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Photovoltaic Properties of n-$(ZnS)_X(CdTe)_{1-X}$/p-Si

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Abstract

Hetrojunction solar cells n-$(ZnS)_x(CdTe)_{1-x}$/p-Si, with Al, In and Au as front grid contacts, have been fabricated by thermal evaporation technique. Their photovoltaic properties and the forward I-V characteristics of the annealed cells at 400 °C were studied. The efficiency, ideality factor and other parameters have been obtained. The results showed that the efficiency, as well as the ideality factor, depends on the ZnS content in the cell and the efficiency is high for Au front contact compared with that of Al and In.

Key Words: Photovoltaic properties, n-$(ZnS)_x(CdTe)_{1-x}$/p-Si, Hetrojunction solar cells, thermal evaporation technique, efficiency, ideality factor.

1. Introduction

Group IIb-VIa compound semiconductor materials has gained considerable attention during the last few years for their use in photovoltaic, solar cells and other optoelectronic applications [1, 2, 3].

IIb-VIa compound semiconductors have high and direct band gap [4] and can form multilayer structures having different band gap which are suitable for various optoelectronic devices covering from the near infrared to visible and ultraviolet spectral range [5]. Cadmium telluride (CdTe) and zinc sulphide (ZnS) belongs to II-VI compounds and have direct band gaps of 1.5 eV and 3.7 eV, respectively [6, 7]. Recently high interest has been given to heterojunctions because of low cost and wide applications such as transistors, thyristors. semiconductor lasers and solar cells [8]. Via the solar photovoltaic (SPV) route, the solar radiation is converted directly into electricity through the use of solar cells. A solar cell is basically a p-n junction semiconductor device [9].

In order to increase the conversion efficiency of a heterojunction solar cell the window material should have as large gap as possible and the lattice mismatch and the difference in electron affinities between the materials should be minimum [10].

In a previous work, the electrical and optical properties of $(ZnS)_x(CdTe)_{1-x}$ have been studied [11, 12]. In the present work a heterojunction of n-$(ZnS)_x(CdTe)_{1-x}$/p-Si has been fabricated and their photovoltaic characteristics were studied.

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2. Experimental Details

A stoichiometric mixture of $(ZnS)_x(CdTe)_{1-x}$ where $0.1 < x < 1$ have been prepared according to the atomic ratio of their constituent elements. The mixture was put in sealed evacuated quartz ampoule ($\sim 10^{-2}$ torr). The ampoule was kept in a furnace at a temperature high enough to melt the mixture for about two (2) hours and then quenched in water at ambient temperature.

Thin films of the prepared compounds were deposited onto a cleaned and polished (111) surface of p-type Si single crystal wafers at room temperature by thermal evaporation technique using Balzar coating unit model 370 unit.

Pure aluminum (Al, 99.999%) was used as the back electrode contact. The front contact was made by Al, indium (In) and gold (Au) materials in a grid form. Figure 1 shows the schematic diagram of the fabricated hetrojunction. The prepared samples were annealed in vacuum at 400 °C for 1 hour.

The photovoltaic and I-V characteristics of the samples at AM-1 intensity (100 mW/cm^2) were measured using digital electrometer (keithley 616).

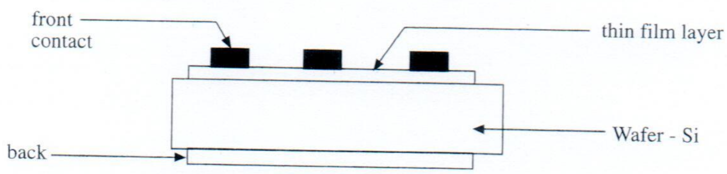

Figure 1. Schematic diagram of n-p hetrojunction solar cell. The thin film layer was n-$(ZnS)_x(CdTe)_{1-x}$ on p-Si.

