DESIGN, SIMULATION AND OPTIMIZATION OF THE EFFICIENCY OF CdS – CdTe SOLAR CELL

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DECLARATION

This is to declare that this thesis is our original work based on research. No part of this report has been submitted elsewhere for award of a degree. All sources of materials and knowledge used for this research have been properly acknowledged.

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APPROVAL

This is to certify that the thesis titled as “Design, Simulation and Optimization of the efficiency of CdS –CdTe Solar Cell” submitted to the respected members of the Board of Examiners of the Faculty of Engineering of East West University, Dhaka for partial fulfillment of the requirements for the degree of Bachelor of Science in Electronics & Telecommunications Engineering by the following students and has been accepted as satisfactory, under complete supervision of the signatory.

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ABSTRACT

Everything in this age of science and technology is dependent upon energy. A lot of the sources of energy like fossil fuels pollutes the environment, is non - renewable and is quickly and easily used up like sands in an hourglass. On the other hand, nuclear energy, once considered to run the world of the future is slowly ditched after the incidents of Chernobyl and recent incidents of the tsunami in Fukushima. These days, one of the known, efficient, renewable source of energy where the bulk of the research is focused on is the light from the sun. That's how solar cells came into existence. In the solar cells of today, mostly Silicon is used because of its abundance and its minimal price. Works are going on with other materials suitable for displacing silicon. One such candidate is CdS and CdTe, about whom this whole thesis is based upon. CdS – CdTe solar cells provide similar efficiencies when $1/100^{th}$ of thickness of Silicon and with prices affordable for common citizen. In this specific thesis, by using 55 nm CdS, 1 µm CdTe and a back contact made up of Iridium, an efficiency of 27.056% was achieved with other parameters as Voc = -1.151 V, Jsc = 26.315 mA/cm^2, FF = -0.893. All the simulation has been carried out by Analysis of Microelectronic and Photonic Structures (AMPS – 1D) simulator.

CONTENTS

CHAPTER 3: SIMULATED RESULTS AND DISCUSSIONS

CHAPTER 4: CONCLUSION AN FUTURE WORKS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 ENERGY

Providing enough energy to meet an ever - increasing demand is one of the greatest problems the world is now facing. Energy is the key to an industrialized economy, which calls for a doubling of electrical output every ten to twelve years. Meanwhile, the days of cheap abundant and environmentally acceptable power may be coming to an end.

Coal is plentiful but polluting, natural gas is scarce and oil is not found everywhere. Nuclear power now is costly and risky [1]. Global warming is projected to raise the average temperature of the earth's atmosphere by 1.4 – 5.8 °C by the end of this century. Finding access to a clean form of energy, with little or no emissions and environmental friendly technology, will be one of the major challenges of the 21st century.

1.2 IMPORTANCE OF SOLAR CELL

Renewable energy is increasingly viewed as critically important globally. One promising attempt is the application of solar cells to utilize the immense amounts of energy that the earth receives with every second from the sun [2]. Solar energy has been used by human beings since time immemorial. Solar power is used in a widespread of the ever so progressing technologies of the world.

Solar energy can prove to have an immense amount of constructive and helpful impact on the environment. Contrasting to the fossil fuels that we consume and use on a daily basis, solar energy does not fabricate the excessively injurious pollutants, like carbon dioxide, oxides of sulphur or oxides of nitrogen that are liable for the greenhouse effect which is known to lead to global warming, acid rain or other harmful processes.

Solar energy is ultra clean and its use reduces the quantity of contamination and toxic waste, not to forget pollution that the engendering plants have to produce.

Solar energy is natural and a sustainable source of energy that can be utilized in the use of making solar electricity, solar heating appliances, solar cooling appliances and also solar lighting appliances.

Another key aspect of using solar energy is that it has massive financial benefits. They can generally be seen in the reduction of the utility bills [3]. Also, solar energy does not require any fuel and thus avoid the problems of transportation of fuel or the storage of radioactive waste.

Solar cells make no noise at all and there are no moving parts in solar cells which makes them long lasting and require very little maintenance. Solar energy provides cost effective solutions to energy problems where there is no electricity at all [4].

In the developed and underdeveloped countries, where electricity is scarce or electricity hasn’t reached yet, solar cells can be the source of energy to light their homes and may be the cities. Also, engineers are working on projects which will help take the excess electricity that will be produced in the solar cells of the homes of the citizens and will contribute to the total regional or national electricity grid to decrease the scarcity of electricity.

