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# Parametric Analysis of CdTe/CdS Thin Film Solar Cell

**Erteza Tawsif Efaz[1], Atiya Anjum Ava[1], MD. Tanzidul Alam Khan[1], MD. Mohaiminul Islam[1], Afrin Sultana[1]**

Dept of EEE Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh

**Abstract:** This paper mainly represents Cadmium Telluride (CdTe) and Cadmium Sulfide (CdS) thin film solar cell's parametric analysis of fill factor and efficiency with the variation of electron and hole mobility. From this analysis, results showed that the variation of electron and hole mobility gives an effective improvement in fill factor and efficiency, though variation of hole mobility gives higher fill factor and efficiency than variation of electron mobility. On the other hand, varying the thickness of CdS layer also gives a slight improvement on efficiency of CdTe solar cell. But the rate of change of efficiency is quite low.

**Keywords:** Heterojunction device, Cadmium Telluride, Thickness, Efficiency, Fill factor

## I. INTRODUCTION

Scarcity of fossil fuel and global warming issue lead us to investigate renewable and green energy sources. As a result, photovoltaic conversion of sunlight into electricity became the most reliable one to mitigate the huge future energy demand.Thin Film solar cell is the second generation solar cell that is made by depositing one or more thin layers of photovoltaic material on a substrate. It is actually much thinner than thin-film's main rival technology, conventional first generation Crystalline Silicon (c-Si) solar cell. This allows thin film solar cells to be flexible, lower in weight and have less friction. It is also known as Thin Film Photovoltaic (TFPV) cell. CdTe photovoltaic technology is the most suitable one, based on thin film CdTe to absorb and convert sunlight to electricity.

There was a theoretical and experimental research to improve the performance of these devices. Hegedus et al. reviewed a few theoretical models to describe the current-voltage (J-V) characteristics in CdTe/CdS solar cells [1]. They have shown the most successful model calculating the photocurrent by considering carrier drift and utilizing Hecht collection efficiency formula in the nearly intrinsic CdTe layer.

In this paper,effects on variation offill factor and efficiencyof CdTe/CdS thin film solar cell has been emphasized. With different values and comparisons, the effects have been showed with respect to electron and hole mobility on heterojunction device.

## II. BRIEF DESCRIPTION

Air Mass is one of the main considerable properties for designing photovoltaic devices. The degree to which atmosphere affect the sun light received at the earth surface is define by the Air Mass. AM1.5 is almost universal when characterizing terrestrial power generating panels. The uncertainty in using AM1.5 spectra to predict field performance depends on the particular PV device design and climate.

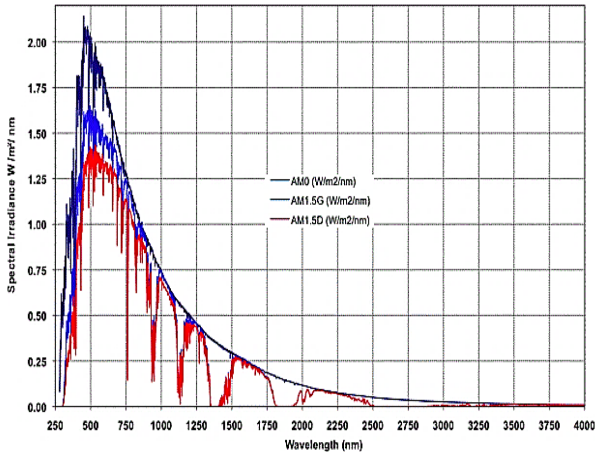


Figure 1: Solar spectrum as function of photon energy AM1.5 [2]

AM1.5 condition represents a satisfactory energy weighted average for terrestrial applications. So PV device design should be based on a range of spectra representing various atmospheric conditions and AM.

The CdTe solar cell is produced on a substrate of ordinary window glass, around 2-4mm thick, this protects active layers from environment and provides mechanical strength.Transparent conducting oxide is usually of tin oxide or Indium Tin Oxide (ITO) which acts as the front contact to the device. The polycrystalline CdS layer is n type doped and therefore provides one half of the p-n junction. The CdTe layer of the structure is like CdS polycrystalline, but it is p type doped. Because it is less highly doped than the CdS, the depletion region is mostly within the CdTe layer. This is therefore the active region of the solar cell, the thickness of this layer is typically around 10µm.Back contact is made of gold or aluminum, provides low resistance electrical connection to the CdTe.Generally, p type CdTe is a notoriously difficult material on which to produce an Ohmic contact and so the junction will inevitably display some characteristics of Schottky Diode.

