Fabrication and characterization of ZnSe/ZnTe/CdTe/HgTe multijunction solar cell

P. SAIKIA[*], P. K. SAIKIA, D. SAIKIA[a]
Thin film laboratory, Department of Physics, Dibrugarh University, Dibrugarh-786004, India
[a]*Material Science Laboratory, Department of Physics, Sibsagar College, Joysagar-785665, India*

A multijunction solar cell with the structure ZnSe/ZnTe/CdTe has been fabricated on tin oxide coated glass substrate by vacuum evaporation method. The multijunction ZnSe/ZnTe/CdTe solar cell showed remarkably higher conversion efficiency over the single layer ZnSe/CdTe solar cell. The conversion efficiency of the multijunction ZnSe/ZnTe/CdTe solar cell was found to depend on the thickness of the CdTe layer. Optical band gaps of each of the layers in the multijunction solar cell were calculated from the UV-Vis absorption spectra. The photovoltaic parameters of the cells were measured and the cell showed its best performance with the following set of photovoltaic parameters: I_{sc} = 1.52 mA, V_{oc} = 765 mV, conversion efficiency ≈ 10% and fill factor = 65.05%.

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1. Introduction

Solar electricity or photovoltaic is one of the promising renewable sources of energy which convert solar energy into electrical energy [1]. Photovoltaic can generate electricity for a wide range of applications. It is a cost-effective way to provide power to remote areas and for space applications [2, 3]. With a traditional single layer solar cell, much of the energy of incident light is not converted into electricity. When the incident photon of energy $h\nu$ is greater than the band gap (E_g) of the active layer, then the excess energy is lost in the form of heat within the junction. Since the solar spectrum contains photons over a wide range of energies from 0 to 4 eV, the efficiency of any single-junction solar cell is inherently limited. Multijunction solar cells can make better use of the solar spectrum by having multiple semiconductor active layers with different band gaps.

The multijunction concept requires a way of sending the different regions of the incident solar spectrum to the corresponding junctions. The conventional and probably the most elegant way of accomplishing this "photon sorting" is to stack the junctions with the highest band gap material on top, the next highest band gap material underneath, and so on [4]. Present-day multijunction solar cells shows capabilities of generating approximately twice as much power under same conditions as made by traditional single junction solar cells [5]. With 86.8%, multi-junction solar cells have the highest theoretical limit of conversion efficiency as compared to other photovoltaic technologies [6]. A present-day record efficiency of 41.1% was achieved with a multi-junction solar cell using III-V semiconductors [7, 8]. As per our knowledge only few works has been done on II-VI tandem structured solar cell [9, 10]. P. Gashin et al. [9] studied the properties of ZnSe/ZnTe/CdSe tandem solar cell and reported 10.8% conversion efficiency of the cell.

In the present work, multijunction solar cells with the structure ZnSe/ZnTe/CdTe have been fabricated and its photovoltaic parameters were measured. A comparative study was made between the ZnSe/CdTe single junction and ZnSe/ZnTe/CdTe multijunction solar cells. The effects of thickness of the CdTe layer on the efficiency of the ZnSe/ZnTe/CdTe multijunction solar cell were also reported.

2. Experimental details

All reagents were of analytical grade, obtained from Merk (India) Ltd. and used as received without further purification. The schematic diagram of solar cell is shown in Fig. 1. All the layers in the cell were deposited by vacuum evaporation method except the transparent conducting oxide (TCO) layer which is tin oxide (SnO_2) in our case.

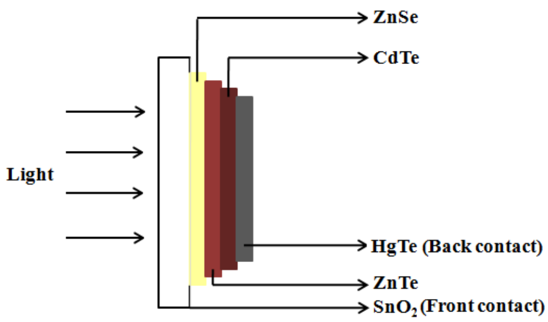

Fig. 1. The schematic diagram of multijunction solar cell.

Tin oxide (SnO_2) films were used as a front electrode in the present cell structure. SnO_2 thin films were deposited on glass substrates by chemical vapour deposition method at an atmospheric pressure. ZnSe, ZnTe and CdTe layers were deposited on the top of the SnO_2 layer sequentially one above the other by vacuum evaporation method. During deposition the vacuum inside the chamber was maintained at ~ 10^{-6} torr. After deposition, each of the layers in the cell was annealed at 200°C for better crystallisation. HgTe layers were used as back contact, which is a semi-metallic compound [11, 12]. Prior to the deposition of back contact, CdTe layer was treated with $CdCl_2$ and then annealed at 200°C for 45 minutes.