1.3 IMPORTANCE OF CdS – CdTe SOLAR CELL

One of the most promising thin film candidates is CdTe owing to its higher conversion efficiency with reduced material usage and stable cell operation. CdTe solar cells have some advantages. Firstly, the layer of CdTe solar cells can be deposited using different low cost techniques such as Sputtering, Close-spaced sublimation (CSS), chemical bath deposition etc [5]. Secondly, CdTe has a direct optimum band gap (1.45eV) with the high absorption coefficient over 5×10^5 /cm, which means that the incident photons with sufficient energy can be absorbed within a few micrometers of CdTe absorber thickness. The requirement of less material reduces relatively the cost of CdTe based solar cells. To date, the highest reported conversion efficiency of CdTe solar cell is 20.4%, which is still lower compared to the theoretical efficiency (near to 30%).

One of the reasons for choosing CdTe over Silicon is the cost of manufacturing. "First Solar", the first manufacturer of Cadmium telluride panels to produce solar cells for less than $1.00 per watt. Some experts believe it will be possible to get the solar cell costs down to around $0.5 per watt.

Another reason for choosing CdTe over Si is the ease of manufacturing. The necessary electric field, which makes turning solar energy into electricity possible, stems from properties of two types of cadmium molecules, cadmium sulfide and cadmium telluride. This means a simple mixture of molecules achieves the required properties, simplifying manufacturing compared to the multi-step process of joining two different types of doped silicon in a silicon solar panel.

Also, CdTe absorbs sunlight at close to the ideal wavelength, capturing energy at shorter wavelengths than is possible with silicon panels.

Cadmium is an abundant material, which is produced as a by-product of other important industrial metals such as zinc [5].

1.4 PURPOSE OF THE THESIS

The purpose of this thesis is to design and simulate a single – junction, two layer CdTe – CdS solar cell by the use of AMPS – 1D software. The main goal is to create the most efficient and cost effective solar cell by the use of CdTe and CdS materials.

In summary, the purpose of this research is –

1. Designing a highly efficient two layered CdTe – CdS solar cell
2. The optimization of the thickness of the layers of CdTe and CdS materials
3. The optimization of the Back Contact
4. Sinulation of the design of the CdTe – CdS solar cell by the use of AMPS – 1D software

1.5 OUTLINE OF THE THESIS

The thesis is broken down and organized in four distinct chapters.

1. Chapter 1 discusses about energy, the importance of solar cells, the importance of CdS – CdTe solar cells and the purpose of the thesis.
2. Chapter 2 discusses the AMPS - 1D software, its features and parameters that are used to design and simulate the solar cell.
3. Chapter 3 discusses about the optimization of the layer thickness and the back contact to obtain the high efficiency of the solar cell. This chapter also represents the final proposed structure of the solar cell.
4. Chapter 4 is about the conclusions of the research and about future works.

CHAPTER 2

AMPS - 1D SOFTWARE

2.1 INTRODUCTION TO MODELLING AND SIMULATION

The major objectives of numerical modeling and simulation in solar cell research are testing the validity of proposed physical structures, geometry on cell performance and fitting of modeling output to experimental results. Any numerical program capable of solving the basic semiconductor equations could be used for modeling thin film solar cells. The fundamental equations for such numerical programs are (i) Poisson's equation for the distributions of electric field (φ) inside the device and (ii) the equation of continuity for conservation of electrons and holes currents.

The AMPS-1D program has been developed to pragmatically simulate the electrical characteristics of thin film hetero-junction solar cells. It has been proven to be a very powerful tool in understanding device operation and physics for single crystal, poly-crystal and amorphous structures. To date, more than 200 groups worldwide have been using AMPS-1D for solar cell design [6].

2.2 AMPS - 1D AND ITS FEATURES

AMPS is the abbreviation of Analysis of Microelectronic and Photonic Structures. It is a one – dimensional device simulation program and it is a very general program for analyzing and designing transport in microelectronics and photonic structures. AMPS – 1D is the creation of Professor Stephen J, Fonash of Pennsylvania State University and some of the students.

Later, it was developed with the support of the Electric Power Research Institute and equipment support by IBM [7].

For the modelling, design and the simulation of the Solar Cell for this thesis, the Beta version 1.0 is used here. The beta version is commonly used worldwide for the design of solar cells.

