29.42	**011**	3.028	3.033	8.47	18.42
	30.58	30.46	**111**	2.920	2.932	23.23	139.21
	43.42	43.34	**411**	2.082	2.086	59.64	18.52
275Cº	**27.18**	29.42	**011**	3.277	3.033	24.61	2.81
	30.80	30.46	**111**	2.900	2.932	11.36	16.51
	47.83	43.34	**411**	1.899	2.086	14.54	77.35

Surface morphology of SnSe thin films in different temperatures (as prepared, 125, 200, 275) °C are illustrated in Fig.2. The figure also shows smooth and uniform distribution for the surface and have a spherical grain shape. The average grain size (G.S), root mean square (R.M.S) values, and roughness have been shown in table (2). The effect of annealing appears by increasing the roughness and the grain size of the SnSe films, because it effects on crystallization through annealing process. The SnSe film has an average grain size of ~87nm, then grain size will be increased with different annealing temperatures (as prepared, 125, 200, 275) °C.

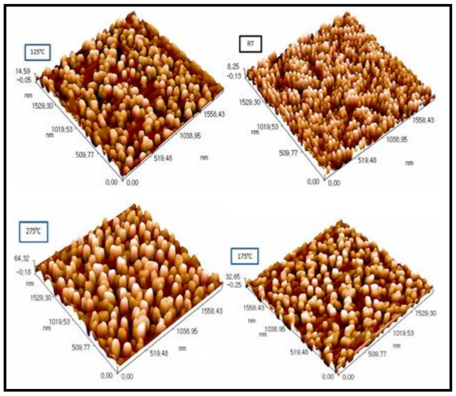

Figure 2. Morphology variations by AFM images for SnSe film.

Table 2. Morphology parameters for SnSe film.

Sample	Roughness (nm)	Root mean square	verage G.S(nm)
As- prepared	2.4	2.42	62.07
152°C	3.65	4.2	71.50
200°C	8.22	9.5	83.11
275°C	16.1	18.6	87.75

b- Optical properties

The prepared thin films samples were investigated through transmittance spectra to evaluate the optical properties for them. The transmittance spectra were done by the range (300-1100) nm as shown in fig.3. the curves illustrated a very high transmittance in the UV-VIS region of the electromagnetic spectrum. The effect of annealing will increase the transmittance spectra especially in the visible region which become a good window for penetration of visible spectrum.

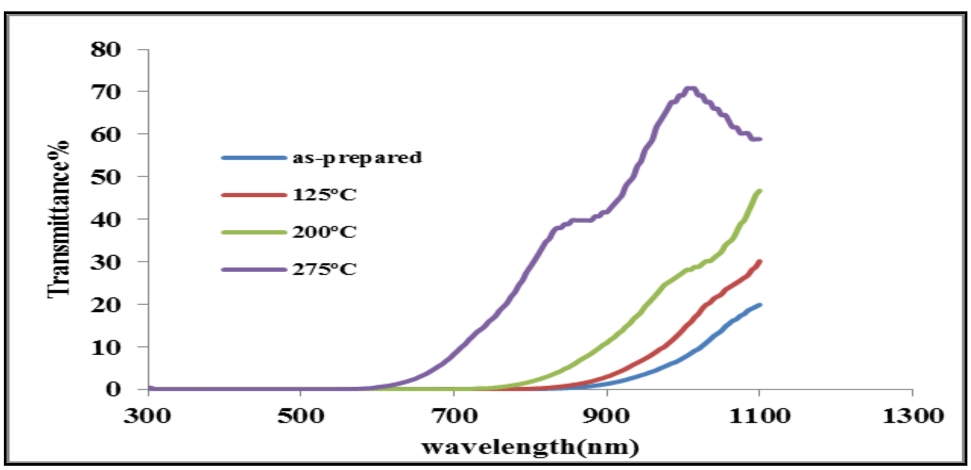

Figure 3. Transmittance of SnSe thin film at (as -prepared, 125,200,275) **°C**

The absorption coefficient which is a function of the photon energy (hυ) is calculated from the optical transmittance spectra using the following equation [16, 17]:

$\alpha = (1/t) \ln (1/T)$…….(1)

The optical energy gap (Eg) was calculated and found in the range of (1.25–1.95) eV. Thus, the process of annealing become an effective procedure for increasing the optical energy gap. The relations between annealing temperature and the optical energy gap are shown in Fig.4. This result is compatible to the work done by [18, 19]. The transition appears to be direct as shown in figure 4, and the band gap for the film is 1.95 eV.

