Fabrication of AgInSe2 heterojunction solar cell

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Fabrication of AgInSe2 Heterojunction Solar Cell

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Abstract. Silver, Indium Selenium thin film with a thickness (5001±30) nm, deposited by thermal evaporation methods at RT and annealing3temperature (Ta=400, 500 and 600) K on a substrate of glass to study structural and optical properties of thin films and on p-Si wafer to fabricate the AgInSe2/p-Si heterojunction solar cell. XRD analysis shows that the AgInSe2 (AIS) deposited film at RT and annealing3temperature (Ta=400, 500 and 600) K have polycrystalline structure. The average grain size has been estimated from AFM images. The energy gap was estimated from the optical transmittance using a spectrometer type (UV.-Visible 1800 spectra photometer). From I-V characterization , the photovoltaic parameters such as, open-circuit voltage, short-circuit current density, fill factor, ideality factor, and efficiencies, were computed. As well as the built-in potential, carrier concentration and depletion width were determined under RT and (Ta=400, 500 and 600) K from C-V measurement.

Keywords: AgInSe2/p-Si, heterojuncion, thin film, solar cell, annealing3temperature.

INTRODUCTION

In recent years the semiconductors from I–III–VI2 group of direct gap has been studied for solar cell applications due to their material properties as an absorber layer for optical devices, diodes, tandem solar cell and optoelectronics [1]. In 2007 studied the annealing temperature effect on the film properties so they prepared AgInSe2 thin films on the indium-tin-oxide (ITO) by conventional thermal vacuum evaporation. Annealing at temperatures (373-573) K for 30 min in a vacuum. AFM images give the RMS roughness and the average grain size, the optical energy band gap measured at room temperature (RT) of the as-deposited AgInSe2 film was 1.76 eV [2]. In (2008) Kenji Yoshino et al, studied the structures and electrical characterization of AgInSe2 crystals were grown by the hot-press method at temperatures (673 – 973)K under high pressure (25 MPa). XRD measurements indicate the growth of the AgInSe2 crystal begins at 673K. This suggests that donor-type defects, this is supported by Hall effect measurement which indicated n-type conductivity in the sample [3]. the AgInSe2 crystals have been grown by Hamdy T. Shaban and Melaad K. Gergs (2014) using Bridgman technique. The structural, electrical and thermo-electric power properties of the obtained AgInSe2 crystals have been determined. The energy gap was found to be 1.24 eV. Conductivity type was found to be n-type [4]. The one step electrodeposition process was used to prepare Ag-In-Se thin films by Mounir Ait Aouaj et al. (2015), which have non vacuum, low cost and reproductive technique. The effect of growth conditions on chemical composition of Ag-In-Se films was studied. The morphology and crystallinity of these films is improved by annealing, the band gap value of about 1.24 eV. Solar cells an efficiency of about 10.7 %, the obtained results on AgInSe2 semiconductor films make them of interest for photovoltaic devices [5]. AgInSe2 is one of the potential candidates due to its band gap 1.2 eV, which makes it ideal absorber material for solar cell, AgInSe2 crystallizes in the chalcopyrite structure which is closely related to zinc blend structure with the c/a ratio approximately equal to 2 [6]. The aim of this study was focused on the fabrication of AgInSe2 /p-Si heterojunction for solar cells with different annealing3temperature.

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EXPERIMENTAL

In this study, used glass and p -type Si wafer slides as substrates to study the photovoltaic, the electrical, structural, optical properties of AgInSe2/p-Si heterojunction, the glass slides cleaned with chromic acid, ultrasonic cleaner, soap water, distilled water and then with acetone. Si substrates were put in diluted HF solution with 1%, washed in deionized water several times and dried using soft paper. Ag InSe2 with different RT and annealing3temperature(Ta=400, 500 and 600) K deposited on the glass and p-Si substrates slides by thermal evaporation system Edwards type with pressure deposition 5×10-5 mbar and thickness was (500±30) nm with molybdenum boat. X-ray diffract meter XRD-6000 SHIMADZU-Japan was used to investigate the structure and crystalline of deposit films with (λ = 1.5418 Å).

