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The Effect of Change the Thickness on CdS/CdTe Tandem Multi-Junction Solar Cells Efficiency

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Abstract: Researchers in the field of simulation have been mainly interested in the question of how to increase the efficiency of solar cells. Therefore this study aimed to investigate CdS/CdTe solar cells by applying AMPS-1D software. The impact of semiconductor layers thickness on the output parameters of the CdS/CdTe solar cell is being analyzed and studied carefully, for example, fill factor, efficiency, the density of short-circuit current and open circuit voltage. To acquire the most efficiency estimation, a new tandem multi-junction structure is intended by using two solar cells connected back to back with each other and designed based on the results gained from the single-junction solar cells. Numerical simulations demonstrated that the highest CdS/CdTe efficiency is 31.8% which can be achieved whenever the p-CdS layer thickness is equal to 50 nm, and the n-CdS layer thickness is equal to 200 nm, while the thicknesses of the n-CdTe layer and p-CdTe layer are kept fixed equal to 3000 nm and 1000 nm, respectively.

Key words: tandem solar cell, efficiency, thickness, optimum, simulation.

1. INTRODUCTION

Considering the cadmium telluride CdTe solar cells, it is tentatively accepted that the CdTe film minimal thickness for absorbing 99% of incident photons with energies greater than the band gap E_g, is about 1-2 microns [1,2].The CdTe absorber layer thickness reduction is practical both based on reducing the cost of material in the production process, and in terms of

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improving the efficiency of the solar cell based on the recombination losses reduction by volume [3,4].To diminish the absorption and to minimize the surface recombination current in the CdS/CdTe solar cells, a CdS layer thickness reduction has been consistently conducted to 1000 Å and less [5].The study sought to conduct the numerical simulation of CdS/CdTe hetero-junction and multi-junction tandem solar cells and determine the optimal structure of the CdS/CdTe tandem multi junction solar cells entailing two CdS/CdTesolar cells with back to back connection with each other having the highest conversion efficiency.

Tandem structures are characteristically high-efficient and high-cost cells for the multiple layers presence and their energy-intensive processing nature. Generation process of these cells is very complicated, accordingly, they can be rarely found and they are only used for spaceship sites.This innovation can be viewed as promising, but additional cost drops are essential before they become competitive enough with the incumbent devices.

1.1. Multijunction Tandem CdS/CdTeSolar Cells

Multi-junction solar cells are generated from multiple p-n junctions of diverse semiconductor materials with dissimilar band gaps, so that they are able to absorb most of the solar spectrum energy. The application of such elements serves as another way to augment the efficiency of solar cells using a certain part of the solar radiation spectrum for the manufacture of electric current. Tandem solar cells may be utilized in single or serial connection enjoying a similar current in both cases. The series connection solar cells have simple structures, but owing to the limitations instigated by wide band gaps, the single connection solar cells, viewpoint of efficiency, are more optimal. The most widely recognized strategy for producing tandem solar cells is their growing even when the layers are structured sequentially on the substrate resulting in tunneling contact layers establishment in individual cells. The element efficiency will face an increase owing to the band gaps number increase. The element upper part absorbs photons, having higher energy of the incident light spectrum because of having the largest band gap, so it, while the element lower part absorb low energy photons due to having a small band gap width [6].

1.2.Multi-Junction Tandem Solar Cells Theoretical Approach

The light spectrum radiated toward the upper part of the solar cells contains all wavelengths, including ultraviolet waves, visible waves and infrared waves. As a result of high values of short wavelengths absorption coefficient, most of the blue light in the near-surface layer are absorbed for generating theoptical carriers. For the first layers, the lights with higher energies than that of band gaps will be absorbed and the lights with lower energies pass through the band gap and would be absorbed by other subsequent cells. The generated optical carriersby short wavelength of the light spectrum diffuse in the cells as long as they are collected at the p-n link. When all optical carriers are collected in the junction, rather than recombining in any other parts of the cell, the solar cell efficiency increases.In initial approximation, multi-junction tandem solar cells act like single cell junction in series connection, therefore, their open circuit voltage equals their open circuit voltage and their short circuit current is equal to the lowest basic cells current.

