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I-V and C-V characteristics of $ZnSe_{1-x}$ AL $_x$/ n and p-Si Solar Cell

KEYWORDS: ZnSe; Structure; Optical transmission; I-V; C-V

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ABSTRACT *$ZnSe_{1-x}$ Al_x (where x %=0, 2, 4,6 and 8) thin films were prepared by using a vacuum evaporation technique under a vacuum of $5*10^{-4}$ mbar. The structure and Optical properties of the ZnSe thin films were studied by using X-ray diffraction and were measured I-V, and C-V characteristics. X- ray diffraction shows that prepared films are poly-crystalline with preferred (111) orientation and having a zinc blend cubic structure (2θ=27.35) at (x=0, 2 and 4%), but at high concentration and annealing at 373K appeared new bond leads to Al_2Se_3. It was found that optical band gap, Eg, decreases on dopping Al. The values changes from 2.85 eV (for ZnSe) to 1.99eV with Al concentration increase. The current–voltage characteristics of $ZnSe_{1-x}$ Al_x/Si heterojunction show that the solar cell which is produced at all aluminum concentrations. $ZnSe_{1-x}Al_x$/Si heterojunction has been prepared at different concentrations of (x). The reverse bias capacitance was measured as a function of bias voltage.*

2. Introduction

Zinc Selenide (ZnSe) is a wide band gap II-VI semiconductors and has attracted considerable attention for their wide range of applications in various optoelectronic devices and in solar cells[1]. ZnSe has a direct bandgap of 2.7 eV and is transparent over a wide range of the visible spectrum[2]. ZnSe is the most popular material for infrared applications because of its high refractive index , low dispersion rate at infrared (IR) wavelenghs, and towering transmission band from 0.6 μm to 0.2 μm [3]. ZnSe films has been prepared by various growth techniques, including molecular beam deposition, chemical deposition, electrochemical deposition, pulsed laser deposition and thermal evaporation technique[4]. Bulk ZnSe is very important material to be used as a substrate for operating in blue range[5]. In the present investigation we able to fabricate solar cell form ZnSe doped with aluminum thin film.

3. Experimental techniques

Aluminum doped ZnSe alloy has been prepared from its own constituent elements. Appropriates weights of Zn, Se and Al (99.999%) were taken in a quartz tube, which is then evacuated (10^{-2} mmHg with rotary pump) and sealed. The temperature of the furnace was raised gradually to 500 C° and left at this temperature for about 4 h and then, the ampoule was slowly cooled to room temperature. The ZnSe ingots was taken out form the ampoule and into fine powder and used for evaporation. Zinc selenide thin films were prepared on to cleaned glass substrates using a vacuum evaporation technique under a vacuum $5*10^{-4}$ mbar. The optimized deposition parameters were used: target (material), ZnSe powder, substrate glass, room temperature (300C), substrate to target distance 15cm, current (I), deposition time 5 min. and deposition rate (1) nm/sec.

Then structure was examined by X-ray diffraction (Philips PW) and optical properties by using UV-Visible (Cary 100) spectrophotometer.

Results and discussion

1. X-ray analysis

XRD was performed at the grazing angle to obtain the information about the crystallographic structure, crystallinity, orientation and crystalline grain size. The XRD pattern of ZnSe thin film deposited on glass at room temperature is shown in fig. (1). In the XRD pattern, the peak positions indicates that the deposited ZnSe film has a cubic (zinc blend) crystal structure with the preferred orientation along the (111) plane corresponds to the Braggs reflection at 2θ= 27.35°. Figure (1 and 2) illustrated the XRD patterns of the deposited $ZnSe_{1-x}Al_x$ films on glass at substrate temperature equal to R.T with thickness equal to 0.3 μm, for annealing temperatures (373) K. This figure reveals polycrystalline structure of deposited and annealed samples. Similar result has been emphasized by Taj Muhammad Khan [3] and S. Venkatachalam[2]. It indicates that these films have stoichiometric structure. The variation of X–ray diffraction parameters with annealing temperature is listed in Tables (1), (2).

