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Performance profile analysis of ZnO/CdS/CdTe solar cells thin film : A review of absorber thickness and device temperature

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Abstract. ZnO/CdS /CdTe solar cell performance modeling has been done using AFORS-HET. The performance of solar cells is assessed based on the thickness of the CdTe absorber and device temperature. The thickness of CdTe varies from 100 nm - 5 μm and the temperature of the device is varied from 295 K, 300 K and 305 K. The characteristic I-V results show that samples with higher CdTe thickness have greater performance efficiencies. Conversely, the temperature variation of the device shows that the higher temperature of the device, the performance of solar cell efficiency will decrease. The optimum performance of ZnO/CdS/CdTe solar cells is owned by solar cells with a thickness of 4,500 nm CdTe absorber with V_{OC}, J_{SC}, FF, and efficiency values at 300 K device temperature respectively for 967 mV; 27.6 mA / cm2; 86.95%; and 23.21%.

1. Introduction

Solar cell or photovoltaic devices are technology that converts direct sunlight into electrical energy. The solar cells can operate without emitting pollutants into the environment. In addition, solar cells have a lifetime of more than 30 years [1], so it can be said that solar cells or photovoltaics are environmentally friendly technologies (green technology) that have higher potential for use in the future.

Class II-VI semiconductors are in great demand because the energy band gap has good physical properties for solar cell applications. In particular, solar cells originating from semiconductors with ZnO/CdS/CdTe structures are of much concern [2]. CdS is usually applied as a window layer on solar cells because it has an energy gap of 2.4 eV and is stable at room temperature. Whereas CdTe is commonly used as a absorber layer on solar cells because it has a relatively small energy gap of 1.5 eV [3]. ZnO acts as a transparent conducting oxide (TCO) layer on solar cells with an energy gap of 3.37 eV and has high conductivity [4].

The performance of ZnO/CdS/CdTe solar cells is largely determined by the thickness of the CdTe absorber layer which plays an important role in the process of photon absorption [5]. On the other hand, in general the performance of solar cells is also determined by the stability of the structure of the layers and connectors which are determined from the performance response to the temperature of the device [6]. The modeling method can be used as an analysis to get the optimum parameters of solar cells that can be a guide in the fabrication of high-performance solar cells. AFORS-HET is a software commonly used for modeling heterostructures such as solar cells because it resolves partial and coupled differential diffusion equations [7]. Based on this analysis, we will study the modeling of

ZnO/CdS/CdTe solar cell performance using AFORS-HET in terms of the influence of CdTe thickness and device temperature to determine the optimum response to environmental changes.

2. Methods

Modeled solar cells consist of ZnO as a transparent conducting oxide layer with a thickness of 500 nm [7], CdS as an n-type semiconductor with a thickness of 100 nm [8] and CdTe as a p-type semiconductor with varying thickness. Figure 1 shows the ZnO/CdS/CdTe solar cell layer scheme.
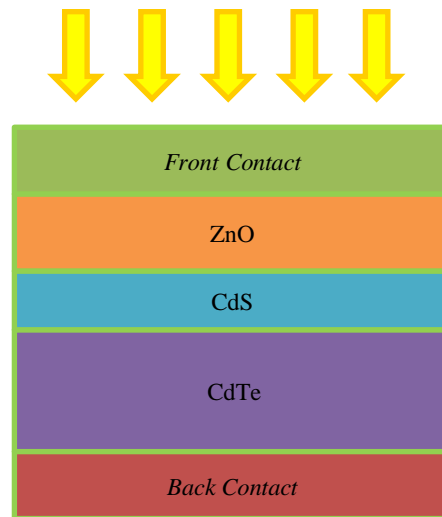

Figure 1. Schematic of a ZnO / CdS / CdTe solar cell layer

ZnO/CdS/CdTe solar cell parameters are taken from a series of previous studies as shown in table 1. These parameters are inputted in modeling with AFORS-HET. Furthermore, the output data are characterized by I-V characteristics and QE characteristics to determine the electrical performance and quantum efficiency. Modeling results that appear in the form of graphs of the relationship of voltage to current density, and graphs of wavelength relationships with QE. Based on the characteristics of the I-V obtained can be known, among others, open circuit voltage (V_{OC}), short circuit current (J_{SC}), fill factor (FF), and efficiency (η) using the following set of equations,

