Radiation effect on the 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. They are then fabricated in the form of n-CdeSe(In)/p-Si heterojunction cells by electron beam evaporation of a stoichiomteric mixture of CdSe and In to make a thin film on a p-Si single crystal wafer with a thickness of 100 μm and a resistivity of $\sim$ 1.5 Ω·cm at a temperature of 473 K. The short-circuit current density (j_{sc}), open-circuit voltage (V_{oc}), fill factor (ff) and conversion efficiency (η) under 100 mW/cm^2 (AM1) intensity, 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 cell performance parameters are measured and discussed before and after gamma and electron beam irradiation.

Key words: n-CdSe(In)/p-Si solar cells performance; electron beam; radiation effects

DOI: 10.1088/1674-4926/33/10/102001 **EEACC:** 2520

1. Introduction

The development of a new generation of highly efficient photovoltaic cells of GaAs, AlGaAs/GaAs, InP, CdSe/Ge, Si and others[1−6] is of real interest for future space power applications. Solar cells employing new materials are likely to be more resistant to radiation effects than Si cells[3]. Heterojunction cells of n-CdSe/p-Si using silicon as an absorber show different advantages, including its easier fabrication as compared with conventional Si-homojunction cells[7−13]. CdSe is an important group II–VI direct bandgap (visible) semiconductor material with attractive electronic, spintronics and optoelectronic properties. It has shown great potential in applications such as light emitting diodes and photodetectors. The CdSe(In) films have high conductivity due to the addition of 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 less critical. In addition, an 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 seen in the homojunction 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 bandgap 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 evaporator of a stoicion mixture of CdSe and In forming a film on a p-Si instead of individual evaporation for CdSe as has been presented in pervious works[7, 14−16]. The effects 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) of the Indium (In) to CdSe is chosen for the n-CdSe(In)/p-Si structure. To produce this structure, each composition was placed inside a well cleaned sealed silica tube in a vacuum of 3 $\times$ 10^{-5} Torr. The temperature of the mixture was increased gradually, by 278 K/min in a microprocessor coprolite furnace up to a temperature of 1223 K and kept at this temperature for about 5 h. As a result, we got a stoichiomteric mixture of CdSe and In after cooling it gradually to room temperature. The p-Si (111) of 1.5 Ω·cm resistivity was firstly cleaned in a bath of antigrease acetone and was then etched for 3 min in a CP_4 solution (15 cm^3 HF, 25 cm^3 acetate acid) to remove any oxides .

Secondly, it was rinsed for 3 min in deionized water and finally it 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 a vacuum of 2 $\times$ 10^{-5} Torr for back contact formation. After that, the heterojunction n-CdSe(In)/p-Si structure was fabricated by vacuum evaporation of the CdSe(In) mixture, which was put in

Table 1. The name, thickness and 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

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Received 7 April 2012, revised manuscript received 12 May 2012

Table 2. Resistivity, doping diffusion length before and after irradiation.

Sample name	Thickness (μm)	Resistivity (Ω·cm)	Composition ratio	Doping (cm^{-3})	Diffusion length (μm)		Dose (Mrad)
					Before	After	
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

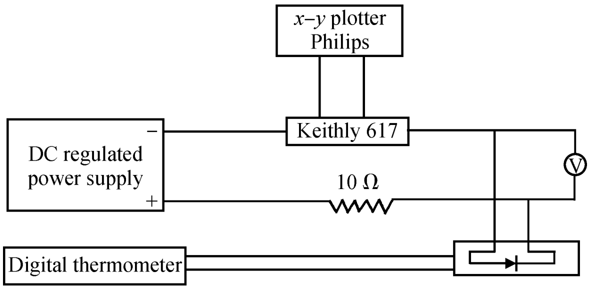

Fig. 1. Circuit diagram for I–V measurements (before and after irradiation).

a single boot, to be deposited on a single crystal p-Si substrate at 473 K with an evaporation rate of 5 Å/s. The upper Al-grid contact coating followed the junction formation using a suitable mask. At the end the cells were annealed at 523 K for 2 h, to activate the junction formation. As a result, a heterojunction photovoltaic solar cell with an area of 2 cm^2 with different compositions and CdSe layer thicknesses was fabricated as presented in Table 1. Also, the layer thicknesses were deposited at the same time and in the same way as previously on a glass substrate (12 samples) for measuring the optical transmission. The samples were exposed to an electron beam of 1.5 MeV, with a beam current of up to 25 mA, and a beam power of up to 37.5 kW, the absorbed doses were to 350–650 Mrad. Also, the samples were exposed to a cobalt-60 gamma cell, with an absorbed dose of 650 Mrad, and a dose rate of 7.1 kGy/s.