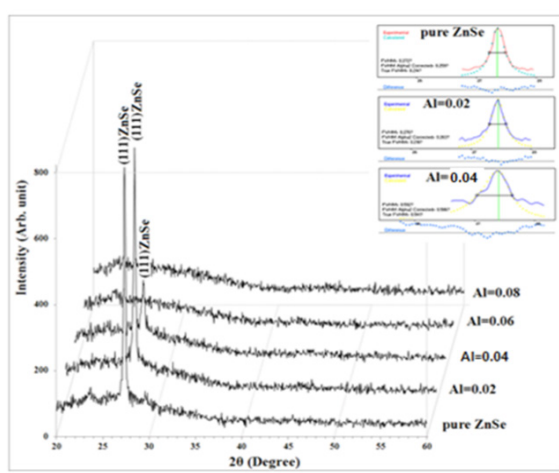

Fig. 1. X-ray diffraction spectra for $ZnSe_{1-x}$ Al_x thin films

Table (1): X-ray diffraction data for $ZnSe_{1-x}Al_x$ thin films at different concentrations deposited at R.T

X%	2θ exp. (Deg.)	d Exp. (Å)	d Std. (Å)	Phase	(hkl)	Card No.	FWHM (Deg.)	G.S (Å)
0	27.35	3.258	3.273	Cub. ZnSe	(111)	37-1463	0.214	360
2	27.45	3.247	3.273	Cub. ZnSe	(111)	37-1463	0.218	353
4	27.35	3.258	3.273	Cub. ZnSe	(111)	37-1463	0.541	142
6	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-

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Peaks appear at 2θ equal to(27.35°) for concentration (0%), (27.45°) at concentration (x=4%), (27.35°) at concentration (x=2%), which correspond to reflection from (111) plane at R.T, but in (x=6%) and (x=8%) not peaks appear (amorphous). In (373,473)K annealing temperature peaks appear at 2θ equal to (23.5°) for concentration (x=6%) and 2θ (29.45) for concentration (x=8%), which correspond to reflection from (220), (222) planes, these peaks lead to Al_2Se_3 compound. These peaks mean that Al atoms have made solid solution with ZnSe by replacing Zn atoms or by occupying any Zn vacancy in the lattice [1].

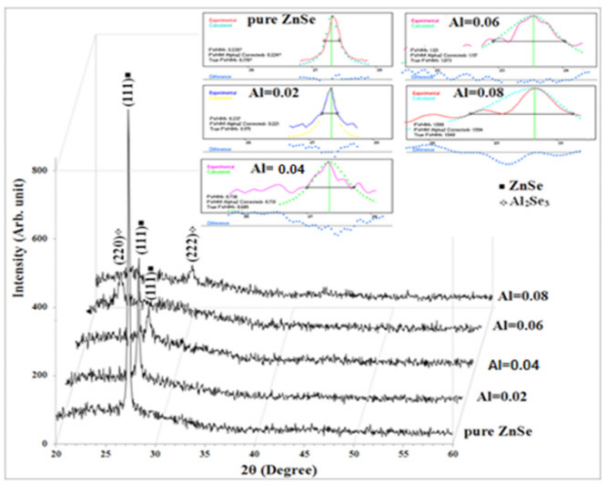

Fig.(2) X-ray pattern for $ZnSe_{1-x}$ Al_x thin film at 373K

Table(2): X-ray diffraction data for $ZnSe_{1-x}$ Al_x thin films at different concentrations deposited at 373K

X %	$2\theta_{exp.}$ (Deg.)	$d_{Exp.}$ (Å)	$d_{Std.}$ (Å)	Phase	(hkl)	Card No.	FWHM (Deg.)	G.S (Å)
0	27.30	3.264	3.273	Cub. ZnSe	(111)	37-1463	0.178	433
2	27.35	3.258	3.273	Cub. ZnSe	(111)	37-1463	0.175	440
4	27.35	3.258	3.273	Cub. ZnSe	(111)	37-1463	0.485	159
6	23.45	3.791	3.710	Cub. Al_2Se_3	(220)	26-0036	1.073	71
8	29.45	3.031	3.010	Cub. Al_2Se_3	(222)	26-0036	1.549	50

There is another explanation, it will probably be clusters inside crystal lattice from Al2Se3, these bonds are undesirable and can control the amount of these ties through the preparation conditions, thin means effectively Al association with Se due to the negative charge dissimilarity of the electricity.A point of interest is that the preferential orientation is the (111) direction of the films, this may be due to the layer stability of the (111) planes which reflects the more relaxed bonds with minimum energy. Another interpretation is that this stability originates in the larger density of bonds [7]. It is clear that there is little shifting of 2θ location to higher values.

