

Radiation Effect on Optical and Electrical Properties of CdSe(In)/P-Si Heterojunction Photovoltaic Solar Cells

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Abstract The efficiency and radiation resistance of solar cells are graded up. They are, then, fabricated in the form n-CdSe (In)/P-Si Heterojunction cells by electron beam evaporation of a stoichiometric mixture of CdSe and In to make a thin film on a P-Si single crystal wafers with thickness 100 μm and resistivity $\sim 1.5 \Omega\cdot\text{cm}$ at a temperature 473 $^{\circ}\text{K}$. The short-circuit current density (j_{sc}), open-circuit voltage (V_{oc}), fill factor (ff) and conversion efficiency (η) under Am1 are 20 mA/cm^2 , 0.49 V, 0.71 and 6% respectively. The cells were exposed to different electron doses (electron beam accelerator of energy 1.5 MeV, and beam intensity 25 mA). The cells performance parameters are measured and discussed before and after irradiation.

Keywords N-CdSe(In)/P-Si Solar Cells Performance, Electron Beam, Radiation Effects

1. Introduction

The output power for space solar cells can be increased by improving in the efficiency (η) and the radiation resistance. In such case radiation resistance is an important factor, since the continuous impact of high energy particles damages the semiconductor lattice, degrading the cell performance and, hence limiting their lifetime[1,2].

The development of a new generation of highly efficient photovoltaic cells GaAs, AlGaAs/GaAs, InP, CdSe/Ge, Si and others[3-6] is of real interest for future space power applications. Solar cells employing new material are to be more resistant to radiation effect than Si – cells[3]. Heterojunction cells n-CdSe/p-Si using silicon as an absorber show different advantages including its easier fabrication as compared with conventional Si-heterojunction cells[7-13]. CdSe is an important group II-VI direct band gap (visible) semiconductor material with attractive electronic, spintronics and optoelectronic properties. It has shown great potential in the applications, such as biosensing/bioimaging, light emitting diode, and photodetectors. The CdSe (In) films have high conductivity due to the added indium (In) and therefore, they are very suitable as a window layer for solar cells. In these cells, most carriers are generated in the base (Si), so that the control of the thickness and doping of the window layer (CdSe) is very critical. In addition, n-CdSe/p-Si structure can be prepared by low temperature processes (evaporation

sputtering or chemical spray), thereby avoiding lifetime degradation[14-16], which is suitable for low cost space solar cells.

Furthermore, this structure has no energy spikes[7] and the surface recombination velocity seen in heterojunction can be neglected.

Low resistivity CdSe films are needed in heterojunction solar cells to lower the cell series resistance, to confine the band bending to the narrow band gap material and to minimize the conduction band-Fermi level energy gap[17].

The cells were fabricated at different compositions of CdSe (In: CdSe weight ratio) and thicknesses. In this work, the n-CdSe/p-Si solar cell was fabricated by electron beam evaporation of a stoichiometric mixture of CdSe and In forming a film on a p-Si instead of individual evaporation for CdSe as has been presented in previous works[7,14-16]. The effect of fabrication condition and irradiation with gamma radiation and electron beam on optical and electrical properties of heterojunction solar cells were investigated.

2. Cell Fabrication

In this method, the composition (namely 4:1000 and 6:1000 weight) for the Indium (In) to CdSe is chosen for n-CdSe (In)/p-Si structure. Each composition in a well cleaned sealed silica tube under a vacuum of 3×10^{-5} Torr. Then the temperature of the mixture was increased gradually, with 278 $^{\circ}\text{K}/\text{min}$ in microprocessor controlled furnace up to temperature for 1223 $^{\circ}\text{K}$ and kept at this temperature for about 5 hours. As a result, we got a stoichiometric mixture of CdSe and In after cooling it gradually to the room temperature. On the other hand, the p-Si(111) – of 1.5 $\Omega\cdot\text{cm}$ resistivity was

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cleaned first in a bath of antigrease Acetone and then was etched for 3 min. in a CP4 solution ($15 \text{ cm}^3 \text{ HF}$, 25 cm^3 Acetate acid) to remove any oxides.