The optical properties of the films were studied using SINCO-3100 spectrophotometer. The thickness of the films was determined using multiple beam interference method. The current-voltage (I-V) characteristic of the thin film solar cells (both single junction and multi junction) were measured with a high impedance (~10^{14}) ECIL electrometer amplifier (model EA812) and shown in Fig. 4, 5. The intensity of illumination was measured with a Lutron LX-101 lux meter. The observed photovoltaic parameters of the cell are tabulated in Table 1 under 0.8 AMI illuminations.

3. Results and discussion

3.1 Optical properties

The optical properties of the active layers of the multijunction solar cell were studied by transmission, absorption and reflection spectra. The optical band gap of the layers were calculated using absorption and transmission data and following the relation [13] for

$$\alpha h\nu = A\left(h\nu - E_g\right)^{\frac{1}{2}} \quad (1)$$

semiconductors where '$h\nu$' is the incident photon energy, 'E_g' represents band gap and 'A' is a constant and α is the absorption coefficient. Figs. 2, 3 and 4 show the plot of $(\alpha h\nu)^2$ versus $h\nu$ for the ZnSe, ZnTe and CdTe films respectively. The value of the optical band gap Eg was calculated by extrapolating the linear portion of the respective curve to $(\alpha h\nu)^2 = 0$. The band gaps of the ZnSe and ZnTe films were found to be 2.75 eV and 2.16 eV respectively. For the CdTe thin films, band gaps were in the range 1.48-1.49 eV where thickness was varied from 760 nm to 840 nm. The band gaps of the CdTe layers were found to decrease with the increase of film thickness. This can be attributed due to the increase of tellurium content in the film and also the lattice constant increases with the increase of thickness and comes closer to the bulk value [14].

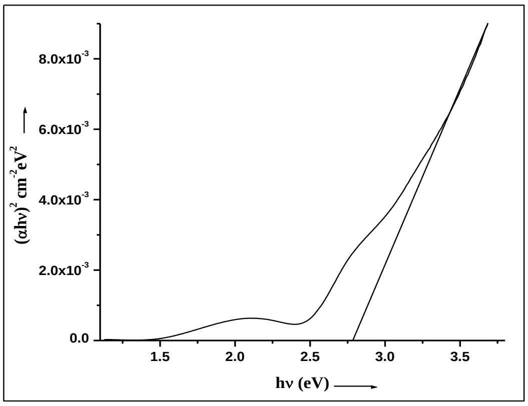

Fig. 2. $(\alpha h\nu)^2$ vs hν plots for ZnSe thin films.

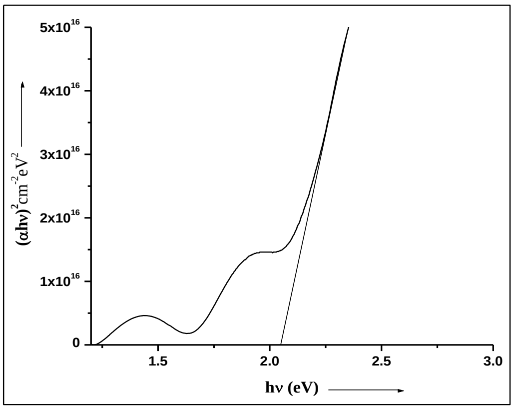

Fig. 3. $(\alpha h\nu)^2$ vs hν plots for ZnTe thin films.

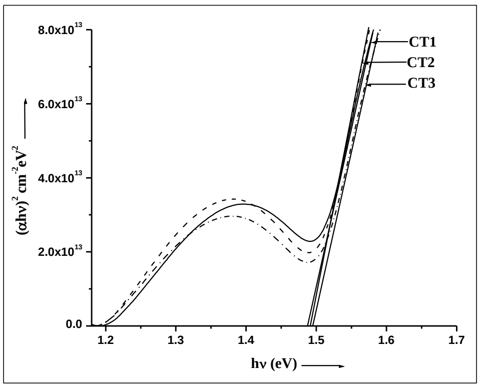

Fig. 4. $(\alpha h\nu)^2$ vs hν plots for CdTe thin films.

3.2 Photovoltaic properties of the cells:

The photovoltaic properties of the ZnSe/ZnTe/CdTe multijunction and ZnSe/CdTe single junction solar cells were investigated by illumination through the wide band gap ZnSe layer at 300 K. We had also studied the effect of thickness of active layer CdTe on the photovoltaic properties of the cell.