3. Measurement technique

The Tektronix curve tracer 571 and the circuit outlined 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. The light source (a 1000 W halogen lamp), connected with variac, was positioned.

4. Results and discussion

As mentioned in the previous section, the CdSe (In) was deposited on the glass substrate to measure its transmission and refractive index before and after the gamma and electron beam irradiation. The measurements were considered with respect to the w.r.t 100% transmission. Figure 2 shows the spectral transmission $T(\lambda)$ for four groups of samples at 3 μm CdSe and CdSe(In) layer thicknesses. In fact, before irradiation, the adding of Indium in general decreases the transmission. The range of wavelength for the two types of cells

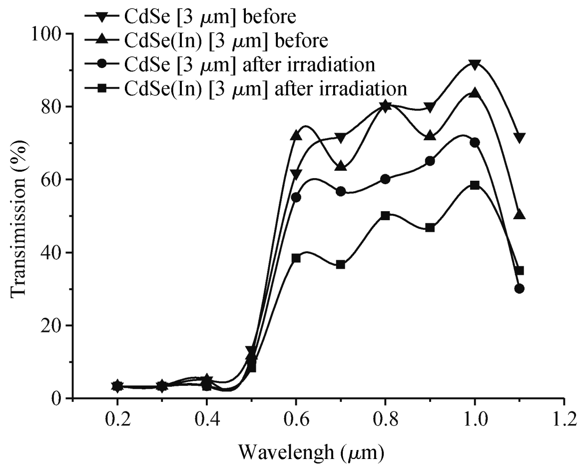

Fig. 2. Spectral transmission before and after the electron beam irradiation for CdSe(In) and CdSe at the same thickness (3 μm).

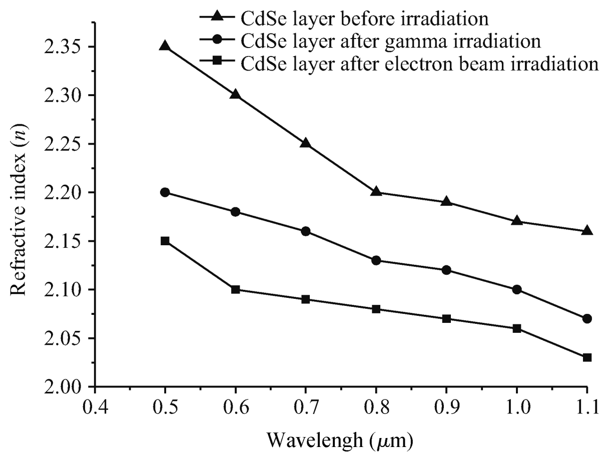

Fig. 3. CdSe spectral refractive index before and after gamma and electron beam irradiation.

is from 0.5 to 1.1 μm. From the transmission curve, the refractive index (n) of the CdSe layer can be determined using the 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.

After exposing the samples to gamma and electron beam irradiation, the color of the CdSe layer becomes darker due to the bond breaking or reorientation[18] which changes the optical absorption of the CdSe layer. The transmission and the refraction index are decreased after the irradiation with the 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 In concentrations of 4 : 1000 and 6 : 1000. It is shown that

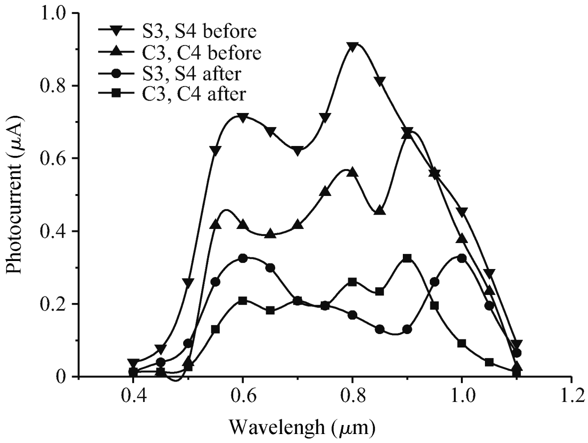

Fig. 4. Spectral response of C3, C4 and S3, S4 groups as a function of photocurrent before and after electron beam irradiation.