$$V_{OC} = V \ at \ J = 0 \ (V)$$

$$J_{SC} = J \ at \ V = 0 \ (mA \ cm^{-2})$$

$$P_{max} = \max \ (J \times V) \ (W \ cm^{-2})$$

$$FF = 100 \times \frac{P_{max}}{V_{OC} \times J_{SC}} \ (\%)$$

$$\eta = 100 \times \frac{P_{max}}{P_{ill}} \ (\%)$$

Table 1. ZnO/CdS/CdTe solar cell parameters

Parameters	ZnO	CdS	CdTe
Thickness (nm)	500 [7]	100 [8]	100-5000 [10]
Dielectric constant (dk)	9 [7]	8,9 [7]	10,9 [7]
Electron Affinity (eV)	4,5 [7]	4,5 [7]	4,28 [7]
Energy gap (eV)	3,4 [9]	2,53 [9]	1,42 [11,
Conduction band density	$2,2 \times 10^{18}$ [11]	$2,22 \times 10^{18}$ [11]	$1,8 \times 10^{19}$ [11]
Valence band density	$1,8 \times 10^{19}$ [7]	$1,8 \times 10^{19}$ [7]	$7,8 \times 10^{17}$ [7]
Electron mobility (cm^2/v.s)	100 [7]	340 [7]	500 [7]
Hole mobility (cm^2/v.s)	25 [9]	50 [9]	60 [9]
Acceptor density (cm^{-3})	0 [7]	0 [7]	7×10^{16} [7]
Donor density (cm^{-3})	1×10^{18} [12]	1×10^{18} [12]	0 [12]
Electron thermal velocity ve (cm/s)	1×10^7 [9]	1×10^7 [9]	1×10^7 [9]
Hole thermal speed vh (cm/s)	1×10^7 [9]	1×10^7 [9]	1×10^7 [9]

3. Result and Discussion

I-V characteristic test results are in the form of graphs of the relationship of current density (J) to voltage (V). Figure 2 shows a graph of the relationship of current density to ZnO/CdS/CdTe solar cell voltage with a thickness of 500 nm ZnO, 100 nm CdS thickness and varying CdTe thicknesses.
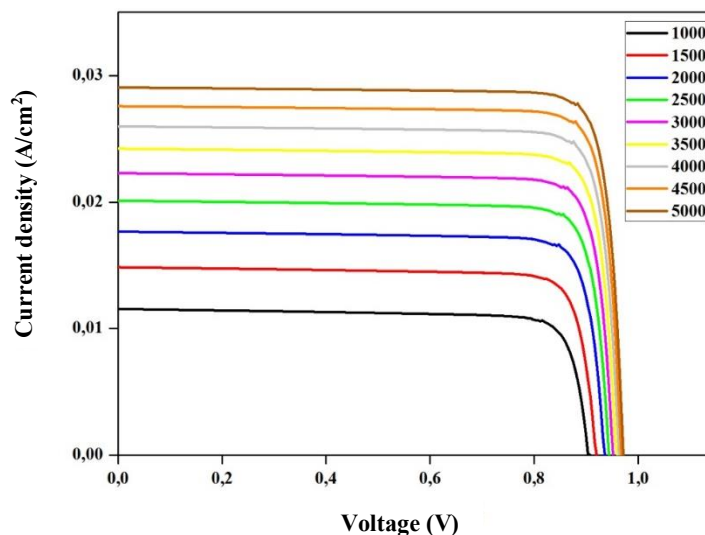

Figure 2. Graph of relationship of current density to voltage on ZnO/CdS/CdTe solar cells

Figure 2 shows the increasing thickness of CdTe causing the current *J* to increase. This is because an increase in the thickness of CdTe causes CdS electrons diffuse to CdTe to increase so that the space charge region (SCR) widens to the CdTe region so that the acceptor concentration (N_A) increases. The