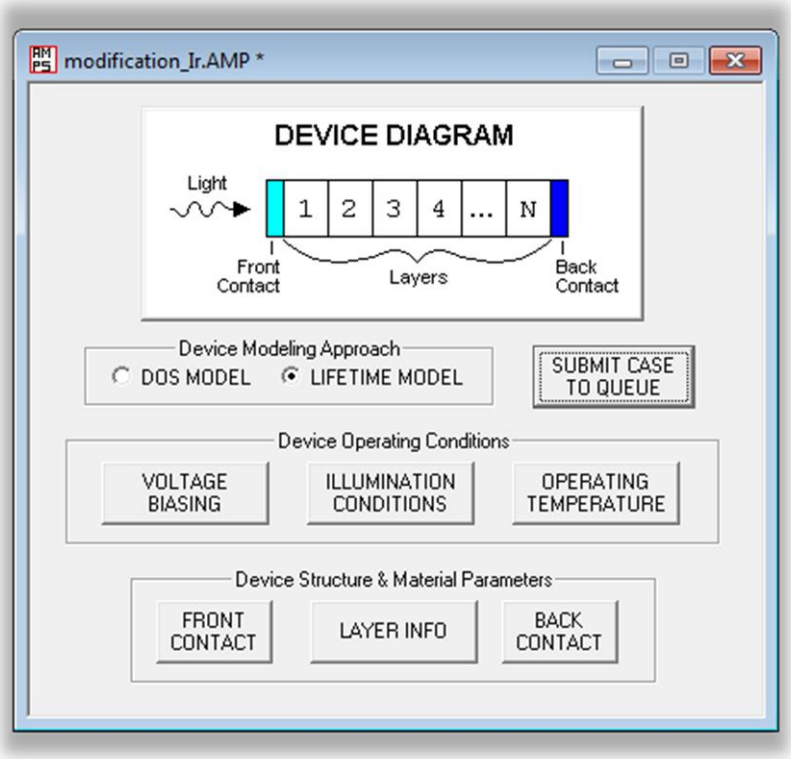

FIG – 2.1: AMPS 1D

AMPS may be used to examine a variety of device structures that include:

- Homojunction and heterojunction p-n and p-i-n, solar cells and detectors;
- Homojunction and heterojunction p-n, p-i-n, n-i-n, and p-i-p microelectronic structures;
- Multi-junction solar cell structures;
- Multi-junction microelectronic structures.

The advantages of AMPS include the user friendly interface, flexible plotting program, spectral response, band diagrams, carrier concentrations, current density, electrical field distribution and recombination profiles [8].