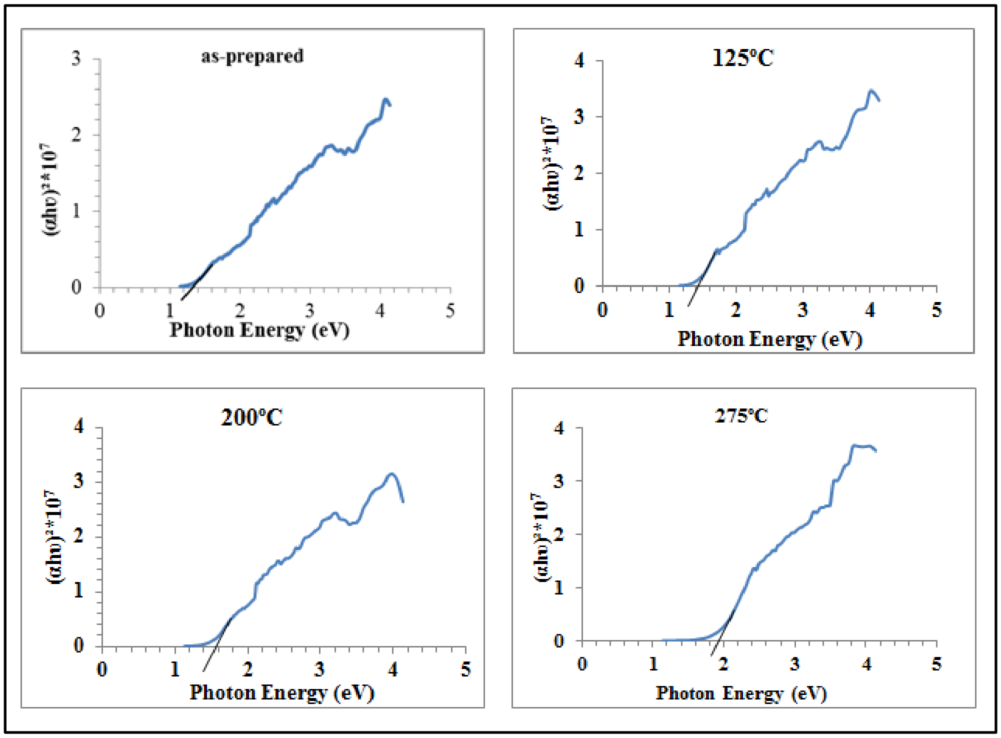

Figure 4.$(\alpha h\nu)^2$ versus photon energy for SnSe films with different annealing temperature (as -prepared, 125,200,275) °C

Table 3. Energy band gap for SnSe films with various annealing temperature.

annealing temperature	as -prepared	125°C	200°C	275°C
Eg	1.25	1.56	1.8	1.95

c- Electric properties

The electrical properties or I-V characteristics under dark or light mode are illustrated in fig.5. It can be noticed that the inverse current value under illumination are higher comparing with dark mode, and that fits with [20]. The I-V characteristics andthe efficiency of the solar cell devices illustrated in table-4. The annealing procedure improved the device efficiency.

Table 4. (I-V) characteristic of SnSe thin film in different annealing temperature (as -prepared, 125,200,275) °C

SnSe thin film	Voc (Volt)	Jsc (mA/cm2)	Vmax (volt)	Jmax (mA/cm2)	FF	η%
as-prepared	0.83	0.25	0.62	0.22	0.65	0.13
125ºC	0.91	0.42	0.77	0.31	0.62	0.23
200ºC	0.93	0.44	0.81	0.39	0.77	0.31
275ºC	0.97	0.45	0.89	0.4	0.81	0.35

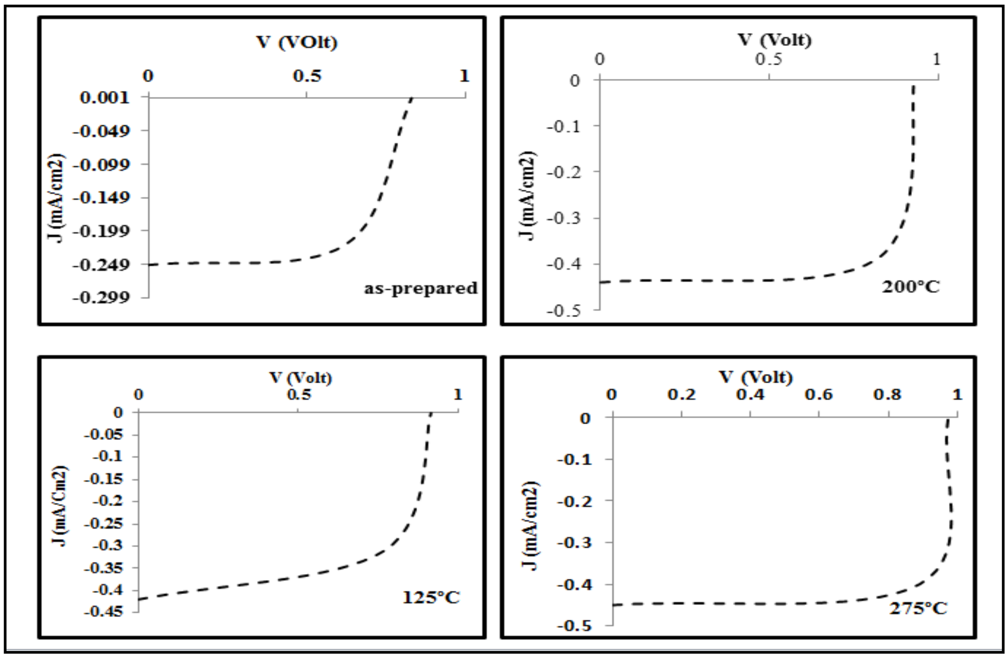

Figure 5. Dark and illuminated (I-V) characteristic of SnSe films with different annealing temperature (as -prepared, 125,200,275) °C

Conclusion

Tin selenide films have been successfully carried out using Thermally evaporated deposition technique. The samples were managed with various annealing temperatures (as-prepared, 125, 200, 275) ºC. The band gap was found to be indirect and about 1.95 eV at various annealing temperatures. The films found to have high absorbance in the UV region and underestimate it as the wavelength increased, they have commonly exalted transmittance. The thin film helpful the potential for use as aesthetic window glaze and in forming p-n junction application solar cell. The solar cells efficiencies were slightly improved with increasing annealing temperature.

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