The average crystallite size (CS) of AgInSe2 thin films was calculated from the Scherrer's formula [7]:

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

Where (β) is the full-width at half-maximum of the main peak and (θ) is the reflection angle [7].

While, the topography of the surface investigations was carried out using atomic force microscopy (AFM).

The optical Transmission spectrum of the AgInSe2thin films onto glass was obtained using UV/Visible 1800 spectrophotometer in the range of 400-1100nm. The energy gap and the absorption coefficient α were determined by equations [8], [9]:

$$\alpha h\upsilon = D\,(h\upsilon - E_g)^r \ldots\ldots\ldots\ldots\ldots (2)$$

$$\alpha = 2.303\ A/t \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, D is a constant dependent on the properties of the bands, Eg is the optical energy gap (eV) ,r is constant and may take values (2, 3,1/2, 3/2) reliant on the type of the optical transition, A is the absorbance and t, the thickness.

The I-V characteristic curves for AgInSe2 /p-Si heterojunction were measured using (Keithley digital electrometer 616), D.C power supply and (F30-2, Farnell Instrument). The measurements were performed in under standardized illumination (100mW/cm2) can a description of the equation [7].

$$I = I_S\left(\exp\left(\frac{qV}{\beta K_B T}\right) - 1\right) - I_L \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The photovoltaic conversion efficiency and Fill Factor are given by [10]:

$$\eta = \frac{P_m}{P_{in}} x100\ \% = \frac{I_m V_m}{P_{in}} x100\ \% \ldots\ldots\ldots\ldots (5)$$

$$F.F = \frac{J_m V_m}{J_{sc} V_{oc}} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The capacitance–voltage measurements are determined exploitation (LRC meter GWinstek 8105G) at a fixed frequency of (100 KHz) from equations [10].

$$W = \frac{\varepsilon_S}{C_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$\varepsilon_S = \frac{\varepsilon_n \varepsilon_p}{\varepsilon_n + \varepsilon_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$C = \left[\frac{q\,\varepsilon_n\,\varepsilon_p\,N_n\,N_p}{2\left(\varepsilon_n N_n + \varepsilon_p N_p\right)}\right]^{1/2} \left(V_{bi} - V\right)^{-1/2} \ldots\ldots\ldots (9)$$

Where, C_o is the capacitance at zero biasing voltage and ε_s is the dielectric constant of the heterojunction, N_n and N_p are the donor concentrations in n-$AgInSe_2$ and the acceptor concentrations in p-Si respectively. As well V_{bi} is the built- in potential , and V is the applied voltage, ε_n and ε_p are the dielectric constants of n-$AgInSe_2$ and p-Si severally.

RESULTS AND DISCUSSION:

Figure (1) shows the of $AgInSe_2$ thin films at RT and different annealing temperature (Ta=400, 500 and 600) K, one can observe that the thin films have the polycrystalline tetragonal structure as shown in figure (1). The figure indicates that the patterns include sharp peaks referred to (112), (204) and (312) direction. As well, this figure confirms that the preferential orientation is in the (112) direction. The structural parameters of annealed $AgInSe_2$ thin films were illustrated in Table (1). The crystallite size has been estimate of the FWHM value of the (112) peak dependeing on equation (1) and is observed it increased with Ta as shows in Tables (1). These results were matched with [2,3]. By increasing the Ta the intensities of the peaks rise. This is due to the improvement of crystalline of the films and decrease the grain boundary of the structure.