2. Optical properties

The optical properties of the deposited $ZnSe_{1-x}$ Al_x films on glass substrate at R.T for thickness (0.3) μm, composition have been determined by using UV-visible near infrared transmittance spectrum in the region (0.2–0.8)μm. In general, we can observe from Fig.3. that transmittance decreases with increasing of Al concentration. In pure ZnSe the transmittance spectrum reveals a high transmission of 90 % in the near infrared region (≥ 600nm). The band gap was calculated from transmission data using absorption coefficient and direct band gap relation: [3].

$$(\alpha h\upsilon)^2 = A(h\upsilon - Eg) \quad (1)$$

Where α is the absorption coefficient, hν is the photon energy, E_g is the band gap and A is a constant with separate values for different transitions. From the above relation we can find out the optical band gap (E_g) by extrapolating the linear part of the curve $(\alpha h\nu)^2$ vs $(h\nu)$ to the energy axes as shown in Fig.5. The band gap was found 2.85eV which is in close agreement with theoretical value (2.8eV) and other experimental results.

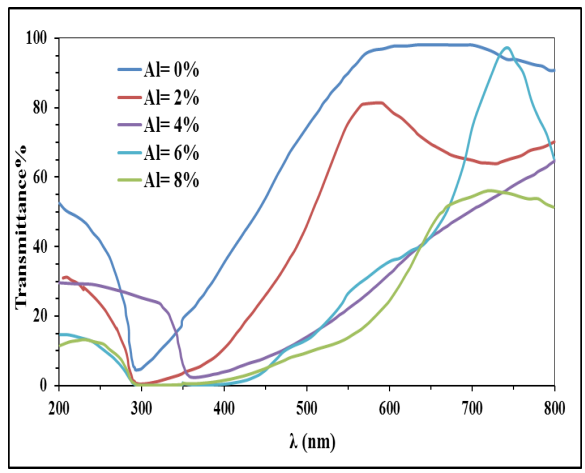

Fig.3. Transmission spectrum of the ZnSe thin films prepared at room temperature

The optical energy gap decrease with increasing aluminum (x) concentration for all samples is shown in Fig.4.Indeed E_g decreases from 2.85 eV to 1.9 eV at deposited $ZnSe_{1-x}$ Al_x films, as shown in table 3.

Table (3): Variation of E_g with Al concentration

Sample	Eg
0.0	2.85
0.02	2.67
0.04	2.3
0.06	2.2
0.08	1.99

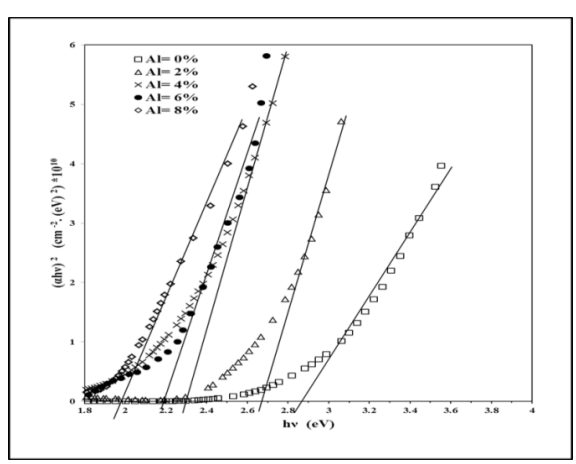

Fig.(4): band gaps of the ZnSe thin films prepared at room temperature

3. I-V Characteristic for $ZnSe_{1-x}$ Al_x/Si HJ at Dark:

The current–voltage characteristics are important parameter to identify the significance of the various components under reverse and forward bias as well as other important parameters._Fig.(5) and (6), shows the I-V characteristic for $ZnSe_{1-x}$ Al_x /Si HJ at forward bias voltage for different (Al) contents

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within the range (0-1 Volt). These curves demonstrate the behavior of the current with the forward bias voltage. There are two regions for the forward current curves at (x=0:8 % Al), the first region for the voltage range (0-0.3Volt) which the recombination current is dominate and the second region (V>0.3 volt), the variation is of exponential type and it is due to the tunneling current [8]. The initial part of Fig.(5) could be approximated by an expression of the type I~ exp (qV/ßK$_B$T) where (ß) is the ideality factor. So from the logarithm of the initial part of the forward current, the ideality factor (ß) could be calculated using equation[9]:

$$\beta = q/K_B T(V/Ln(I_F/I_S)) \qquad (2)$$

It should be noticed here that the ideality factor gives indication about the defects in the junction. The ideality factor increase with the increasing of Al content as shown in table (4) due to increasing of the structural defects accompanies the addition of aluminum to ZnSe.