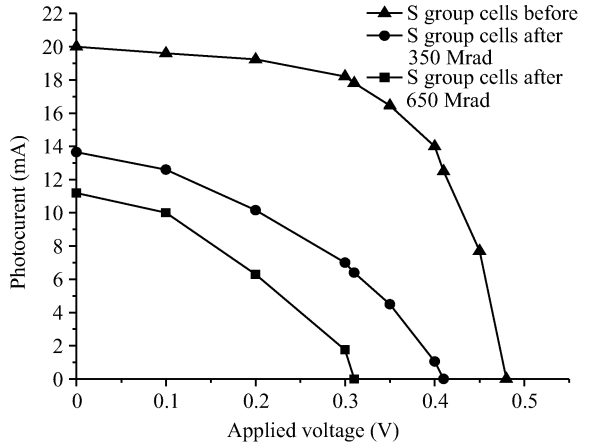

Fig. 5. $I-V$ characteristics for group S (3 μm) before and after electron beam irradiation.

the cells with higher composition have higher conductivity[11].

Figure 4 shows the spectral response of the group C and group S cells before and after electron beam irradiation for the same CdSe layer thickness (3 μm). These responses for the heterojunction n-CdSe/p-Si are in good agreement with the published data, which had been produced by thermal vacuum evaporation of In and CdSe[7, 14, 15]. Clearly the sensitivity in the short wavelength region for the n-CdSe/p-Si heterojunction solar cell is higher than the published sensitivity for the case of the Si homojunction[1]. This is due to the surface recombination and dead layer effects. It can be seen from Fig. 4 that the change in spectral response due to group C cell irradiation is less than that of S group cells. This behavior shows that the increase of the indium ratio increases the conductivity and as a consequence the spectral response increases as well. 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 decrease in thickness. The spectral response is decreased due to the damage in the crystal lattice[20]. Clearly, before irradiation, this is better in the group S cells than in group C cells due to the better spectral response for group S cells than group C cells.

Figure 5 shows the $I-V$ characteristics for different cells at AMI before and after electron 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 μm) respectively. Also from Fig. 5, the effects of electron beam irradiation 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 (650 Mrad) irradiation. This is attributed to the permanent damage created in the base region reducing the electron lifetime[21].

Figure 6 shows the effect of gamma irradiation (650 Mrad) on $I-V$ characteristics of S group cells. Figures 5 and 6 show the effect of gamma and electron beam irradiation (with the same dose of 650 Mrad) on J_{sc} and V_{oc} characteristics of S group cells. It is shown that the electrons have a greater effect

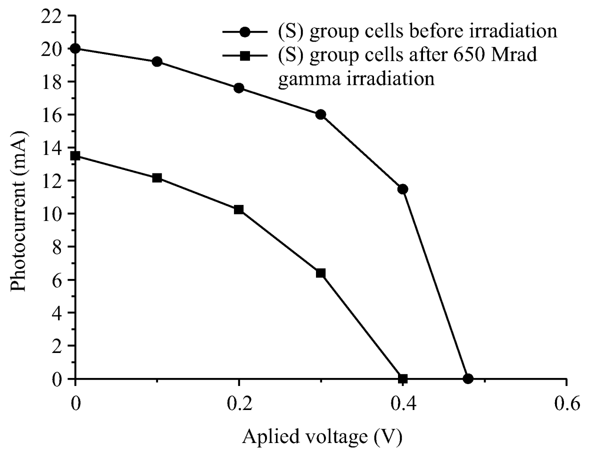

Fig. 6. $I-V$ characteristics for group S (3 μm) before and after gamma irradiation.

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

5. Conclusion

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

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