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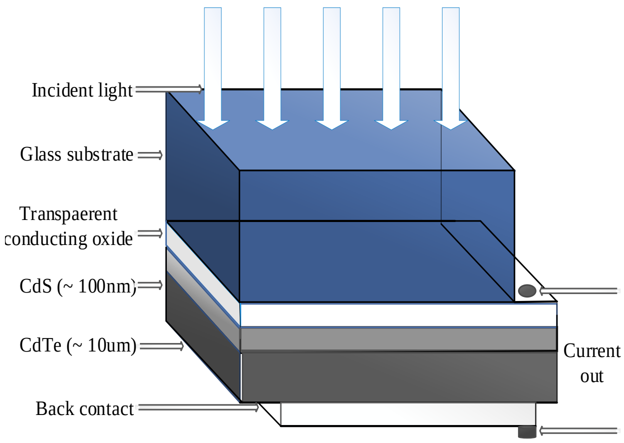


Figure 2: CdS/CdTe solar cell [1]

As the voltage dependent electric field near the top interface of the absorber layer is slightly higher than that near the bottom interface, the photo generated carriers will drift with a slightly higher velocity near the top interface compared to that near the bottom interface.

## III. MATHEMATICAL MODEL

A. Photocurrent

Photocurrent is the electric current that passes through a photosensitive device, such as a photodiode, as the result of exposure to radiant power.The photocurrent may occur as a result of the photoelectric, photo emissive or photovoltaic effect.When a suitable radiation is used, the photoelectric current is directly proportional to the intensity of radiation.

The photocurrent density for carriers drifting towards the bottom contact can be derived as follows [3][4],

$$j_b(\lambda, V) = \frac{Fe\mu_b}{W}\int_0^W C_b(x,\lambda)dx$$

$$= \frac{eGW}{(\tau_b^{-1}-\Delta^{-1})}\{\Delta\left(1-e^{-\frac{1}{\Delta}}\right)-\tau_b\left(1-e^{-\frac{1}{\tau_b}}\right)\} \quad (1)$$

Where, e=elementary charge,
$\Delta=1/\alpha W$=normalized absorption depth,
$\tau_b=F\mu_b\tau'_b/W$=normalized carrier lifetime.
Normalized carrier lifetime is the carrier lifetime per unit transit time for the carriers drifting towards the bottom contact. Since F is voltage dependent, $\tau_b$ also voltage dependent, so does $j_b$.
Similarly, the photocurrent density for the carriers drifting towards top contact is,

$$j_t(\lambda, V) = \frac{eGW}{(\tau_t^{-1}+\Delta^{-1})}\{\Delta\left(1-e^{-\frac{1}{\Delta}}\right)-\tau_t\left(e^{-\frac{1}{\Delta}}-e^{\frac{1}{\Delta\tau_t}}\right)\} \quad (2)$$

Here, $\tau_t=\mu_t\tau'_t F/W$.
Subscript t refers tothe carrier type drifting towards top contact.
The resultant photocurrent densityis [5],

$$j_L(\lambda, V) = j_b(\lambda, V) + j_t(\lambda, V)$$

$$= eGW[(\tau_b^{-1}-\Delta^{-1})^{-1}\left\{\Delta\left(1-e^{-\frac{1}{\Delta}}\right)-\tau_b\left(1-e^{-\frac{1}{\tau_b}}\right)\right\}+ (\tau_t^{-1}+\Delta^{-1})^{-1}\left\{\Delta\left(1-e^{-\frac{1}{\Delta}}\right)-\tau_t\left(e^{-\frac{1}{\Delta}}-e^{-\frac{1}{\Delta}-\frac{1}{\tau_b}}\right)\right\}] \quad (3)$$

The Electron-Hole Pair (EHP) generation rate is,

$$G(\lambda) = \alpha(\lambda)e^{-\alpha_1 d}\frac{\{1-R(\lambda)\}\lambda I_0(\lambda)}{hc} \quad (4)$$