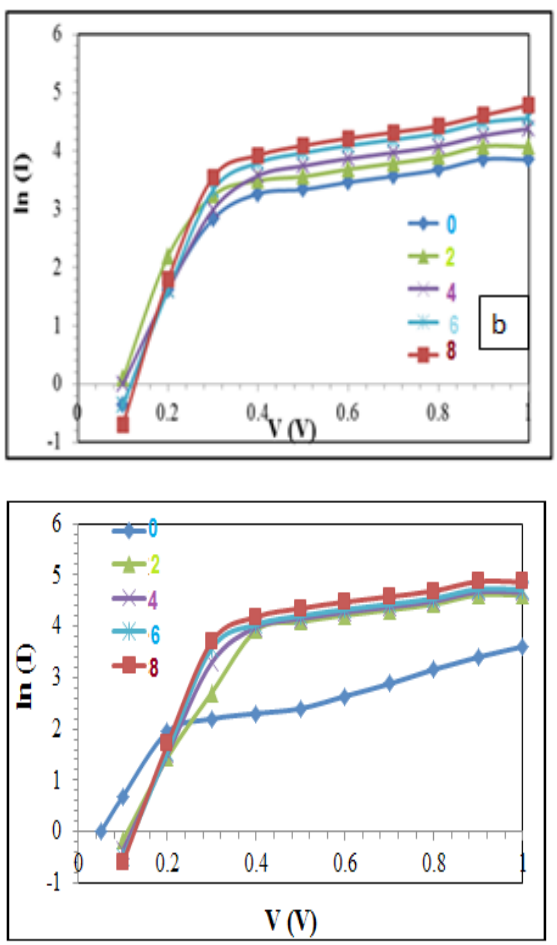

Fig.(5) I-V characteristics at forward bias voltage on semi logarthmic scale for a) $ZnSe_{1-x}$ A l_x/n-Si HJ , b) $ZnSe_{1-x}$ A l_x/p-Si HJ at different Al concentrations.

Table (4) shows the values of ideality factor for $ZnSe_{1-x}Al_x$/ Si HJ

	Sample x%	slope	ß
	0	15.95	2.43
	2	15.72	2.46
n	4	14.98	2.58
	6	18.44	2.10
	8	21.22	1.82
	0	12.91	3.00
	2	14.35	2.70
p	4	18.26	2.12
	6	20.40	1.90
	8	21.52	1.80

4. I-V Characteristic for $ZnSe_{1-x}Al_x$/Si HJ Under Illumination

The relation between illumination current and voltage of the $ZnSe_{1-x}Al_x$ heterojunction prepared with different aluminum content with thickness of (0.3) µm are presented in Fig. (6). The measurements were carried out under illumination with power intensity equal to (105) mW/cm^2. From these figures it can be observed that the photocurrent increases with increasing the bias voltage, also it can be seen that the photocurrent in the reverse bias is larger than that in the forward bias. This can be attributed to the fact that the width of the depletion region increases with the increase of the applied reverse bias voltage which leads to the separation of the electron–hole pairs. Therefore the photocurrent is a function of the generation and diffusion of carriers.

