High Efficiency CdTe/CdS Thin Film Solar Cell

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Abstract— **Cadmium telluride is a promising photovoltaic material for thin-film solar cells. A study has been made to improve the efficiency of CdTe/CdS solar cell. To obtain the highest efficiency, the thickness of CdTe and CdS has been modified separately to check the improvement of cell efficiency in PC1D simulator and efficiency beyond 20% has been achieved.**

Keywords—CdTe/ CdS, Solar cell, thin film

I. INTRODUCTION

Polycrystalline thin film CdTe continues to be a leading material for the development of cost effective and reliable photovoltaics. The two key properties of this material are its band gap (1.5 eV), close to the ideal for photovoltaic conversion efficiency (1.45 eV), and its high optical absorption coefficient. On the other hand, CdS has a bandgap energy of 2.42 eV, and transmits most of the visible spectrum [1]. Thin film CdTe solar cells are typically hetero-junctions with CdS being the n-type partner, or window layer. The absorber layer thickness for thin film CdTe solar cells is normally between 2 and 10 μm [2]. Efficiencies as high as 16.5% have been achieved [6], but still there is some potential for increasing them.

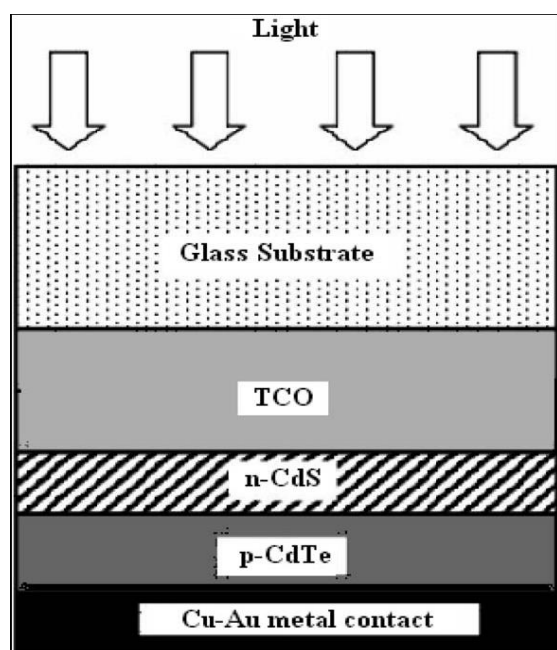The schematics of CdS/CdTe Solar cell is shown in Fig 1.

Fig 1. Schematics of a typical superstrate CdS/CdTe solar cell structure

The typical superstrate structure of a CdTe/CdS solar cell is composed of four layers as follows:
1. A transparent and conducting oxide (TCO) which acts as a front contact
2. A CdS film which is also called window layer
3. A CdTe film which is the absorber layer
4. The back contact on top of the CdTe layer.

CdTe is an ideal absorber material for high-efficiency low cost thin film polycrystalline solar cells. CdTe is a direct bandgap material with an energy gap of 1.5 eV, and an absorption co-efficient around 104 cm^{-1} in the visible region, which means that a layer thickness of a few micrometers is sufficient to absorb 90% of the incident photons.

II. ABOUT SIMULATOR PC1D

PC1D is a computer program written for IBM-compatible personal computers which solves the fully coupled nonlinear equations for the quasi-one-dimensional transport of electrons and holes in crystalline semiconductor devices, with emphasis on photovoltaic devices. The program was initially written at Sandia National Labs by Dr. Paul Basore and coworkers and was further developed by Dr. Don Clugston at the University of New South Wales, Australia.

III. INVESTIGATION OF THICKNESS OF THE CDTE CELL

Thickness of CdTe and CdS has been changed separately to check the improvement of cell efficiency in PC1D simulator.

A. Variation of CdS thickness:

At first let us check the impact of CdS thickness variation. Impact of window layer thickness to the performance of the cell has been studied and the performance measurements are given in TABLE 1:

TABLE 1: Performance values for different CdS thickness values

CdS(μm)	Voc(V)	Isc(mA)	FF(%)	η(%)
0.025	0.75	28.6	85.043	21.52
0.05	0.75	28.6	84.645	21.50
0.1	0.75	28.7	84.021	21.54
0.2	0.75	28.9	82.86	21.60
0.5	0.74	29.3	80.273	21.68
1	0.73	30	78.657	21.87