increase in the value of N_A causes the dQ value to increase. This causes the value of current I to increase according to equation I = dQ / dt. The value of J increases because I is proportional to J [5]. In addition, the thin layer of CdTe is not able to absorb enough photons so that the resulting energy is small. However, the CdTe layer which is too thick allows the diffusion length of the charge carrier to be shorter than the thickness of the film so that the charge carrier formed by photo-generation will be combined before reaching contact [12,13].
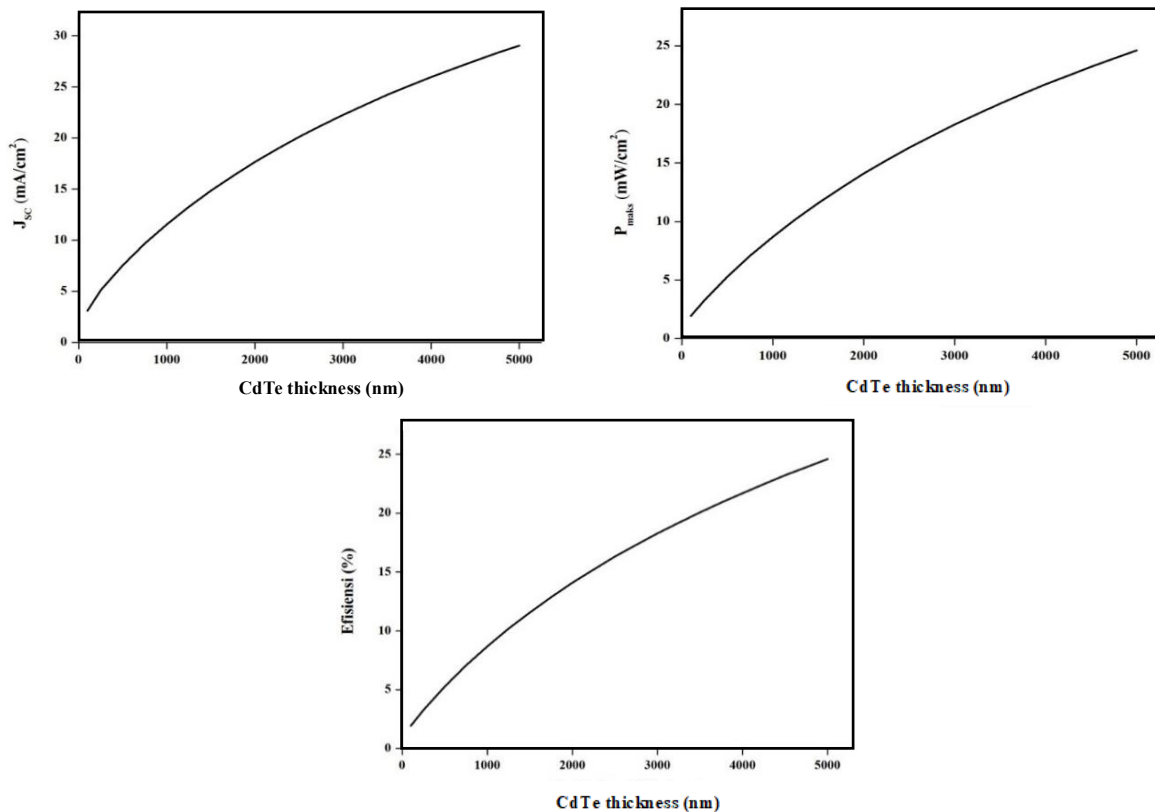

Figure 3. Effect of thin film thickness on: (a) short circuit current (J_{SC}); (b) maximum voltage P_{max}; and (c) efficiency.

In Figure 3(a), the J_{SC} value increases linearly as the CdTe thickness increases. This is due to increasing current density J due to an increase in current I according to the equation J = I/A [14]. Current I increases due to an increase in the charge carrier dQ according to the equation I = dQ/dt. The dQ value increases due to an increase in the concentration of the acceptor N_A. This is because the thick CdTe layer has a large concentration of holes so that more electrons in the CdS layer will be attracted and diffuse into the depletion region [5]. Increasing the thickness of CdTe affects the P_{max} value linearly as shown in Figure 3(b). This is because the current J increases linearly. Efficiency is the ratio of the maximum output power of solar cells to the input power of sunlight. In Figure 3(c), the efficiency value increases linearly. This is because P_{max} experiences a linear increase due to J current.

Figure 4 also shows the ZnO/CdS/CdTe solar cell band diagram and it is seen that in the thick CdTe layer, the energy level of the fermi decreases close to the valence band. In general, the fermi energy level lies halfway between the valence band and the conduction band. The addition of CdTe thickness results in more electrons from the CdS layer diffusing to the CdTe layer so that the concentration of the acceptor in the CdTe layer increases. This results in impurity in the CdTe layer so that the energy level of the fermi falls close to the valence band. The fall in the level of fermi energy