Consequently, the performance of each multi-junction tandem cells can be obtained independently from the function of each cell. The J current density can be generated by the superposition of diode current and photo-generated current. In this equation, J_{ph} is the photocurrent density; J_{01} is the ideal dark saturation current component and J_{02} saturation current component of non-dark space charge non-ideal dark saturation current component requirements. Non-dark and dark density currents are obtained by the sum of optical currents and total generated dark densities in the emitter, the base and the depleted region [7].

$$J_{ph} = J_{emitter} + J_{base} + J_{depleted} \tag{1}$$

$$J_{emitter} = \left[\alpha F(1-R)qL_p / (\alpha^2 L_p^2 - 1)\right] \times \left[\frac{\frac{S_p L_p}{D_p} + \alpha L_p - \exp(-\alpha(d_e - W_n))\left(\frac{S_p L_p}{D_p}\cosh\frac{(d_e - W)}{L_p} + \sinh\frac{(d_e - W)}{L_p}\right)}{\left(\frac{S_p L_p}{D_p}\right)\sinh\left(\frac{(d_e - W)}{L_p}\right) + \cosh\left(\frac{(d_e - W)}{L_p}\right)} - \alpha L_p \exp(-\alpha(d_e - W_n)) \right] \tag{2}$$

$$J_{base} = \left[qF(1-R)\alpha L_n / (\alpha^2 L_n^2 - 1)\exp\left((-\alpha(d_b - W_n + W))\right)\right] \times \left[\alpha L_n - \frac{\frac{S_n L_n}{D_n}\left(\cosh\frac{(d_e - W_n)}{L_n}\right) - \exp(-\alpha(d_b - W_p)) + \sinh\frac{(d_b - W_p)}{L_n} + \alpha L_n \exp(-\alpha(d_b - W_p))}{\left(\frac{S_n L_n}{D_n}\right)\sinh\left[\frac{(d_b - W_p)}{L_n}\right] + \cosh\left[\frac{(d_b - W_p)}{L_n}\right]} \right] \tag{3}$$

$$J_{depleted} = qF(1-R)\exp(-\alpha(d_e - W_n))\left(1 - \exp(-\alpha W)\right) \tag{4}$$

$$J_{01} = J_{01,emitter} + J_{01,base} \tag{5}$$

$$J_{01,emitter} = q\frac{n_i^2}{N_D}\frac{D_p}{L_p}\left[\frac{\left(\frac{S_pL_p}{D_p}\cosh\frac{(d_e - W_n)}{L_p} + \sinh\frac{(d_e - W_n)}{L_p}\right)}{\frac{S_pL_p}{D_p}\sinh\left(\frac{(d_e - W_n)}{L_p}\right) + \cosh\left(\frac{(d_e - W_n)}{L_p}\right)}\right] \tag{6}$$

$$J_{01,base} = q\frac{n_i^2}{N_A}\frac{D_n}{L_n}\left[\frac{\left(\frac{S_nL_n}{D_n}\cosh\frac{(d_b - W_p)}{L_n} + \sinh\frac{(d_b - W_p)}{L_n}\right)}{\frac{S_nL_n}{D_n}\sinh\left(\frac{(d_b - W_p)}{L_n}\right) + \cosh\left(\frac{(d_b - W_p)}{L_n}\right)}\right] \tag{7}$$

$$J_{02} = \frac{Wn_i}{2(V_d - V)\tau} \tag{8}$$

In the equation, Q is the electrical charge, F is the photons incident flux, α is the light absorption coefficient and R is the reflection from the non-reflection surface. N_i is the concentration of intrinsic carriers; N_A and N_D are the concentration of acceptor and the donor carriers. d_e is the thickness of the emitter, $d_b$is the base thickness, L_p is the hole diffusion length in emitter, L_n is the electron diffusion length in the base, $S_p$is the rate of recombination of holes in the emitter, S_n is the electrons speed recombination in the base, $D_p$is the hole penetration in the emitter, $D_n$is the electron penetration coefficient in the baseand the τ is the non-radiative carriers lifetime [8].