Where, c=speed of light,
h =Plank constant,
$I_0$=intensity of the solar spectra,
R=total reflection and scattering loss factor,
$\alpha_1$=absorption coefficient of top semiconductor layer,
d=thickness of the thin top semiconductor layer.
The thin top semiconductor layer refers to the n layer in CdTe and p layer in a-Si:H solar cells. Other losses include shading from the grid, absorption in the top $SnO_2$ layer and incomplete EHP generation in the absorber layer[6].
The total photo generated current density is obtained by integrating over all incident photon wavelengths of the solar spectrum,

$$J_L(V) = \int_0^\infty j_L(\lambda, V)d\lambda \quad (5)$$

The net current density from a solar cell is,

$$J(V) = J_d(V) - J_L(V) \quad (6)$$

$J_d$ (V)=forward diode current.
The external voltage dependent electric field is given by [6],

$$F(V) = \frac{V_0-V_j}{W} = \frac{V_0-(V-JR_s)}{W} \quad (7)$$

Where, $R_s$=effective series resistancewith contact resistances,
$V_j$=V-$JR_s$=junction voltage,
$V_0$=flat band voltage.

Here, $J_L$(V)=0 at (V-JR)=$V_0$.
The flat band voltage $V_0$(~ 0.1V) is slightly higher than open circuit voltage $V_{OC}$.This is expected that the electric field reduces to zero when the applied junction voltage is equal to the built-in potential $V_{bi}$. However, it is found that electric field collapses to zero just beyond $V_{OC}$ and little less than $V_{bi}$. Therefore, $V_0$ is considered asa fitting parameter.

B. Forward Diode Current

The equation for the forward diode current for applied voltage by derivation can be written as,

$$J_d(V) = J_o e^{\{\frac{e(V-JR_s)}{AkT}\}} \quad (8)$$

Where, $J_o$=reverse saturation current ofp/n junction,
A=diode ideality factor,

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k =Boltzmann constant,
T=absolute temperature.

For the p/n junction as described with small depletion region $J_o$ can be expressed as [7],

$$J_o = \frac{qD_p p_{no}}{L_p} + \frac{qD_n n_{po}}{L_n} \qquad (9)$$

But if the depletion region is thick, recombination current within p-region should be dominant over ideal diffusion current [8]. Therefore, the reverse saturation current can be written as follows [9],

$$J_o = \frac{e n_i W}{\sqrt{\tau'_e \tau'_h}} \qquad (10)$$

$n_i$=intrinsic carrier concentration of absorber layer.

C. Photovoltaic Cell Efficiency
Voltage dependent depletion width is the primary dominating factor in the expression of collection efficiency which can be shown as,

$$W(V) = \sqrt{\frac{2\varepsilon}{qN_A}(V_{bi} - V)} \qquad (11)$$

Where, W(V)=voltage dependent depletion width,
$V_{bi}$=built in potential.

Equation (11) represents the current-voltage relationship for the device, which predicts the output power of the cell known as J-V characteristic.

On a J-V plot, the vertical axis refers to current and the horizontal axis refers to voltage. The fill factor and efficiency can easily be determined from J-V curve.

## IV. RESULT DISCUSSION

The J-V characteristics curve, which is a useful parameter for evaluating the overall performance of various thin film solar cells has been analyzed with varying carrier transport properties and operating conditions. For the parametric analysis of fill factor and efficiency with varying the thickness of CdS layer, following data's have been found with corresponding figures which have been explained briefly. The analysis has been done for both electron and hole mobility.

Table I: Fillfactor vsCdS layer width at constant $\mu_e\tau_e$,

| Width (cm) | Fillfactor ($\mu_h\tau_h$=1.0×10$^{-6}$ cm$^2$/v) | Fillfactor ($\mu_h\tau_h$=5.0×10$^{-7}$ cm$^2$/v) | Fill factor ($\mu_h\tau_h$= 5.0× 10$^{-6}$ cm$^2$/v) |
|---|---|---|---|
| $1\times10^{-4}$ | 0.69 | 0.67 | 0.71 |
| $2\times10^{-4}$ | 0.63 | 0.58 | 0.69 |
| $3\times10^{-4}$ | 0.57 | 0.53 | 0.65 |
| $4\times10^{-4}$ | 0.52 | 0.48 | 0.62 |
| $5\times10^{-4}$ | 0.49 | 0.43 | 0.60 |