which approaches the valence band indicates that the energy needed by electrons to escape from the restricted area becomes smaller [15].
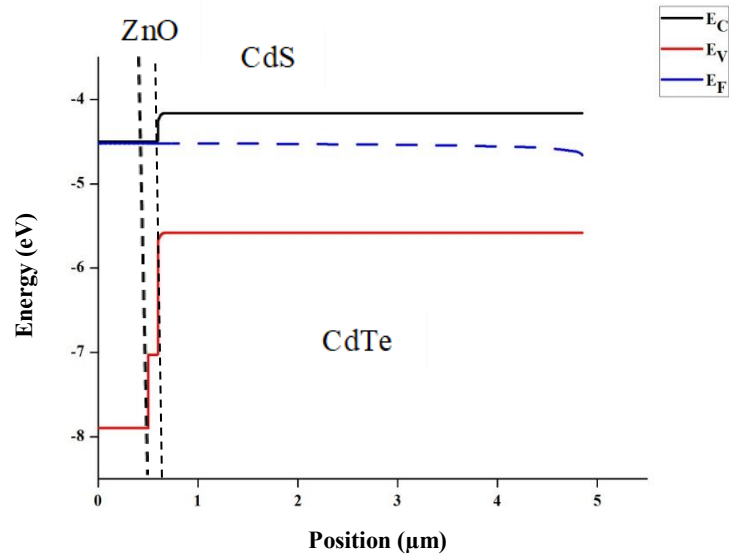

Figure 4. Band diagram of ZnO/CdS/CdTe solar cells in samples with a CdTe thickness of 4,250 nm
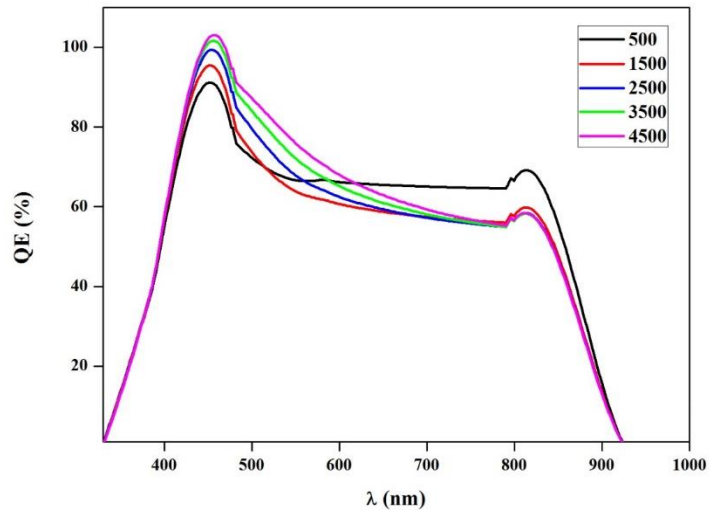

Figure 5. Quantum efficiency of ZnO/CdS/CdTe solar cells with variations in thickness of CdTe

In Figure 5, Quantum efficiency (QE) has 2 peaks, namely at wavelengths of 455 nm and 815 nm which when converted to energy units are 2.75 eV and 1.52 eV, respectively. Theoretically, the energy absorbed by ZnO/CdS/CdTe solar cells is in the range of wavelengths from blue to NIR with wavelengths of 489 nm to 871 nm. The absorbed wavelength range is obtained from the wavelengths transmitted by CdS and wavelengths absorbed by CdTe by converting the gap energy (E_g CdS = 2.53 eV and E_g CdTe = 1.42 eV) in the form of wavelengths. The difference between experimental results and theoretical results can be caused by a shift in the gap energy value (E_g) in modeling. Figure 5 also shows an increase in QE value which is proportional to the increase in thickness of CdTe at the blue

wavelength. This shows the maximum absorption found in the wavelength of blue. But at the NIR wavelength, the increase in QE value is inversely proportional to the browser thickness of CdTe. This does not really affect the performance of ZnO/CdS/CdTe solar cells because the highest intensity of sunlight emitted to the earth is at the wavelength of visible light.

ZnO/CdS/CdTe samples with thicknesses of 100 nm and 500 nm, respectively, anomalies occurred in the wavelength range of 549 nm to 788 nm with a constant QE of 66.67%. In addition, ZnO/CdS/CdTe samples with a thickness of 100 nm and 500 nm also have a high absorption rate at a wavelength of 815 nm compared to other samples. This is because in the thin layer of CdTe, the space charge region that must be passed by the charge carrier will be thinner, so that the charge carrier that flows from CdS will pound a thin embankment and the resulting current value will be even greater.