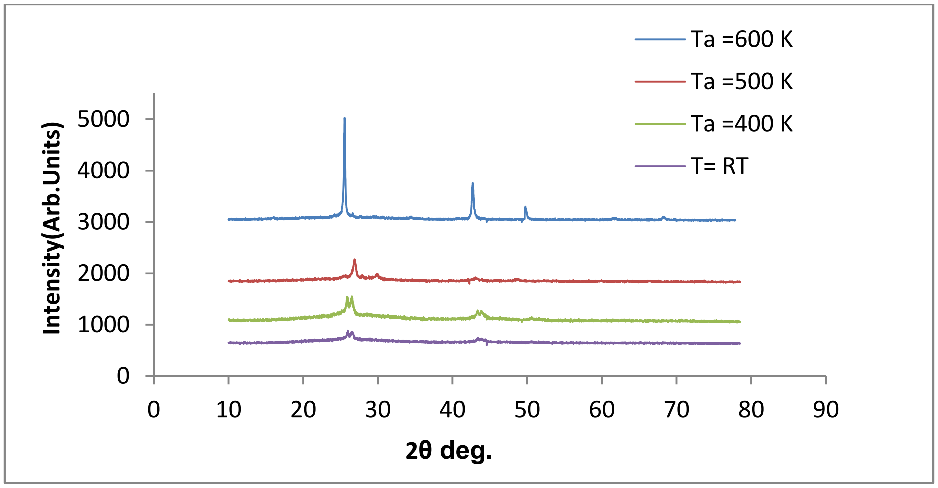

Figure 1. X -ray diffraction pattern of $AgInSe_2$ thin film with a thickness (t=500nm) annealed at different Ta.

Table 1. Experimental XRD data for $AgInSe_2$ thin films at different Ta.

Measurement Temperature		hkl	2Θ	FWHM	**C.S (nm)**
RT		112 204 312	25.54 42.7 49.68	0.5138	28.88
Ta (K)	400	112 204 312	25.66 42.82 49.70	0.4457	33.31
	500	112 204 312	25.7 42.7 49.85	0.3758	39.50
	600	112 204 312	25.75 42.95 49.92	0.3105	47.82

Table 2. The grain size has been calculated by AFM method.

Measurement temperature		Grain sample (nm)
RT		6.6
Ta(K)	400	7.5
	500	8.2
	600	9.3

The result of an AFM method was in agreement with XRD calculated.

The Absorbance8and Reflection spectrum of AgInSe2 thin8film was evaluated as a function8of wavelength at RT and different annealing8temperature in figure (2). This figure shows that absorbance8increase as a function of wavelength with annealing8temperature in the visible region. The behavior of the transmittance spectra8is opposite completely8to that of the 8absorbance spectra and the Reflection spectra show the lowest value in the visible wavelength range when Ta= 600 K. From figure (3) we can observe8that the (α) values, which has been adjusted using equation (3), the α values in general increases8as a function of annealing8temperature high amount reached8above (104) cm-1. It was pointed out that, this attributed to an enlarge in absorbance of the used films. From Table (3) we found8that the α values increases from (5.6 to 9.2) ×104 cm-18with the increase of Ta and the Egopt reduce 8(from 1.75 to 1.45) eV as shown in Table (3) and figure (3). This result8is in agreement8with Ref.[2].