The output current of photovoltaic cell is given by the relation [15],

$$I = I_s \left\{ \exp\left[\frac{q\left(V - IR_s\right)}{kT} \right] - 1 \right\} - I_L \qquad (2)$$

where I_s and R_s are the diode saturation current and series resistance of the cell respectively. The fill factor which measures the quality of solar cell is given by

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}} \qquad (3)$$

where I_m and V_m are the current and voltage corresponding to maximum power point P_{max} and I_{sc} and V_{oc} are the short-circuit current and open-circuit voltage respectively. The important parameter conversion efficiency of the solar cell, which is defined as the ratio of the output power (electricity) to the input power (light) can be calculated also as:

$$\eta = \frac{P_{output}}{P_{input}} = FF.\frac{V_{oc} I_{sc}}{P_{input}} \qquad (4)$$

The current-voltage characteristics of the single junction (ZnSe/ZnTe) and multijunction (ZnSe/ZnTe/CdTe) solar cells are shown in Fig. 5(a) and Fig. 5 (b). The photovoltaic parameters of the cells were calculated from their respective I-V characteristic curve and are tabulated in Table 1.

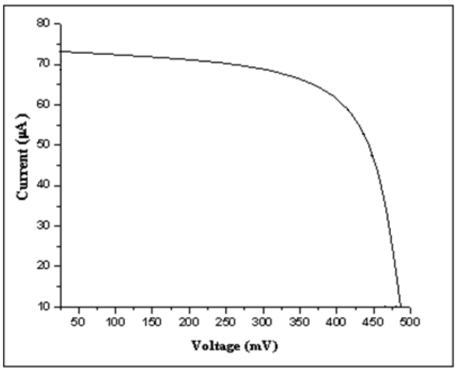

Fig. 5(a). I-V characteristics of ZnSe/CdTe single junction photovoltaic cell.

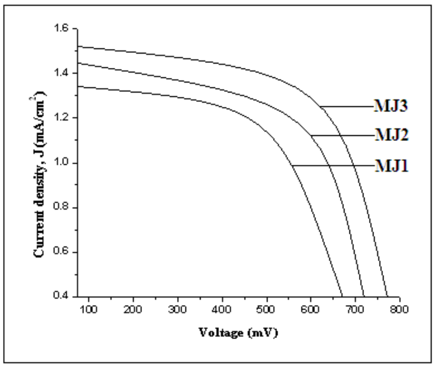

Fig. 5(b). I-V characteristics of ZnSe/ZnTe/CdTe multijunction photovoltaic cells.

Table 1. Photovoltaic cells parameters.

Cell No.	Thickness of ZnSe layer (nm)	Thickness of ZnTe layer (nm)	Thickness of CdTe layer (nm)	Short-circuit current	Open-circuit voltage (mV)	Efficiency of the cell, η (%)	Fill-factor of the cell (%)
SJ	165	-	840	74 μA	485	3.01	55.4
MJ1	165	350	840	1.52 mA	765	9.86	65.05
MJ2	165	350	825	1.45 mA	725	9.64	64.54
MJ3	165	350	760	1.33 mA	670	8.89	62.36

From the table, it has been seen that, the short-circuit current of the multijunction solar cell is increased to the order of mA in comparison to the single junction solar cell which is in the order of μA. As such the conversion efficiency of the multijunction solar cell was found to increase by three times as compared to the single junction solar cell. It is clearly an evidence of the better use solar energy spectrum by the multijunction solar cell in comparison to the single junction solar cell. From the table it is also observed that, the photovoltaic parameters of the multijunction solar cell has improved with the increase in thickness of the CdTe layer and this might be due to the improvement in the grain size of the CdTe layer. The efficiency of the multijunction solar cells were found to increase from 8.89% to 9.86% as the thickness of the CdTe layer was increased from 760 nm to 840 nm.

4. Conclusion

We have fabricated ZnSe/ZnTe/CdTe multijunction and ZnSe/CdTe single junction solar cells by an all vacuum evaporation method using HgTe as back contact and SnO_2 as front contact. The photovoltaic parameters of the multijunction solar cell were compared with single junction solar cell. It was found that multijunction cell exhibits better use solar energy spectrum in comparison to the single junction solar cell. The increase in thickness of the CdTe layer has resulted in an increase in efficiency of the cell and the highest efficiency of 9.86% was observed for the thickness of 840 nm.

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*Corresponding author: psaikia123@gmail.com