1.3. AMPS-1D Program

Among the sophisticated semiconductor device simulation, the AMPS-1D (Analysis of microelectronic and photonic structure-one dimension) is being utilized to analyze transport in a wide variety of device structures including crystalline, polycrystalline, or amorphous layers combinations. The one-dimensional device simulation program (AMPS-1D) developed by S. Fonash et.al at Pennsylvania State University [9].

AMPS is a very general computer program being developed for simulating one-dimensional transport physics in solid state devices. It uses the first-principles continuity and Poisson’s equations approach to analyze the transport behavior of semiconductor electronic and optoelectronic device structures.

2. EXPERIMENTAL DETAILS

2.1. CdTeSolar Cell

As discussed previously, to increase the efficiency and determine the most optimal element, single-junction solar cells connected back to back will be used.These elements parameters are known to us and the optimal performance elements had previously been simulated. Figure ۱ shows the proposed order of the layers in this solar cell. This element is constructed of two layers of CdS, one of which is p-type, and the other is n-type, and two layers of CdTe, which are also of p- and n-type. The outer layer of this element is a layer of ITO with 200nm thickness to provide greater absorption of light spectrum, and the lower layer is a copper layer with the thickness of 500 nm to reflect light spectrum.
We need a new design of cells with a high performance and low cost. In order to increase the efficiency and to determine the most optimal cell, we have two single cells that are connected back to back. This device is composed of the top cell p, n (CdS) with Eg=2.40 eV and bottom cell p, n (CdTe) with E_g=1.50 eV. Firstly, the thickness of p-CdS layer is changed so the optimum thickness is obtained. In the next step, the thickness of p-CdS is fixed and the thickness of n-CdS is changed. The result of this attempt led to the optimum thickness of layer by highest efficiency. Befor the last phase the maximum efficiency of CdS/CdTe multi Junction tandem solar cell is also achieved for standard radiation 1.5AM. This result is approximately twice the efficiency of CdS/CdTe single –Junction solar cells in the same conditions.

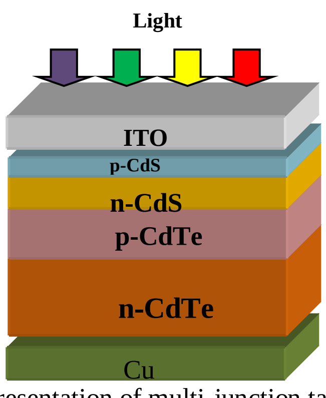


Fig.1. Schematic representation of multi-junction tandem CdS/CdTe solar cells

2.2. Materials

The numerical simulations was conducted and the most effective solar cells is determined by applying AMPS-1D software, all parameters of simulation associated with each layer are listed in Table I.

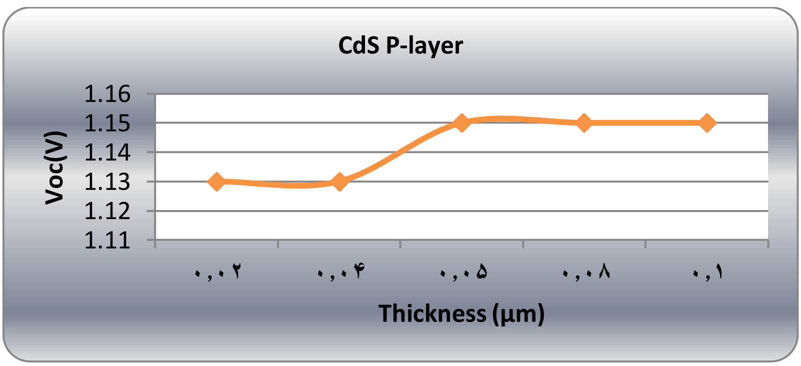
TABLE I
The parameters of the materials used in the simulation of the tandem multi-junctionCdS / CdTe solar cell