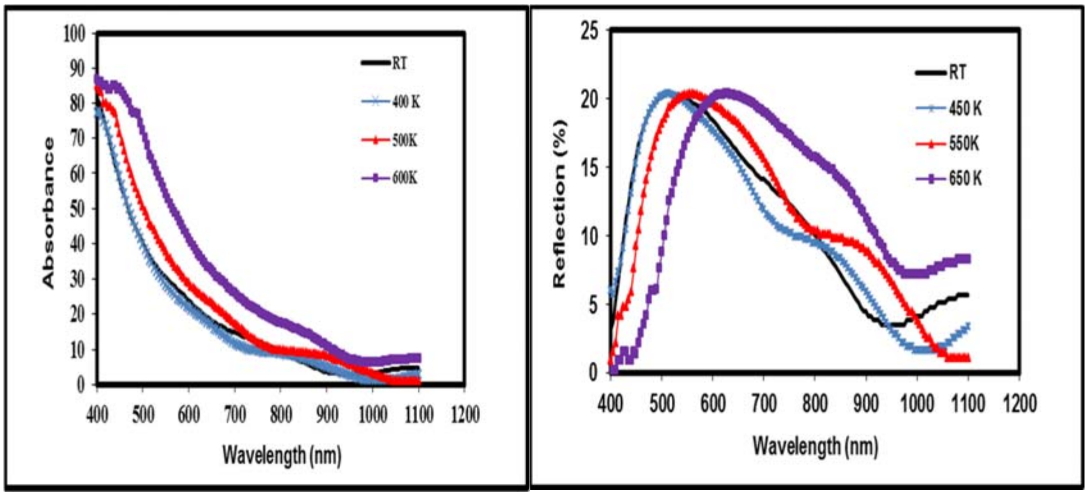

Figure 2. The Absorbance and Reflection spectrum of AgInSe$_2$ thin films at different Ta.

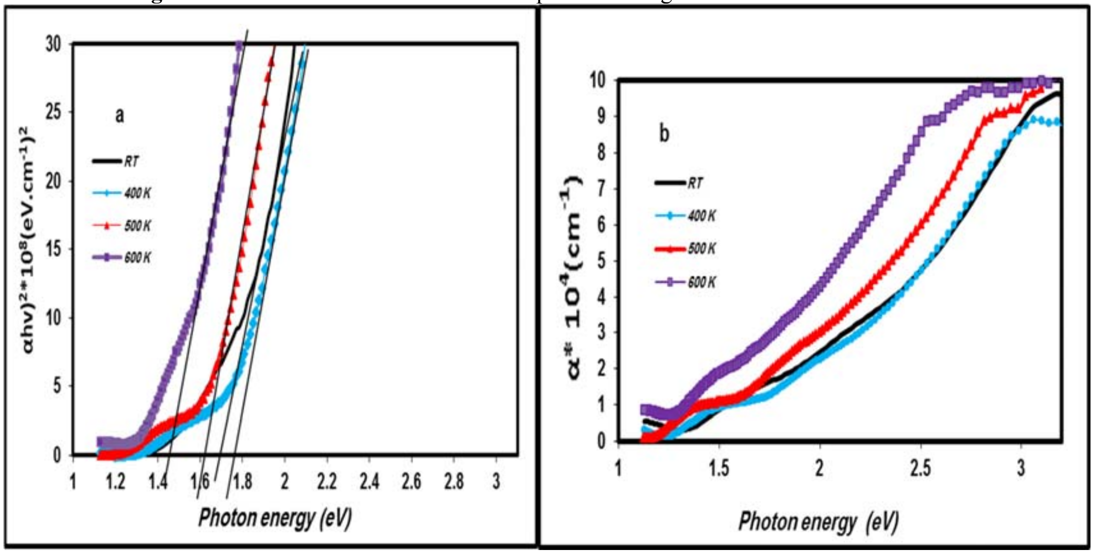

Figure 3.: (a) Variation(αhυ)2 and (b) absorption coefficient verse photon energy of AgInSe2 thin films at different Ta.

Table 3. Optical constant (E_g^{opt} and α) of $AgInSe_2$ thin films at different Ta.

Optical constant at λ=470nm			
Measurement temperature		E_g^{opt} (eV)	$\alpha \times 10^4$ $(cm)^{-1}$
RT		1.75	5.6
Ta (K)	400	1.7	5.7
	500	1.62	7.1
	600	1.45	9.2

Figure 4 presented the (current-voltage) curves of the manufactured AgInSe2/Si heterojunction solar cells under illumination conditions at RT and different annealing temperature. Using equations (4,5 and 6) was the conversion efficiency and Fill Factor calculation were calculated as shown in figure 4, and Table 4. From the obtained results we can notice that there was a clear increase in the value of the open circuit voltage (Voc) and the value of short circuit current density (Jsc). The maximum values for both of them (Vm, Jm) in turn gives the value of solar cell efficiency, which in general, it adds to the increasing of annealing temperature due to the improved in the structure and decrease the grain boundaries and defects with annealing treatment, this result agrees with [14].