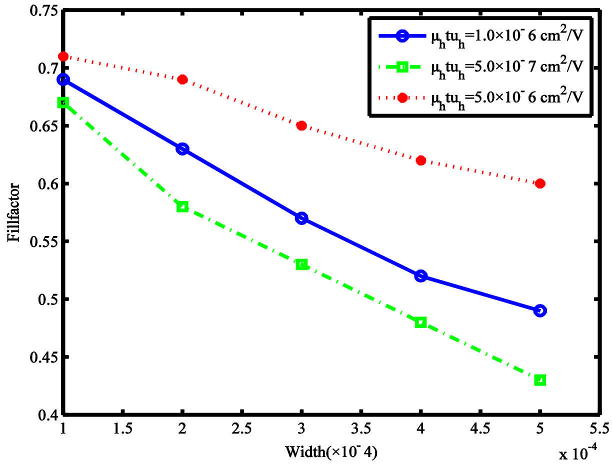


Figure 3: Fillfactor versus CdS layerwidth at constant $\mu_e\tau_e$

Table I with Figure 3 shows, with decreasing values of CdS layer thickness corresponding values of fill factorsare increasing for different values of hole mobility, when electron mobility is constant.

Table II: Fillfactor vsCdS layer width at constant$\mu_h\tau_h$,

| Width (cm) | Fillfactor ($\mu_e\tau_e$=1.8× 10$^{-5}$ cm$^2$/v) | Fillfactor ($\mu_e\tau_e$=3.6× 10$^{-7}$ cm$^2$/v) | Fillfactor ($\mu_e\tau_e$=3.6× 10$^{-6}$ cm$^2$/v) |
|---|---|---|---|
| $1\times10^{-4}$ | 0.65 | 0.64 | 0.65 |
| $2\times10^{-4}$ | 0.63 | 0.61 | 0.63 |
| $3\times10^{-4}$ | 0.57 | 0.57 | 0.59 |
| $4\times10^{-4}$ | 0.53 | 0.54 | 0.54 |
| $5\times10^{-4}$ | 0.50 | 0.49 | 0.49 |

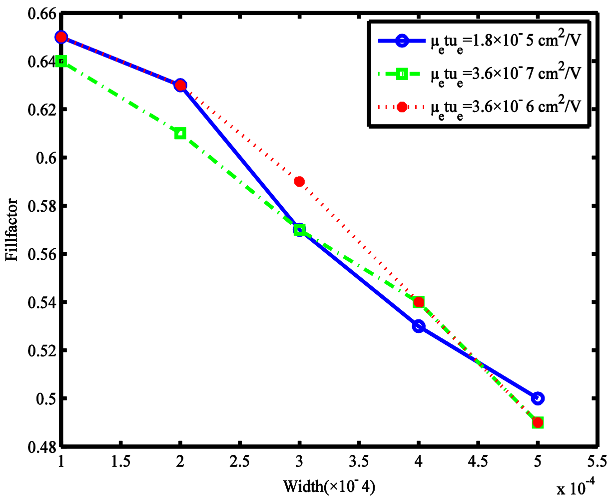


Figure 4: Fill factor versus CdS layer widthat constant $\mu_h\tau_h$

Table II with Figure 4 shows, with decreasing values of CdS layer thickness corresponding values of fill factorsare increasing for different values of electron mobility, when hole mobility is constant.

From both Figures 3 and 4, it can be seen that, the fill factor is higher in case of variation of hole mobility rather than the variation of electron mobility.