3. Results and Discussions

A hetrojunctions n-$(ZnS)_x(CdTe)_{1-x}$/p-Si were fabricated for different zinc sulphide contents (x varying from 0.1 to 1). The open circuit voltage V_{oc} and the short circuit current (I_{sc}) of the annealed samples with Al grid front contact were obtained under illumination at AM-1 intensity using Halogen lamp. Figure 2 shows the variation of V_{oc} and I_{sc} as a function of the x. It is shown that the V_{oc} and I_{sc} should be small and decreased as the amount of ZnS increased in the cells. This reduction in the voltage and the current may be attributed to the electron affinity difference between the window (function of x) and the base materials [13] (since the electron affinity of Si = 4.01 eV, for CdTe = 4.28 eV and ZnS 3.9 eV) [14]. Furthermore the high ZnS content would reduce the carrier concentration in the films as this evidenced from the resulted high resistivity. Also the series resistance plays an important role in controlling the total current in the cell. This resistance of the solar cell represents the sum of all resistance elements distributed in semiconductor; the ohmic contacts, the semiconductor contact interface and the bulk resistances [15]. The photovoltaic (PV) output characteristics of the cells were studied; these are shown in Figure 3. The conversion efficiency η and the and fill factor FF for all cells were determined using the following equations [16].

$$\eta = \frac{v_{mp} I_{mp}}{P_m} \quad (1)$$

and

$$FF = \frac{v_{mp} I_{mp}}{V_{oc} I_{sc}}$$

where v_{mp}, I_{mp} are the maximum voltage and maximum current power and P_{in} is the total power of the incident irradiation on the cell. The obtained values are summarized and tabulated in Table 1.

The data showed that the efficiency decreases as ZnS increases in the films. Similar results have been given by Duchemin et al (1987) [17]. This effect may be attributed to the decrease in I_{sc} and V_{oc} of the cell that mentioned above. The limitation of the efficiency could be partly explained by numerous dislocation induced when ZnS layer increased [17].

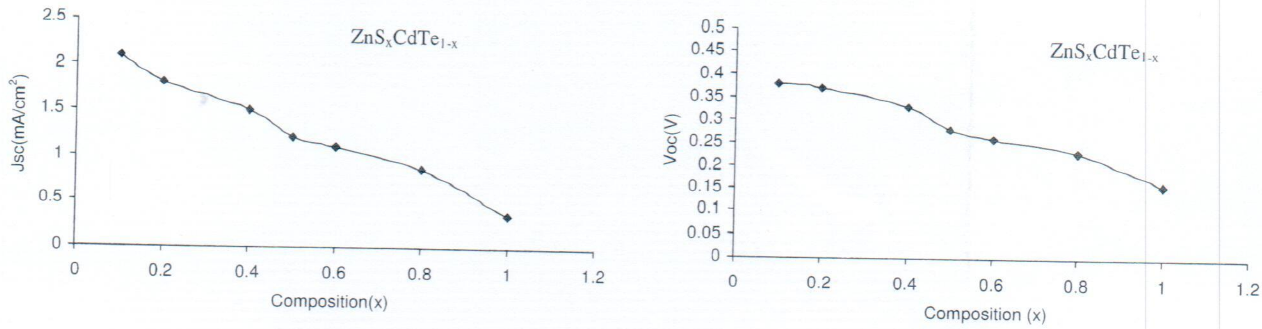

Figure 2. Variation of short circuit current I_{sc} and open circuit voltage V_{oc} as a function of compositon ratio x of n$(ZnS)_x(CdTe)_{1-x}$/p-Si Solar cells.

Table 1. Photovoltaic properties of n-$(ZnS)_x(CdTe)_{1-x}$/P-Si solar cell for Al contact.

ZnS Fractional Concentration x	V_{oc} (V)	I_{SC} (mA/ cm^2)	η%	FF%	R_s (Ω)	R_{sh} (Ω)
0.1	0.38	2.1	0.3	37	100	333
0.2	0.37	1.18	0.25	38	120	400
0.4	0.33	1.5	0.2	40	133	500
0.5	0.28	1.20	0.133	40	140	500
0.6	0.26	1.1	0.114	38	140	480
0.8	0.23	0.85	0.06	33	160	500
1.0	0.16	0.34	0.015	33	225	500

As it is known the values of conversion efficiency and the fill factor are sensitive to the series resistance [14, 18], the magnitudes of the series resistance R_S and the shunt resistance R_{sh} were determined (see Table 1) by taking the slopes at the voltage axis and the current axis of the photovoltaic output characteristics respectively [18]. The R_s and R_{sh} increased firstly and then become nearly constant in their values with increasing the value of x in the cells. This change may refer to the change in the mismatch between the Al grid contact and the window materials. The photovoltaic characteristics of the cells with the indium (In) are presented in Figure 4. The obtained values (for $x = 0.1, 0.2, 0.4$) were tabulated in the Table 2. Obviously a small change is observed in the conversion efficiency of the cells for In grid contact which may be attributed to the improvement of series and shunt resistances of the cells due to the reduction of the mismatch between the contact and the window materials.