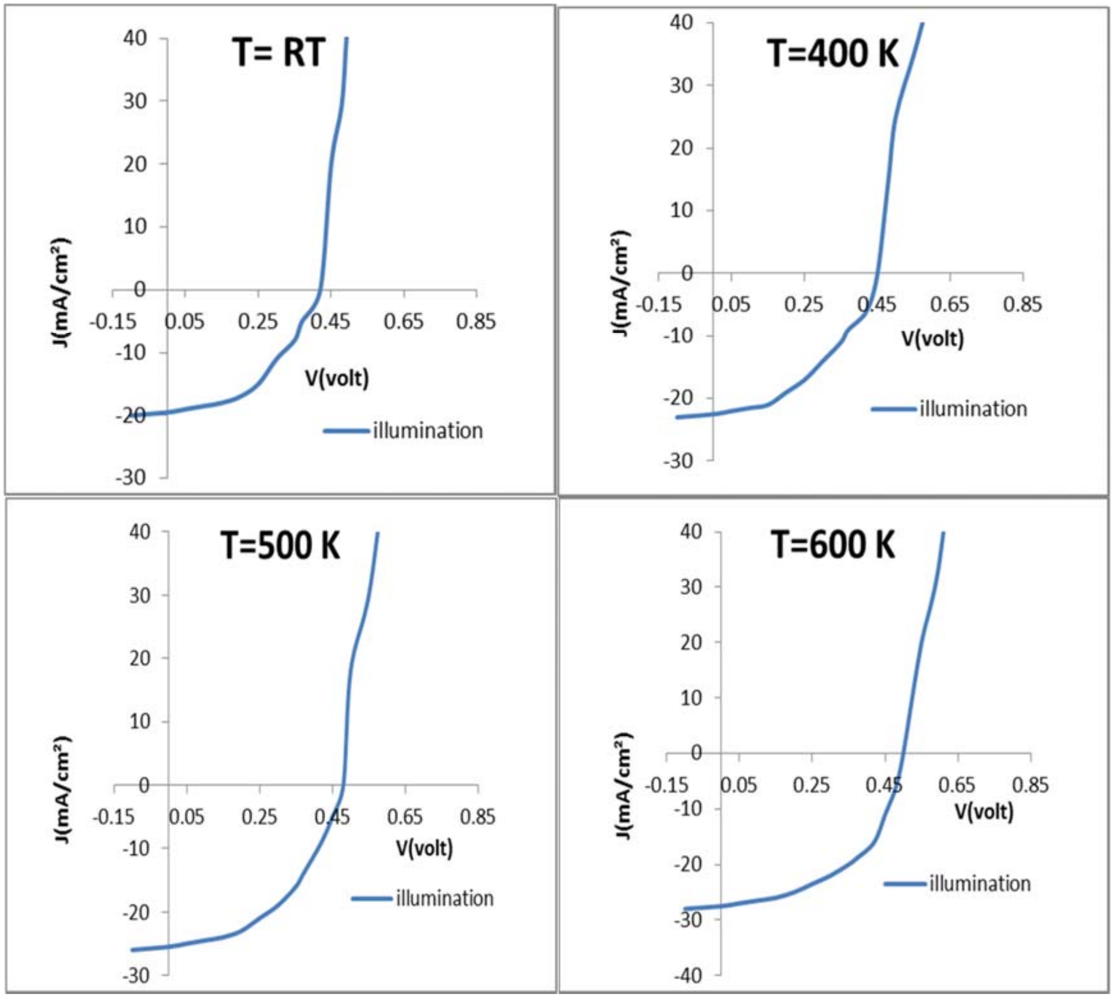

Figure 4. I-V Characteristics curves for the AgInSe2/Si solar cell under illumination thin films at different Ta.

Table 4. The parameter for $AgInSe_2$/Si heterojunction solar cell at different Ta.