Samples with a thickness of CdTe > 500 nm have a thick space charge region so that the charge carrier flowing from CdS will pound a thick embankment and the resulting current value will be smaller. If the number of photons absorbed by ZnO/CdS/CdTe solar cells is constant, the QE value will be smaller. But at a wavelength of photons coming < 549 nm, the energy is large enough to pound a thick potential embankment so that the current remains large, because the number of photons absorbed by the ZnO/CdS/CdTe solar cell is constant, so the QE value will remain high.
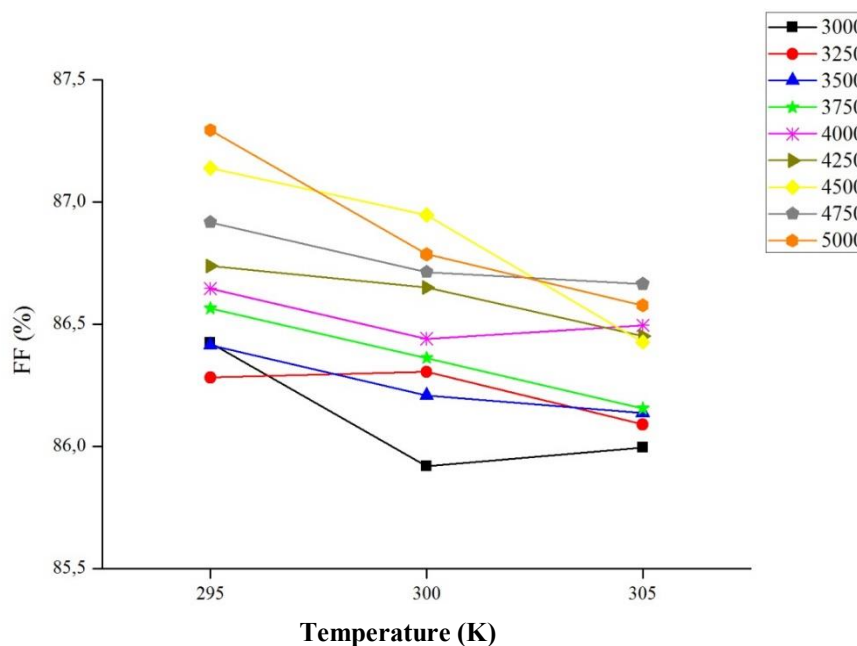

Figure 6. Effect of device temperature change on FF

Solar cells are applied in external environments that are vulnerable to temperature changes due to weather and climate change. This temperature change can affect the performance of ZnO/CdS/CdTe solar cell devices. Modeling the effect of device temperature on the performance of ZnO/CdS/CdTe solar cells is carried out to determine the optimum cell performance and tend to be stable. Figure 6 shows the FF value changing fluctuatively. This is because changes in the values of V_{OC}, J_{SC} and P_{max} occur at different intervals. Samples with a thickness of 3,750 nm CdTe have FF values that tend to be stable against changes in device temperature. In addition, an increase in temperature causes the semiconductor properties to shift by producing a slight increase in current, but produces a large voltage drop. Extreme temperature rise can also damage cells which causes a shorter lifetime [6].

Based on the description above it can be concluded that the optimum performance of ZnO/CdS/CdTe solar cells is a solar cell with a thickness of 4,500 nm CdTe because it shows a downward trend graph with high currents. This is indicated by the increase in the value of FF at a temperature of 300 K. FF is a comparison of the maximum voltage value of P_{max} to the value of V_{OC} and J_{SC}. P_{max} is the maximum value of the multiplication of voltage V and current J. A large FF value indicates a large P_{max} value and a large P_{max} value indicates a large J current value. ZnO/CdS/CdTe samples with a thickness of 4,500 nm CdTe have V_{OC}, J_{SC}, P_{max}, FF, and efficiency respectively at a 300 K device temperature of 967,935 mV; 27.5827 mA / cm2; 23,2133 mW / cm2; 86.95%; and 23.21%.

4. Conclusion

Modeling the effect of CdTe thickness and device temperature on the performance of ZnO/CdS/CdTe solar cells was successfully carried out using AFORS-HET. Based on the results obtained, it can be concluded that the thickness of CdTe influences the performance of ZnO/CdS/CdTe solar cells. In addition, device temperatures also affect the performance of ZnO/CdS/CdTe solar cells. The results of the I-V characteristics show that the higher the temperature of the device, the solar cell performance will decrease. The results of the I-V characteristics show a sample with a thickness of 4,500 nm CdTe has a good performance against changes in device temperature, so it can be concluded that the optimum performance of ZnO / CdS / CdTe solar cells is a solar cell with a thickness of 4,500 nm CdTe with an efficiency reaching 23.21%.

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