Secondly, it was rinsed for 3 min. in deionized water and finally was dried carefully in a furnace at a temperature of 423°K . After cleaning, the unpolished surface of the silicon wafer was coated with Indium (In) by thermal evaporation in vacuum of 2×10^{-5} Torr for back contact formation. After that, the Heterojunction n-CdSe(In)/p-Si structure was fabricated by a vacuum evaporation of CdSe(In) mixture, which was put in a single boat, to be deposited on a single crystal p-Si substrate at temperature 473°K with evaporation rate of $5^\circ\text{A}/\text{sec}$. The upper Al-grid contact coating followed the junction formation by using a suitable mask. At the end the cells were annealed at 523°K for 2 hour, to activate the junction formation. As a result, a Heterojunction photovoltaic solar cells of area of 2 cm^2 with different composition and CdSe layer thicknesses were fabricated as presented in table.(1) Also, the layer thicknesses were deposited at the same time and same previous condition on a glass substrate (12 samples) for measuring its optical transmission. The samples were exposed to electron beam. The absorbed doses were to (350 - 650) Mrad. The samples were exposed to gamma radiation with absorbed dose 650 Mrad.

Table 1. represents the name, the thickness and the composition of n-CdSe(In)/p-Si

| Name of sample | Thickness(μm) | Composition(weight ratio) |
|----------------|----------------------------|---------------------------|
| C1, C2 | 0.6 | 4 :1000 |
| C3, C4 | 3 | 4 :1000 |
| C5, C6 | 4 | 4 :1000 |
| S1,S2 | 0.6 | 6 :1000 |
| S3, S4 | 3 | 6 :1000 |
| S5, S6 | 4 | 6 :1000 |

3. Measurement Technique

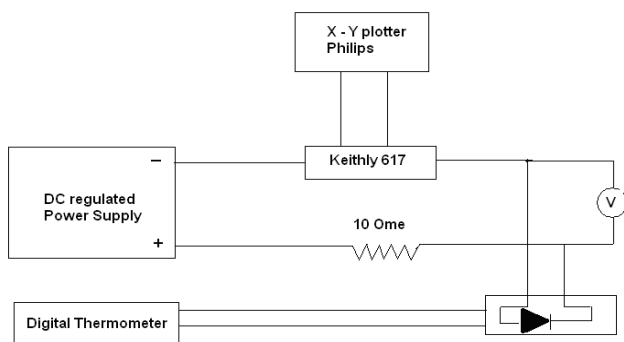


Figure1. Circuit diagram for I-V measurements before and after irradiation

Curve tracer 571 Tektronix and the circuit in Fig.(1) were used for I-V measurement. Oriel monochromator model 77325 provided with radiometer system model 70100 was used for spectral response measurements. To measure the C-V characteristics, a Hp C-V meter, model-4280A was used. Light source (halogen lamp 1000 watts) connected with variac, was positioned vertically on the sample to change the light intensity. The CdSe(In) was deposited on glass sub-

strate for measuring its transmission and refractive index before and after electron beam irradiation.

4. Results and Discussion

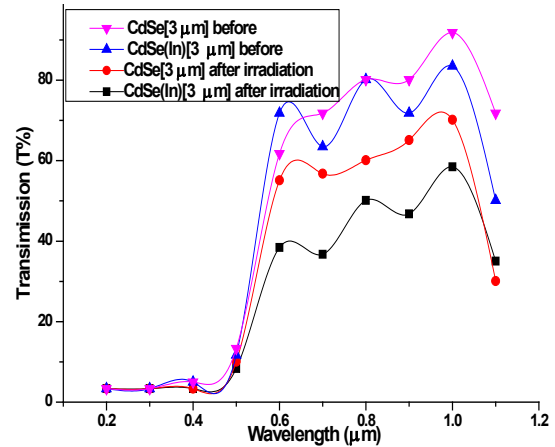


Figure 2. Spectral transmission before and after the electron beam irradiation for CdSe(In) and CdSe at the same thickness $3 \mu\text{m}$