Measurement temperature (K)		J_{sc}(m	V(Volt)	J_m(m	V_m(Volt)	η%
RT		20	0.36	12	0.25	3.00
Ta (K)	400	23	0.45	13	0.30	3.90
	500	26	0.48	15	0.35	5.25
	600	28	0.5	16	0.38	6.08

The (C-V) characteristics of the $AgInSe_2$/Si heterojunction solar cell was shown in figure 5, with different annealing temperature. From Table 5, we note that the capacitance at zero bias voltage (C_o) of $AgInSe_2$ thin film accession with annealing temperature.

The relationship between inverted square amplitude of capacitance ($1/C^2$) with a voltage in reverse bias has linear behavior which indicated that , the heterojunction of abrupt type.

The width of the depletion layer rise with increasing annealing temperature, due to the increasing in the carrier concentration (N_D) which leads to a decline of the capacitance and improvement of (V_{bi}) as shown in Table 5.

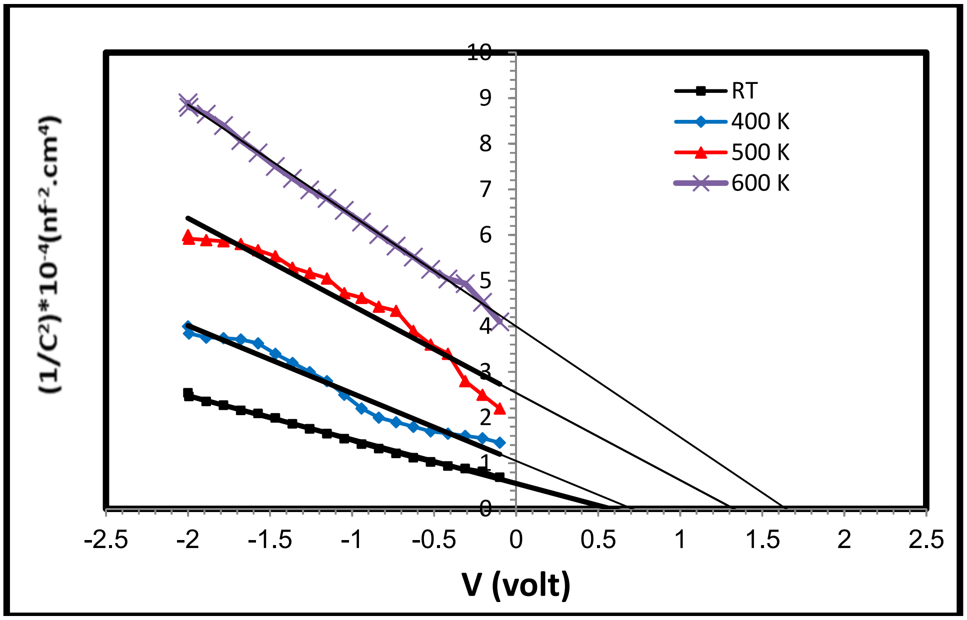

Figure 5. Variation of $1/C^2$ as a function of reverse bias voltage for $AgInSe_2$/Si heterojunction solar cell at different Ta.

Table 5. Values of C_o, W , N_D, and V_{bi} for AIAS /Si heterojunction with different Ta.

Sample Annealing	**C_o(nf/cm^2)**	**$W=\varepsilon_{(s)}/C_0$ (nm)**	**V_{bi}(Volt)**	**N_D (cm^{-3})**
RT	141.4213562	27.70444369	0.5	2.322E+15
400	98.05806757	39.95591691	0.6	2.438E+15
500	63.2455532	61.94901936	1.3	2.824E+15
600	50.06261743	78.2619887	1.6	3.122E+15

CONCLUSIONS:

$AgInSe_2$ thin films was preparation from its alloys using thermal evaporation method. XRD for thin films showed that it has polycrystalline with tetragonal structure of preferential orientation in the [112] direction. The influence of annealing treatment on the values of optical parameters of $AgInSe_2$ thin films was investigated. All thin films exhibited allowed direct optical energy band gap and high absorption in the visible region, The efficiency increases with the increasing of annealing temperature, we get the maximum values of efficiency (6.08) when the Ta= 600 K, while the C-V measurement revealed that those prepared heterojunction are of abrupt type.

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