Material	Band Gap (eV)	Conductivity Type	Conduction Band	Valence Band	Electron Affinity (eV)	Electron Mobility (cm^2/v/s)	Hole Mobility (cm^2/v/s)	Free Carrier Concentration (cm^{-3})	Relative Permittivity
ITO	3.60	n	2.0×10^{20}	1.8×10^{19}	4.10	50.0	70.0	1.0×10^{20}	2.0
CdS	2.40	p	2.2×10^{18}	1.8×10^{19}	4.0	25.0	100.0	1.0×10^{18}	10.0
CdS	2.40	n	2.2×10^{18}	1.8×10^{19}	4.0	25.0	100.0	1.1×10^{18}	10.0
CdTe	1.50	p	8.0×10^{17}	1.8×10^{19}	3.90	40.0	320.0	2.0×10^{14}	9.4
CdTe	1.50	n	8.0×10^{17}	1.8×10^{19}	3.90	40.0	320.0	2.0×10^{16}	9.4

2.3. Results Of Simulation And Discussion

After the numerical simulation and obtaining the current-voltage characteristics of the solar cell, the following results

A) For the first phase, to acquirehigher effective thickness of the top layer of the CdS/CdTe solar cell, the thickness of CdS p-layer was varied from 20 nm to 100 nm. Considering the fact that this layer is placed under the absorbent layer on the top surface, it has a minimum thickness as compared with other layers. Thus, the optimal thickness of 50 nm is achieved for the layer making sure that the highest efficiency was attained.