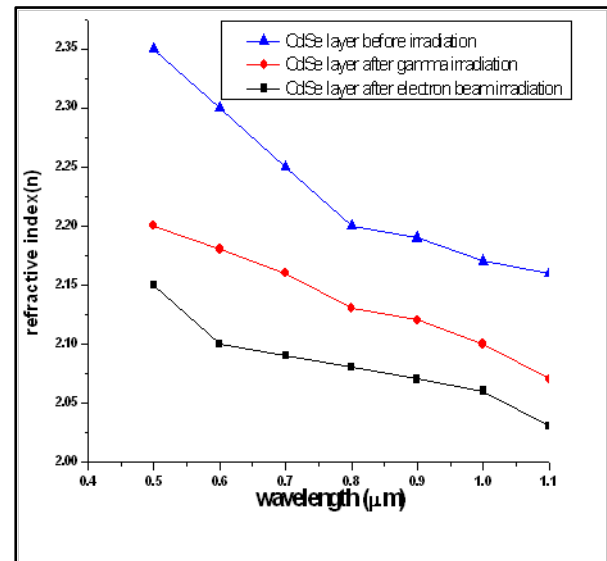
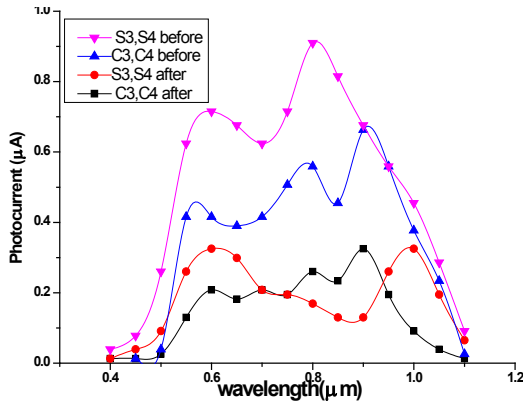


Figure 3. CdSe spectral refractive index before and after gamma and electron beam irradiation

As mentioned in the previous section, the CdSe (In) was deposited on glass substrate for measuring its transmission and refractive index before and after gamma and electron beam irradiation. The measurements were considered w.r.t 100% transmission. Fig.(2) shows the spectral transmission $T(\lambda)$ for four group of samples at $3 \mu\text{m}$ CdSe and CdSe(In) layer thickness. In fact, before irradiation the adding of Indium, in general decreases the transmission. The range of wavelength for two types of cells is from $0.5 \mu\text{m}$ to $1.1 \mu\text{m}$. From the transmission curve, the refractive index (n) of CdSe layer can be determined using Swanepole method[18]. The spectral refractive index before and after gamma and electron beam irradiation with the same dose 650 Mrad, is shown in Fig.(3).

Table 2. shows the resistivity, doping diffusion length before and after irradiation

| Sample name | Thickness micron | Resistivity $\Omega \cdot \text{cm}$ | Composition Ratio | Doping cm^{-3} | Diffusion Length(μm) Before After | | Dose Mrad |
|-------------|---------------------|---|----------------------|-------------------------|---|----|--------------|
| C1 | 0.6 | 3.14×10^{-3} | 4:1000 | 5.2×10^{19} | 63 | 50 | 650 |
| C2 | 0.6 | 3.22×10^{-3} | 4:1000 | 5.31×10^{19} | 66 | 55 | 650 |
| S1 | 0.6 | 3.15×10^{-4} | 6:1000 | 8.3×10^{19} | 66 | 58 | 650 |
| S2 | 0.6 | 3.3×10^{-4} | 6:1000 | 10^{20} | 68 | 60 | 650 |

**Figure 4.** Spectral response of (C3,C4) and (S3,S4) groups as a function of photocurrent before and after electron beam irradiation

On the other hand, after exposing the samples to gamma and electron beam irradiation, the color of CdSe layer is changed to be darker due to the bond breaking or orientation[18] which changes the optical absorption of the CdSe layer. Therefore, the transmission and the refraction index are decreased after the irradiation with electron beam more than the effect of gamma irradiation as shown in Fig.(3). Table (2) shows the thin film CdSe layer parameters for two compositions 4:1000 and 6:1000. It is shown that the cells with higher composition have higher conductivity[11].

Fig.(4) shows the spectral response of the cells group C and group S before and after electrons beam irradiation for the same CdSe layer thickness ($3 \mu\text{m}$). These responses for Heterojunction n-CdSe/p-Si are in good agreement with the published data, which had been by thermal vacuum evaporation for (In) and CdSe[7,14,15]. It is clear that the sensitivity in the short wavelength region for n-CdSe/p-Si heterojunction solar cells is higher than the published sensitivity for the case of Si heterojunction[1]. This is due to the surface recombination and the dead layer effects. It can be seen from Fig.(4) that the change in spectral response due to group C cells irradiation is less than of S group cells. This behavior shows that the increase of Indium ratio increases the conductivity and as a consequence the spectral response increases as well. On the other hand, the decrease in CdSe(In) film thickness decreases the conductivity[11,16,18,19] and in turn the spectral response. But the effect of the enhancement in conductivity due to the increase in the composition is higher than the effect of the reduction in conductivity due to the thickness decrease. The spectral response is decreased due to the displacement in the crystal lattice. It is clear that before irradiation, it is better in group S than in group C cells

due to the better spectral response for group S cells than in group C cells.