Similarly the PV characteristics of $(ZnS)_{0.4}(CdTe)_{0.6}$ cell (the best content) was obtained using Au grid contact (see Figure 5) . Au contact gave the best efficiency as compared with that of Al and In, this may refer to that; Au is found to be the most favorable contact for the window material [19] also Au forms a low resistance contact and low alloying i.e. less diffusive in the films. Table 3 summarizes the different parameters of the cell with Au contact.

Table 2. PV characteristics of n-$(ZnS)_x(CdTe)_{1-x}$/p-Si solar cell for In contact.

ZnS concent	V_{oc}(V)	I_{SC}	η %	FF%	$R_s(\Omega)$	R_{sh} (Ω)
0.1	0.43	1.66	0.33	46	80	1000
0.2	0.36	1.6	0.27	46	100	500
0.4	0.29	1.45	0.2	48	80	500

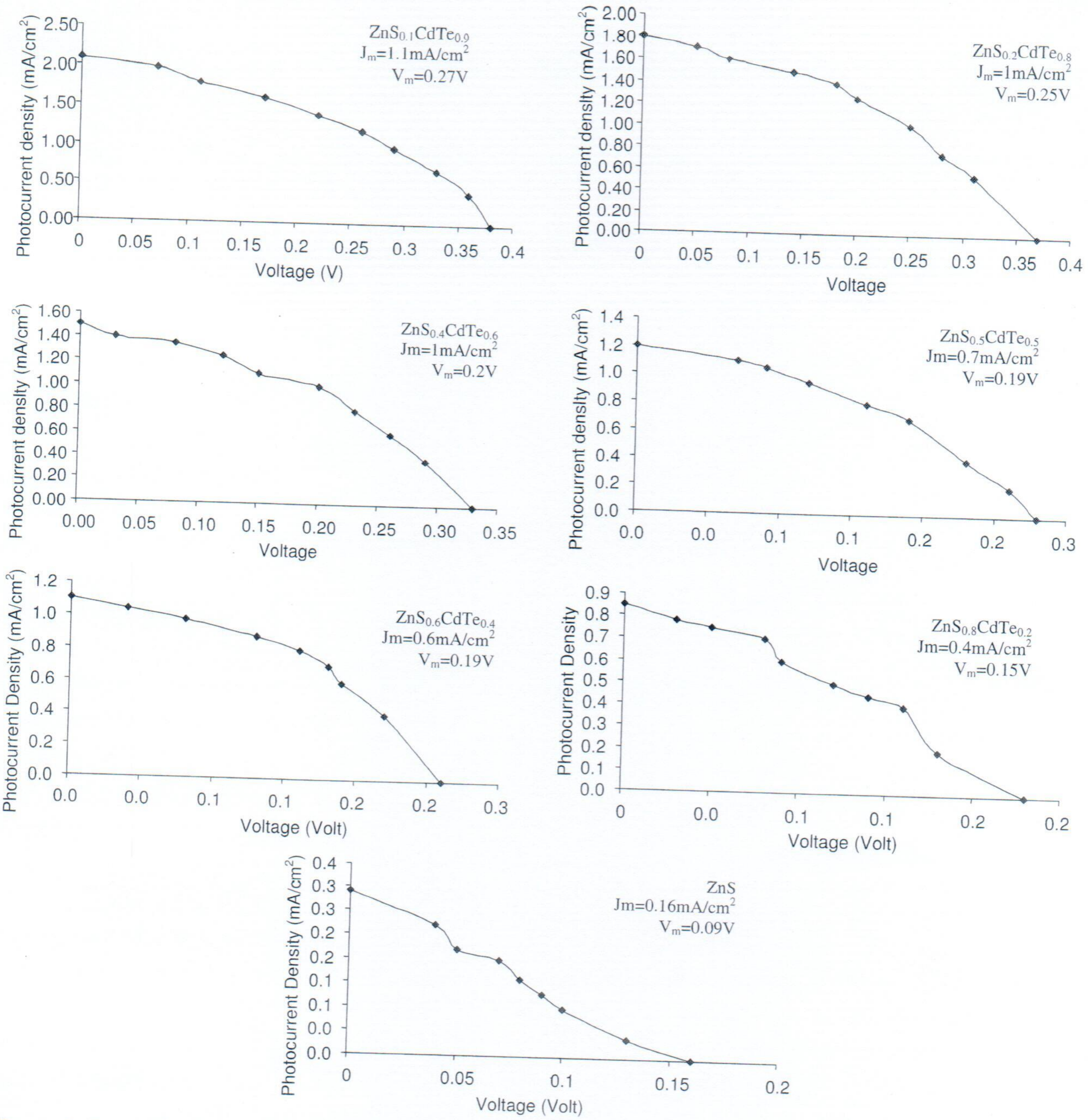

Figure 3. Photovoltaic output characteristics for. n-$(ZnS)_x(CdTe)_{1-x}$/ P-Si Solar cells with Al electrodes (annealing temperature = 400 °C).

Table 3. PV characteristic of n-$(ZnS)_{0.4}(CdTe)_{0.6}$/p-Si solar cell for Au contact.

V_{oc} (V)	I_{SC} (mA/ cm^2)	η %	i%	R_s (Ω)	R_{sh} (Ω)
0.41	2.13	0.42	48	40	500

The current-voltage characteristics of the cell with Al front contact have been investigated. The ideality factor of the diode can be determined from the forward diode equation given by [20]

$$\frac{qV_{oc}}{J_{\circ}} = nkT \cdot \ln J_{sc}, \tag{2}$$

where n is the ideality factor, J_o is the reverse saturation current density, J_{sc} denotes short circuit current density, k is Boltzman's constant and T denotes temperature. Values of J_o were determined by extrapolating the plots of Ln J versus V at $V = 0$.