Here thickness of CdTe has been chosen as 3μm. Associated Quantum efficiency vs wavelength plot is shown in Fig 2.
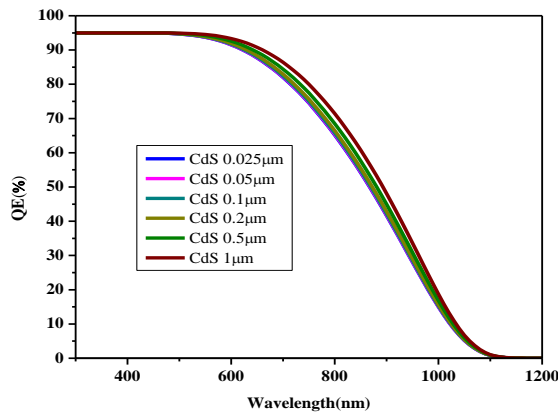

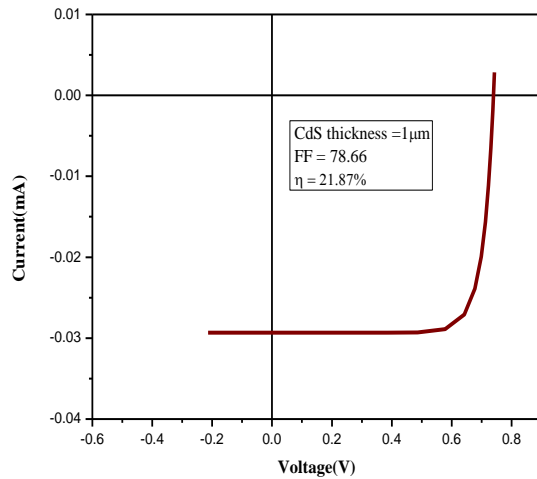Fig 2. QE-Wavelength curve of CdTe/CdS solar cell with different CdS thickness

Fig 3. I-V characteristics of CdTe/CdS solar cell with CdS thickness 1 μm

Now it observed from fig. 3 that there is not much change in fill factor and efficiency. It is observed from the above characteristic curves that efficiency is increasing if CdS thickness is increased. Carriers generated in the CdTe are collected and contribute to the photocurrent, while those in the CdS are lost. Thin CdS, 50 - 100 nm, is therefore preferred to allow above-gap optical transmission. The CdTe need only be 1-3μm thick, but may be thicker to ensure homogeneity.

It will be difficult to substitute CdS as the window layer in this kind of solar cells since this material has shown that it forms an excellent hetero-junction with CdTe. Therefore, we can improve this material only by making it nano-crystalline when oxygen is introduced so that the bandgap becomes larger and a reduction of the absorption losses in the CdS layer is achieved.

B. *Variation of CdTe thickness:*

We need to check the impact of absorber layer thickness to the performance of the cell. As far as cost of the material is concerned we need make the layer thickness small but it may cause the degradation of cell performance.
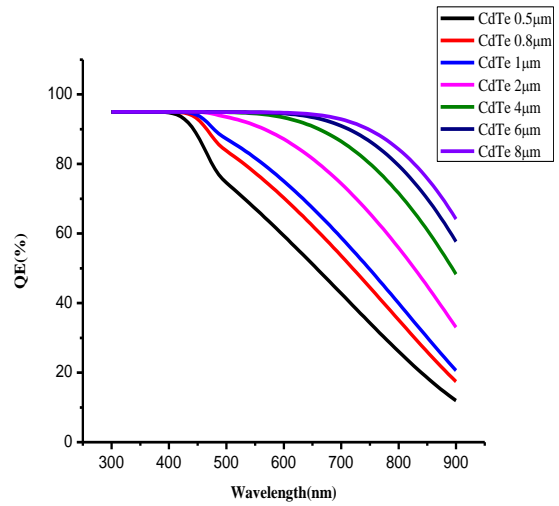

Fig 4. QE vs Wavelength curve of CdTe/CdS solar cell with CdTe thickness 0.5-8 μm

The dependences of the open-circuit voltage, fill factor and efficiency of a CdS/CdTe solar cell on the resistivity of the CdTe absorber layer have been checked with the aim to optimize these parameters and hence to improve the solar cell efficiency. The open-circuit voltage and fill factor are controlled by the magnitude of the forward current. Therefore the I-V characteristic of the device is analyzed which is known to originate primarily by recombination in the space charge region of the CdTe absorber layer.
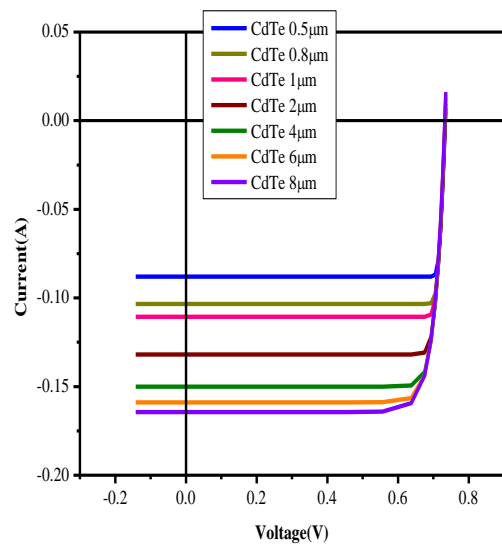