Fig.(5) shows the I-V characteristics for different cells at AMI before and after electrons beam irradiation with different doses. The measured short-circuit current density, open-circuit voltage, fill factor and efficiency are 20 mA/cm^2 , 0.49 V , 0.71 and 6% for group S at the optimum thickness (CdSe layer thickness = $3 \mu\text{m}$) respectively. Also from Fig.(5). The effects of electron on the J_{sc} and V_{oc} are clearly observed, the measured short-circuit current density, open-circuit voltage, fill factor and efficiency are 13.5 mA/cm^2 , 0.4 V , 0.69 and 4% for group S under (350 Mrad) irradiation. This is attributed to the permanent damage (displacement) created in the base region reducing the electron lifetime[21].

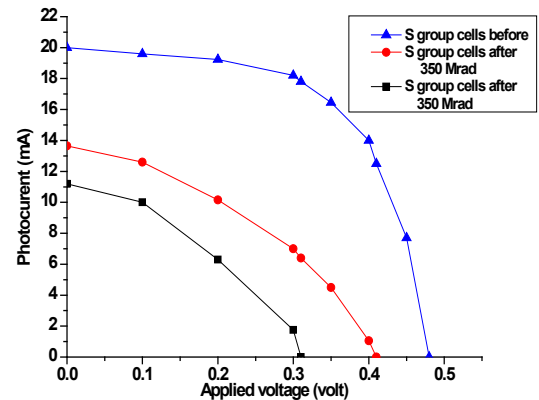
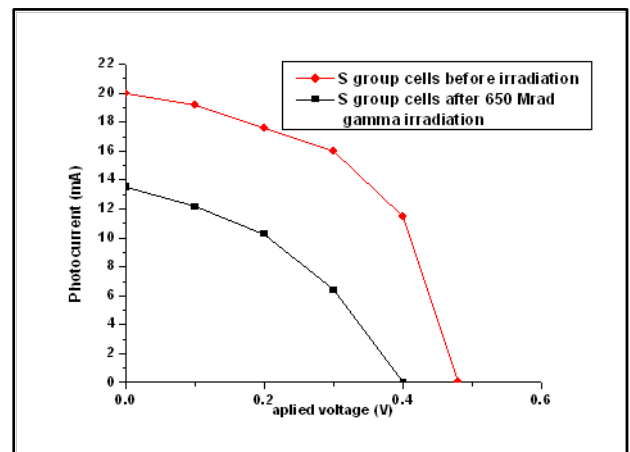
**Figure 5.** I-V characteristics for group (S) $3 \mu\text{m}$ before and after electron beam irradiation**Figure 6.** I-V characteristics for groups $3 \mu\text{m}$ before and after gamma irradiation

Fig.(6) shows the effect of gamma irradiation (650 Mrad) on I-V characteristics of S group cells. Fig.(5) and Fig.(6) shows the effect of gamma and electron beam irradiation (with the same dose 650 Mrad) on J_{sc} and V_{oc} characteristics of S group cells, it is shown that the electron have greater effect than the gamma rays, which is due to the penetration depth of electrons is less than gamma rays and hence the expects higher energy dissipation. Also, the radiations have a greater effect in reducing the J_{sc} than in V_{oc} for all samples. The reduced percentage ratios in J_{sc} and V_{oc} are 48% and 34% for S group cells, and 33% and 21% for respectively.

5. Conclusions

A n-CdSe/p-Si heterojunction solar cells with conversion efficiency 6% at AMI were fabricated by electron beam evaporation using single source of a stoichiometric mixture of CdSe and In. The irradiation with gamma electrons beam with the same dose (650 Mrad) causes a degradation in the cells performance but still with better results than the conventional ones. The cell characteristics show a strong dependence on CdSe layer thickness and In: CdSe ratio before and after the irradiation. However better precautions and handling fabrication parameters theoretical optimization parameters theoretical optimization and applying other techniques such as antireflection coating and back surface field can improve the performance of the can n-CdSe/p-Si Heterojunction solar cells.

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