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Table III: EfficiencyvsCdS layer widthat constant $\mu_e\tau_e$,

| Width (cm) | Efficiency ($\mu_h\tau_h$=1.0× $10^{-6}$ cm$^2$/v) | Efficiency ($\mu_h\tau_h$=5.0× $10^{-7}$ cm$^2$/v) | Efficiency ($\mu_h\tau_h$=5.0× $10^{-6}$ cm$^2$/v) |
|---|---|---|---|
| $1\times10^{-4}$ | 9.72 | 9.10 | 10.16 |
| $2\times10^{-4}$ | 9.10 | 8.13 | 9.87 |
| $3\times10^{-4}$ | 8.21 | 6.98 | 9.73 |
| $4\times10^{-4}$ | 7.20 | 5.70 | 9.45 |
| $5\times10^{-4}$ | 6.19 | 4.66 | 8.96 |

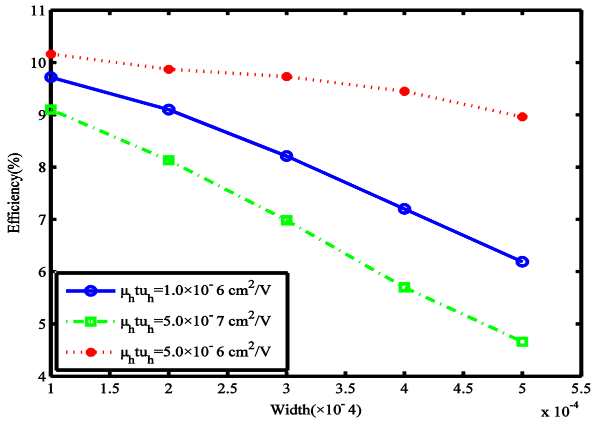


Figure 5: Efficiency versus CdS layerwidthat constant $\mu_e\tau_e$

Table III with Figure 5shows, with decreasing values of CdS layer thickness corresponding values of efficiency are increasing for different values of hole mobility,when electron mobility is constant.

Table IV: Efficiency vs CdS layer width at constant $\mu_h\tau_h$,

| Width (cm) | Efficiency ($\mu_e\tau_e$=1.8×$10^{-5}$ cm$^2$/v) | Efficiency ($\mu_e\tau_e$=3.6×$10^{-7}$ cm$^2$/v) | Efficiency ($\mu_e\tau_e$=3.6×$10^{-6}$ cm$^2$/v) |
|---|---|---|---|
| $1\times10^{-4}$ | 9.10 | 8.79 | 9.10 |
| $2\times10^{-4}$ | 9.09 | 8.31 | 8.93 |
| $3\times10^{-4}$ | 8.05 | 7.59 | 8.05 |
| $4\times10^{-4}$ | 7.18 | 6.76 | 7.07 |
| $5\times10^{-4}$ | 6.19 | 5.69 | 6.06 |

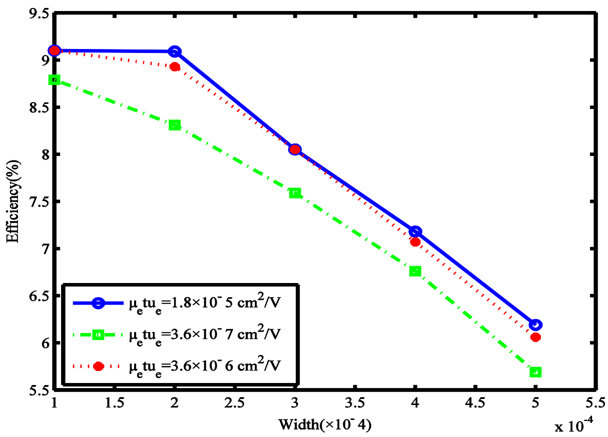


Figure 6: Efficiency versus CdS layerwidthat constant $\mu_h\tau_h$

Table IV with Figure 6 shows, with decreasing values of CdS layer thickness corresponding values of efficiency are increasing for different values of electron mobility, when hole mobility is constant. From both Figures 5 and 6, it can be seen that, the efficiency is higher in case of variation of hole mobility rather than the variation of electron mobility.

## V. CONCLUSION

The current-voltage characteristic curve is a useful parameter for evaluating the overall performance of a solar cell from which efficiency, fill factor and mobility can be determined. Variation of different parameters on the efficiency of CdTe thin film solar cell is emphasized in this paper. Results showed that the variation of electron andhole mobility gives a slight improvement in fill factor and efficiency, which is not a significant one but still effective. Though variation of hole mobility gives higher fill factor and efficiency than variation of electron.

The solar cell efficiency depends critically on the transport properties of the carriers that drift towards the back contact. The photon absorption capability over a wide spectrum and good carrier transport properties of the absorber layer is equally important for achieving higher efficiency.

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