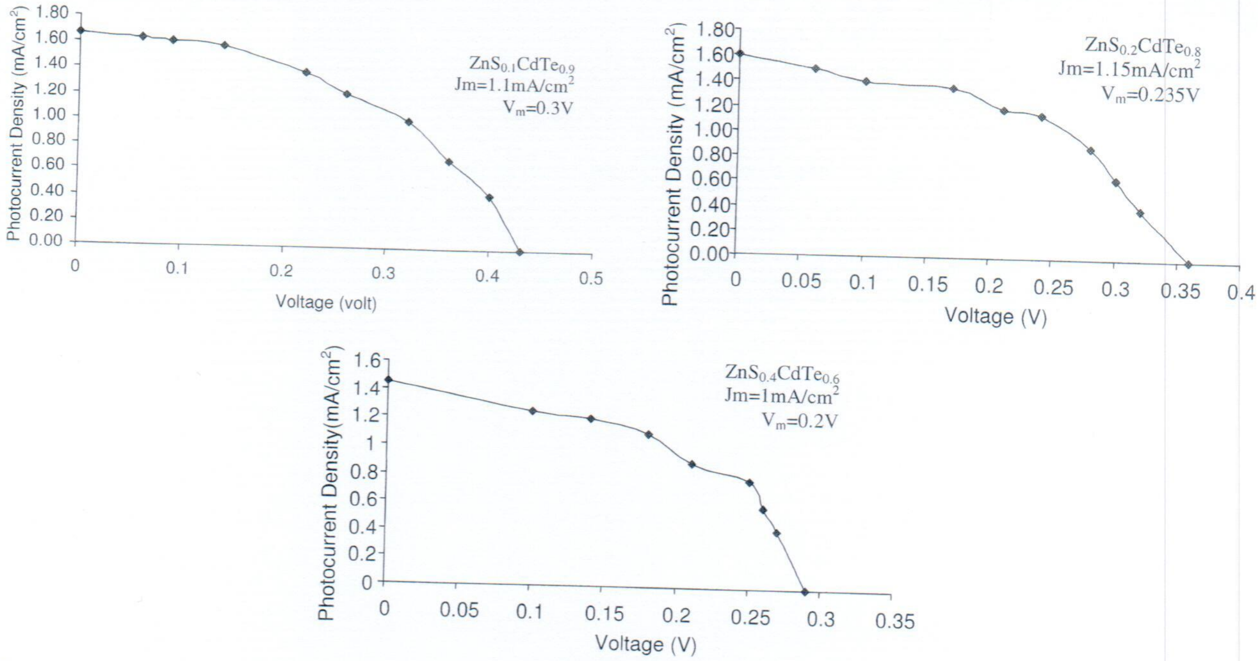

Figure 4. Photovoltaic output characteristics for n-(ZnS $)_x$(CdTe$)_{1-x}$/ P-Si Solar cells with In electrodes (annealing temperature = 400 °C).

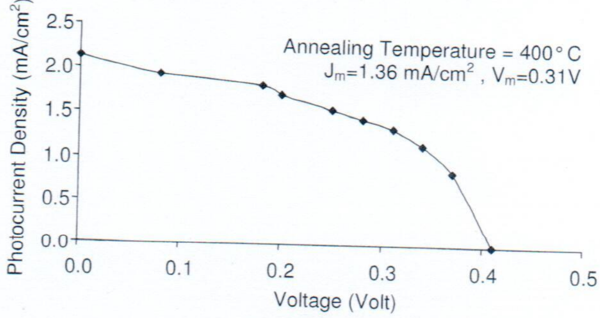

Figure 5. Photovoltaic output characteristics for n-(ZnS $)_{0.4}$(CdTe$)_{0.6}$/P-Si Solar cells with Au- electrodes.

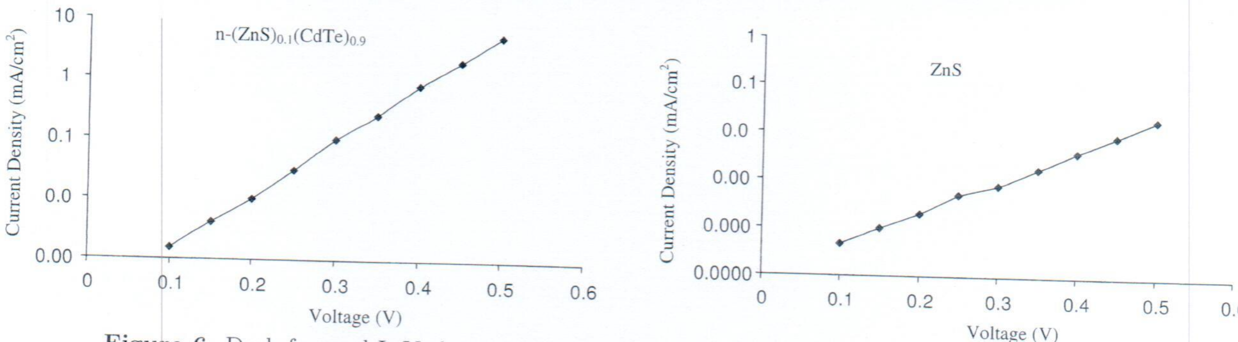

Figure 6. Dark forward I- V characteristics for n-(ZnS $)_x$(CdTe$)_{1-x}$/P-Si hetrojunction diode.

Figure 6 shows the I-V characteristics of the samples at $x = 0.1$ and ZnS which gives the range for which n may change.

The ideality factor varied its value from 1.82 for $x = 0.1$ to 2.7 to $x = 1.0$ and they took place corresponding values of J_o were 1.8×10^{-4} mA/cm^2 and 1.3×10^{-5} mA/cm^2, respectively. This change because of the change in ZnS content and the recombination produced at the interface states at the junction of the diode [20].

4. Conclusion

The n-$(ZnS)_x(CdTe)_{1-x}$/p-Si hetrojunction solar cells were prepared by thermal evaporation and the efficiency showed a decrease in its value as ZnS increased in the cell. The efficiency was improved by using Au front contact compared with Al and In. The ideality factor and the reverse saturation current J_o showed a change in their values as ZnS changes.

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