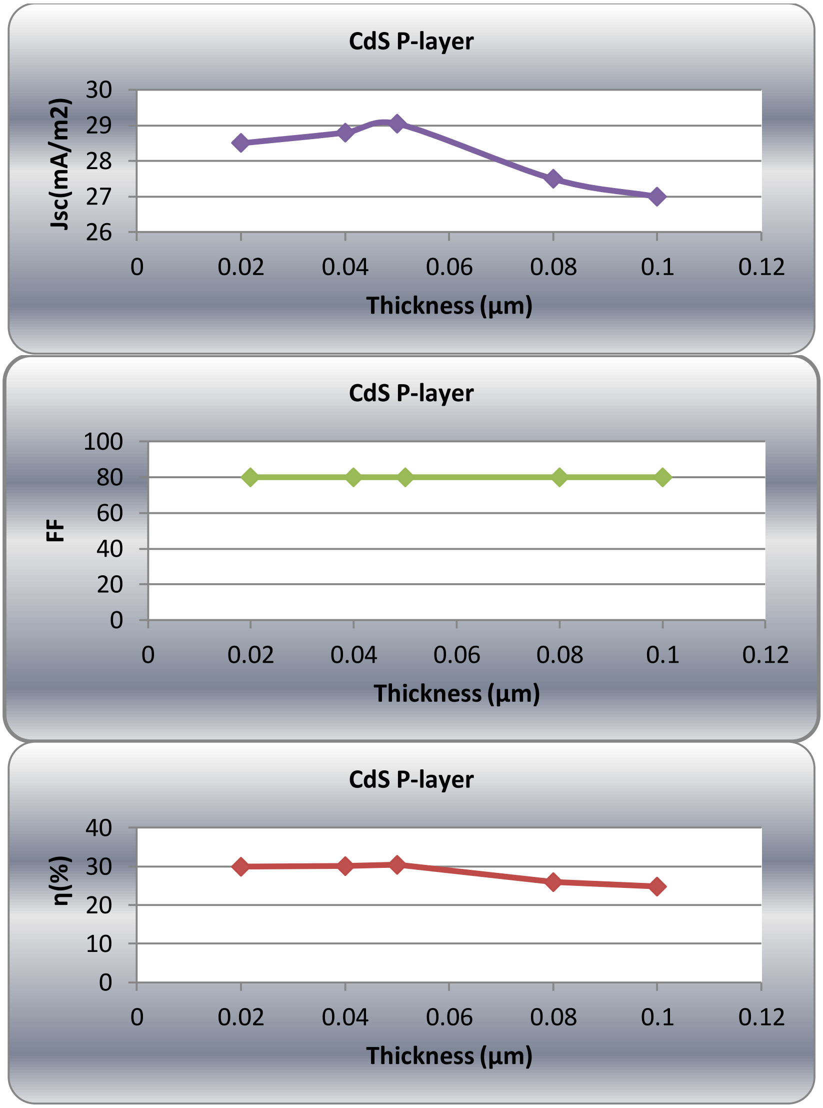
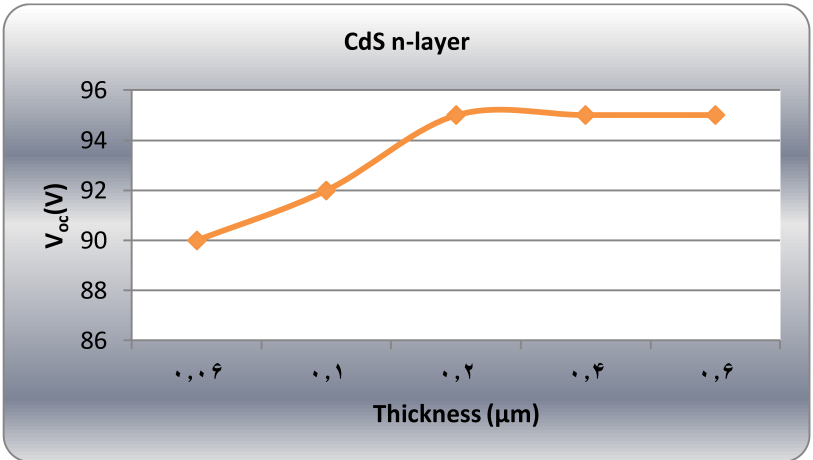
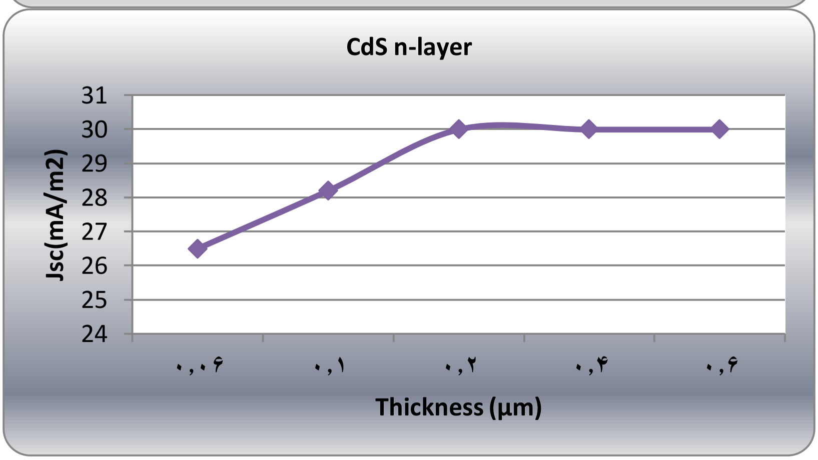


Fig. 2. The dependence of the output parameters (short-circuit current density Js, the open circuit voltage Voc, the fill factor FF and efficiency EFF) of multi-junction tandem CdS/CdTe solar cells on the thickness of CdS p-layer.

B) For the second phase, the thickness of CdS p-layer was kept constant at 50 nm and the thickness of CdS n-layer was changed from 60 nm to 600 nm. Because this layer is located on the CdTe p-layer and the CdS p-layer, it should have a thickness less than the thickness of the lower layer, and greater than that of top layer. The study of the outcomes demonstrates that the optimal thickness

is 200 nm as shown in Figure 3.
At both stages of modeling, the thickness of the CdTe n-layer was fixed and was equal to 3000 nm, and the thickness of the CdTe p-layer remained constant at 1000 nm. The results showed that the optimal efficiency of the tandem multi-junction CdS/CdTe solar cell with the above layer thicknesses was equal to 31.8%, i.e. efficiency of about two times greater than the same single-junction solar cell, under the standard light spectrum of AM 1.5.