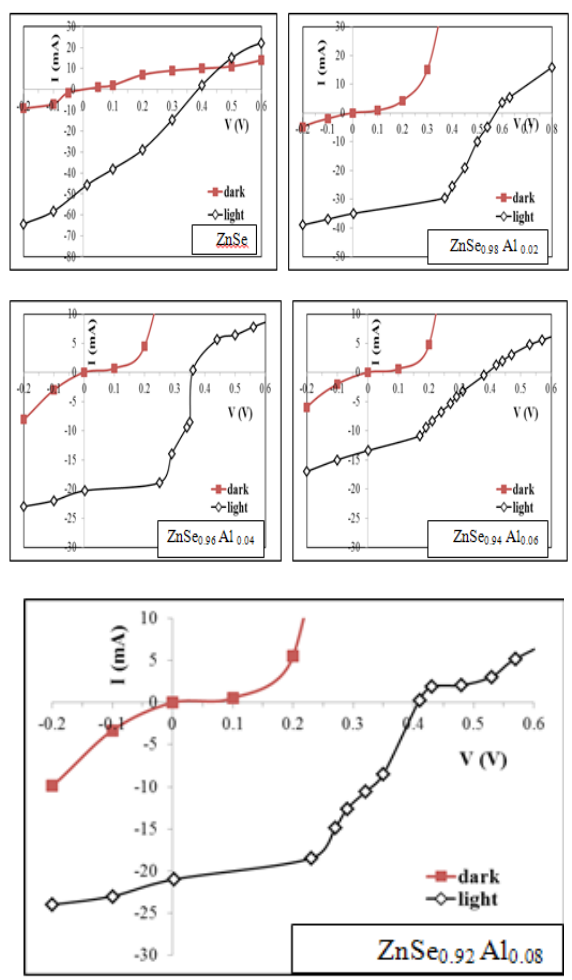

Fig.(6): I-V characteristic for $ZnSe_{1-x}Al_x$ /P-Si isotype heterojuction solar cell for all composition X

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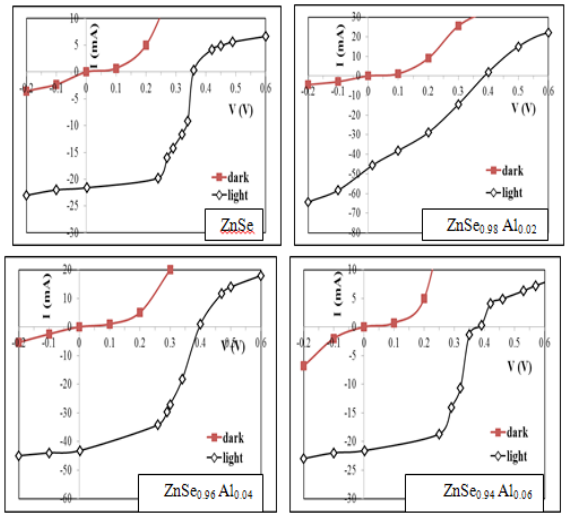

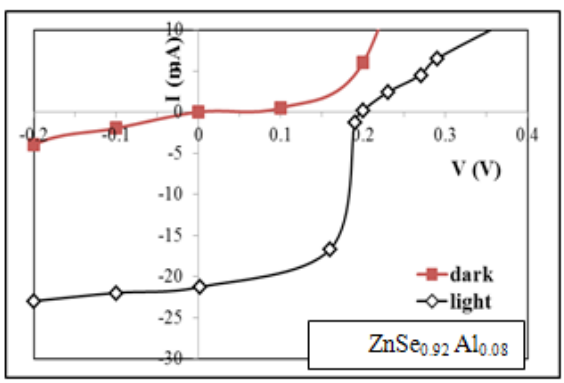

Fig.(7): I-V characteristic for $ZnSe_{1-x}$ Al_x /n-Si isotype heterojuction solar cell for all concentrations

Figure (7) shows I-V characteristics in dark and light by 105mW/cm² white light with different Al concentration. from this figure the values of I-V parameters (V_{oc}, I_{sc}, V_{max}, I_{max}, F.F and η) were calculated and listed in table (5).

Table (5): I-V parameters $ZnSe_{1-x}$ Al_x heterojunction with different content Al

Sub.	sample	V_{oc} (V)	I_{sc} (mA)	V_{max} (V)	I_{max} (mA)	F.F	η%
	1	0.36	22	0.26	18	0.59	4.5
	2	0.38	48	0.25	22	0.30	5.2
n	3	0.40	44	0.27	35	0.54	7.5
	4	0.38	22	0.27	18	0.58	4.6
	5	0.20	22	0.16	18	0.65	2.7
	1	0.38	48	0.24	26	0.34	5.9
	2	0.57	35	0.37	30	0.56	8.8
p	3	0.36	20	0.27	18	0.68	4.6
	4	0.40	13	0.2	10	0.38	1.9
	5	0.42	22	0.25	18	0.49	4.3

It is clear from table (5) that V_{oc} and I_{sc} change in non systematic sequence with gallium content for the junction $ZnSe_{1-x}$ Al_x increases and decreases with the increase of x content., but in general V_{oc} of hetrojunctions $ZnSe_{1-x}$ Al_x increases with aluminum content up to 0.06 after their decreases.

5. C-V Characteristic of $ZnSe_{1-x}$ Al_x /Si Heterojunction

The square of inverse capacitance is plotted against applied reverse bias voltage for $ZnSe_{1-x}Al_x$ heterojunction prepared at Al content (0,0.02, 0.06, and 0.08 %)with thickness (0.3) μm is shown in Fig. (7,8).