Fig 5. I-V characteristics of CdTe/CdS solar cell with CdTe thickness 0.5 – 8μm

From the I-V characteristic of CdS/CdTe solar cell as shown in Fig 4, it is well evident when the thickness of the CdTe absorber layer is increased it is enhancing the short circuit current and thus efficiency. Keeping the cost in mind we can't go on increasing the thickness of the absorber layer\beyond certain limit.

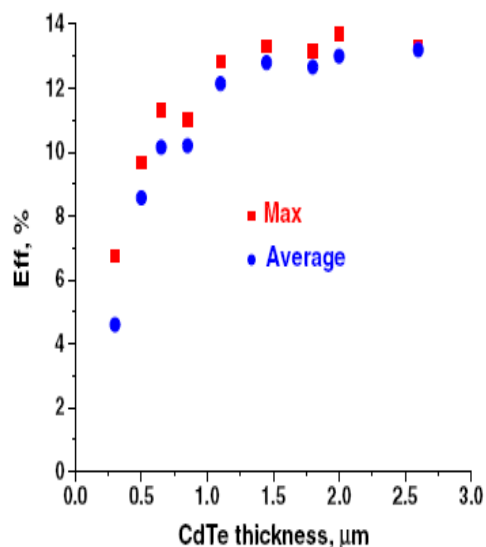The efficiency plot (discrete) for reference [3] has been shown in below Fig 6.

Fig 6. Average and best cell efficiencies as a function of the CdTe thickness [3]

Now TABLE 2 shows that author found better efficiency than the reference one.

TABLE 2: Performance values for different CdTe thickness values

CdTe(μm)	Voc(V)	Isc(A)	FF(%)	η(%)
0.5	0.78	0.09	81.54	11.16
0.8	0.77	0.10	84.24	13.44
1	0.769	0.11	82.70	14.06
2	0.759	0.13	83.60	16.74
4	0.747	0.15	84.39	18.92
6	0.739	0.16	82.43	19.36
8	0.732	0.16	84.45	20.33

Here thickness of CdS has been chosen as 35nm. It is also to be noted that for normal operation absorber layer thickness is kept within 10 μm and within that limit also efficiency found to be satisfactory.

TABLE 3: Typical electrical parameters for CdTe and CdS films

Parameter	CdTe	CdS
Thickness (μm)	1-8	0.025-1
Bandgap (eV)	1.5	2.4
Electron affinity (eV)	3.9	4
Dielectric permittivity (relative)	9.4	10
Electron mobility (cm^2/V-s)	500	350
Hole mobility (cm^2/V-s)	60	50
Electron density (cm^{-3})	-	1.00E+15
Hole density (cm^{-3})	1.00E+17	-
Effective density of states in the conduction band, N_C (cm^{-3})	2.20E+18	8.00E+17
Effective density of states in the valence band, N_V (cm^{-3})	1.80E+19	1.80E+19
Light Intensity (W/cm^2)	0.1	

In TABLE 3, some of the properties of CdTe and CdS thin films are given as used while doing simulation of CdS/CdTe solar cells. The donor concentration will depend strongly on the deposition method, but a desirable value of 10^{17} cm^{-3} is given here. If this value could be increased to 1×10^{18} cm^{-3} by some doping process we could expect better results for the solar cell open circuit voltage. Notice that with these values the electron diffusion length would be around 3–4 μm. However, due to the diverse quality of the CdTe deposited in different laboratories with different deposition techniques we can expect values between 1 and 8 μm. The majority carrier concentration is also very low, about 1×10^{15} cm^{-3}. Increasing this value to 10^{16} cm^{-3} should also cause a higher built-in voltage.

IV. CONCLUSION

The large decrease in device parameters along-with decreasing absorber thickness suggests the cells are limited not only by optical issues but also interface and possibly back contact proximity. By the basic addition of an acceptor defect between the CdS and CdTe, the results may be improved, particularly when ultra thin absorbers would be employed, possibly signifying an increase in the interface defect density with thinner absorbers. Further investigation of the effect of the back contact will need to be carried out to establish any contribution with the p-n junction of ultra thin layers although a long term study of thinner cells should be investigated. For more accurate and device modeling CdTe/CdS needs around 50-100 parameters. Using limited parameter set, the decrease of the absorber thickness does imply an increasing contribution from the interface.

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