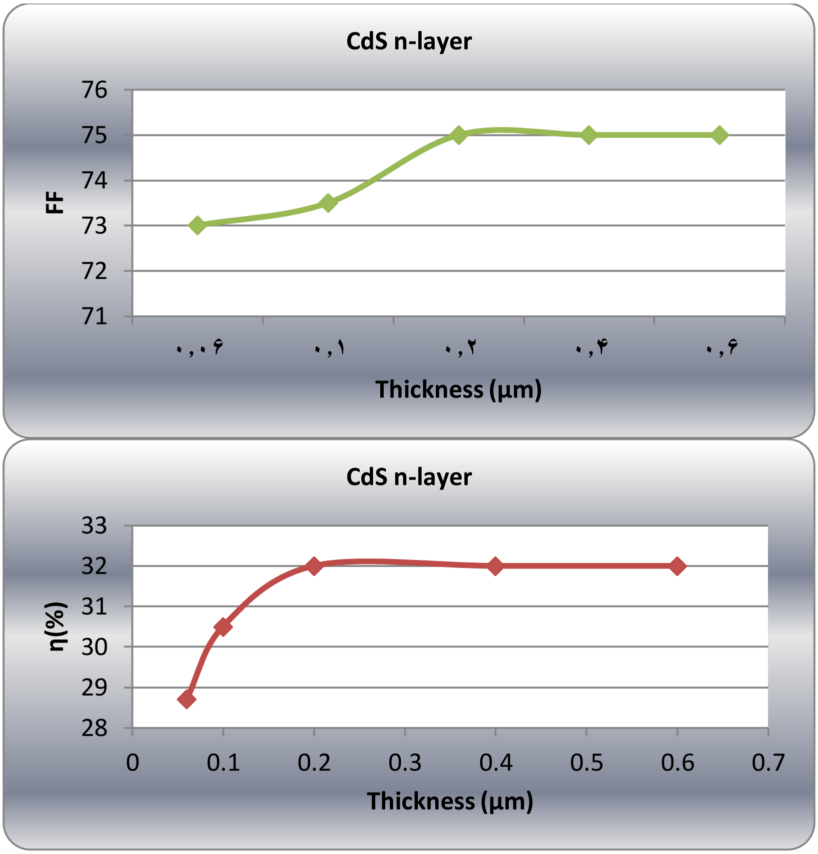


Fig. 3. The dependence of the output parameters (short-circuit current density Js, the open circuit voltage Voc,the filling factor FF and efficiency EFF) of tandem CdS/CdTemulti-junction solar cell on the thickness of CdS n-layer.

DISCUSSION

In 1982, Tyan et al. published an interesting paper on CdTe/CdS thin film solar cells reporting an efficiency of 10% [10]. Afterwards, an efficiency of 15.8% has been reached by Ferekides et al. [11]. Finally a group of NREL researchers reported a record efficiency of 16.5% [12]. Thin film PV devices based on the CdS|CdTe hetero-junction (HJ) have been researched for the past 30 years and record device efficiencies of 17.3% [13]. All of these resultsare about the single CdS/CdTe solar cells. Results in this paper are about the multi-junction tandem CdS/CdTe solar cell, which is not a practical example. All the results have been improved rather than the single junction CdTe/CdS thin film solar cells.

CONCLUSION

Numerical simulation using AMPS-1D demonstrate that the highest efficiency of multi-junction tandem CdS/CdTe solar cell, optimal efficiency in 31.8%, can be obtained at the thickness of CdS p-layer equal to 50 nm, and the thickness of the CdS n-layer of 200 nm, while we kept the fixed thickness of the CdTe n-layer of 3000 nm and CdTe p-type layer equal to 1000 nm.

The thickness changing impact on the output parameters including output cells Short-Circuit current density (Jsc), the open-circuit voltage (Voc), the fill factor (FF) and the efficiency (EFF) was demonstrated with AMPS-1D numerical modeling program.Then, weoffered new structure of these cells in tandem (two single cells joined together back to back) based on a view to increase efficiency results from single cells and considered the impact of thickness on its output parameters. Comparing the results with previous outcomes, we have witnessed greater efficiency.

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