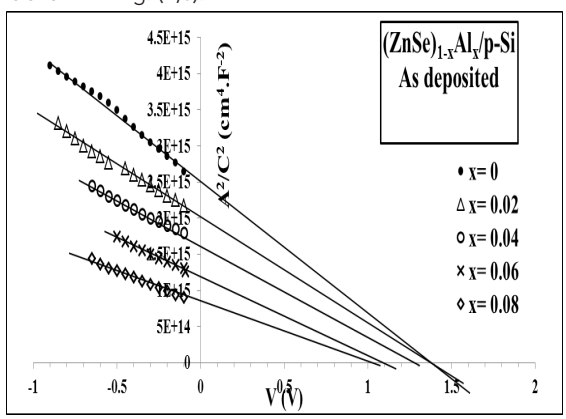

Fig. (7): The variation of A^2/C^2 versus the reverse bias voltage for $ZnSe_{1-x}$ Al_x/P-Si heterojunction for different Al content

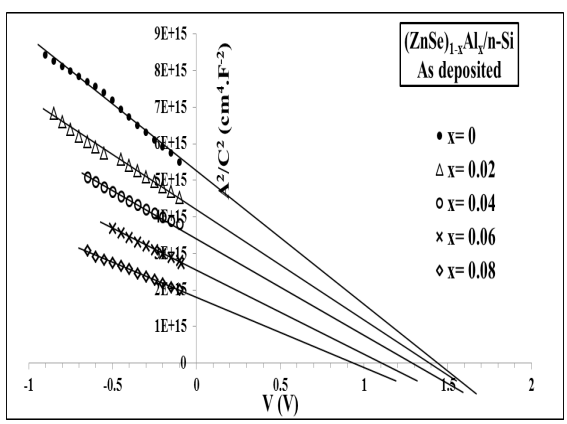

Fig. (8): The variation of A^2/C^2 versus the reverse bias voltage for $ZnSe_{1-x}$ Al_x/n-Si heterojunction for different Al content

The plot reveals straight line relationship which means that the junction is of an abrupt type. The built - in voltage, the carrier's concentrations and the width depletion layer were deduced and listed in table (3). We can see that V_{bi} values decreases with the increase of Al content of the films, and w values decrease due to the capacitance increase with Al content increase, while N_B exhibit to increase with the increasing of Al content in the $ZnSe_{1-x}$ Al_x films.

Table.(3) the values of Vbi, w and N_B for $ZnSe_{1-x}$ Al_x heterojunction for different Al content.

Sub.	Ta (K)		C_0*10^{-10}	$w*10^{-4}$	N_d	Vbi
		x	F/cm^2	(cm)	$*10^{16}$	(V)
		0	13.7	5.70	0.43	1.45
		0.02	15.2	5.13	0.55	1.4
N	as deposited	0.04	17.1	4.56	0.68	1.3
		0.06	20.0	3.91	0.72	1.1
		0.08	24.3	3.23	0.84	0.9
		0	20.0	3.91	0.86	1.4
		0.02	22.4	3.50	1.10	1.4
p	as deposited	0.04	24.3	3.23	1.37	1.3
		0.06	27.7	2.82	1.43	1.1
		0.08	35.4	2.21	1.68	1

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The concentration of carriers was calculated from the relation [9].

$$\frac{1}{C^2}=\left[\frac{2\left(\varepsilon_p N_p+\varepsilon_n N_n\right)}{qN_p N_n \varepsilon_P \varepsilon_n}\right]\cdot\left(V_D-V\right) \quad (3)$$

where $[2(\varepsilon_p N_p + \varepsilon_n N_n)/qN_p N_n \varepsilon_p \varepsilon_n]$ represents the slope.

where can be calculated (w) from relation.

$$W=(2\varepsilon_s V_{bi})^{1/2} \quad (4)$$

where w is width depletion layer and ε_s is the semiconductor permittivity .

Conclusion:

$ZnSe_{1-x}Al_x$ films were deposited onto n and p-Si for by thermal evaporation technique to introduce the anisotype and isotype heterojunction solar cell. From the optical studies, the transition of the deposited film is found to be direct allowed and Eg was found decrease from 2.85 eV to 1.99 eV with Al concentration increase. The variations of ideality factor have been studied. the ideality factor has been found decrease with Al concentration increase. The C–Vanalysis reveals the formation of abrupt hetero-junction in the examined $ZnSe_{1-x}Al_x$ /Si heterostructure.

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