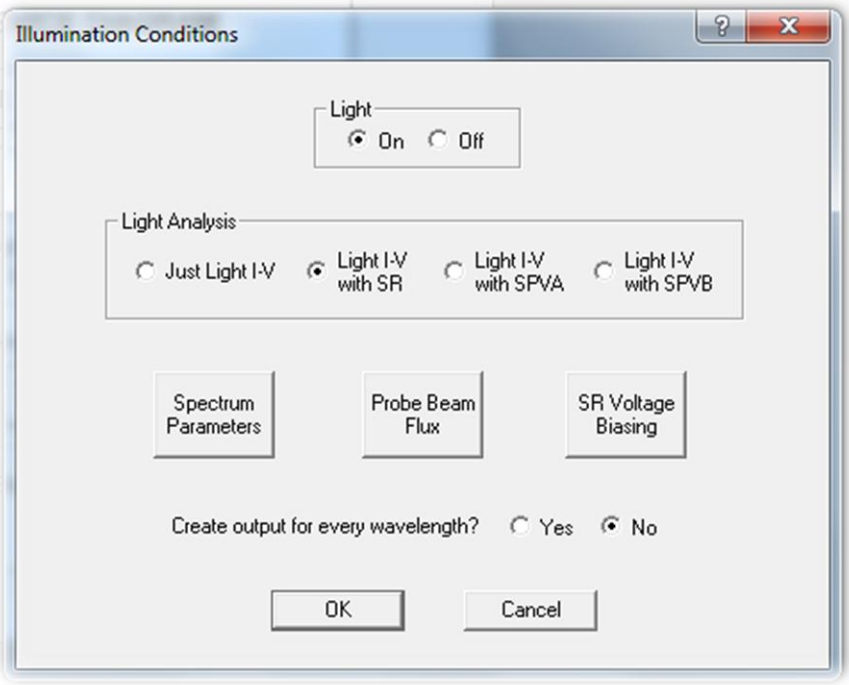

FIG – 2.2: ILLUMINATION CONDITIONS IN AMPS – 1D

2.3 AN OVERVIEW OF HOW AMPS WORKS

The theoretical calculations carried out using AMPS-1D for the analysis were based on Poisson's equation and the first-principle continuity equations of electrons and holes and used to analyze the carriers transport behavior of semiconductor electronic and optoelectronic device structures including solar cells [9]. Determining transport characteristics then becomes a task of solving these three coupled non-linear differential equations, each of which has two associated boundary conditions. In AMPS, these three coupled equations, along with the appropriate boundary conditions, are solved simultaneously to obtain a set of three unknown state variables at each point

in the device: the electrostatic potential, the hole quasi-Fermi level, and the electron quasi-Fermi level. From these three state variables, the carrier concentrations, fields, currents, etc. can then be computed [7]. Then, AMPS solves Poisson equation and the electron and hole continuity equations by using the method of finite differences and the Newton-Raphson technique [10].

In AMPS, the one-dimensional device being analyzed is divided into segments by a mesh of grid points, the number of which the user decides. The three sets of unknowns are then solved for each particular grid point. We note that AMPS allows the mesh to have variable grid spacing at the discretion of the user. Once these three state variables are found as a function of x, the band edges, electric field, trapped charge, carrier populations, current densities, recombination profiles, and any other transport information may be obtained [7].

2.4 LAYER INFORMATION

The layer thickness is chosen by varying the thickness of the various layers that are used and choosing the thickness for which the maximum efficiency is obtained. Dielectric constants, bandgaps, mobility and effective densities of states are calculated from numerical analysis by using the relations found in the literatures [8].

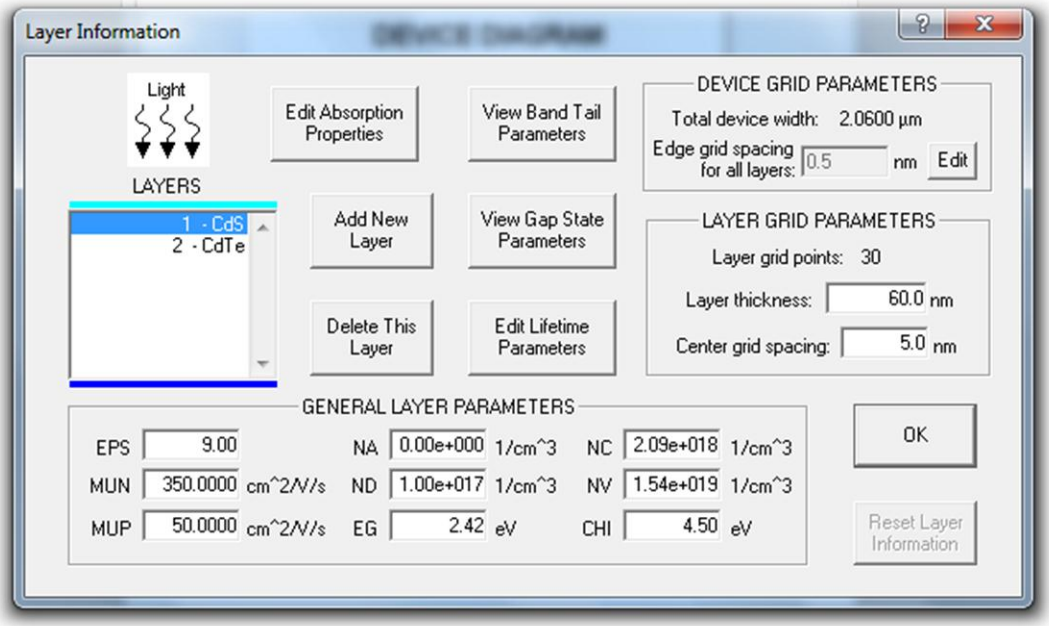

FIG – 2.3: LAYER INFORMATION ON AMPS – 1D

2.5 INPUT PARAMETERS

The following is a list of input parameters that AMPS needs to solve the set of transport equations and boundary conditions. In general, this list will apply to all current program versions, with some minor exceptions. The differences in the parameter list between each program version will be mentioned as they are discussed. Parameters which only apply to non-equilibrium are tagged.

2.5.1 PARAMETERS THAT APPLY TO THE ENTIRE DEVICE:

1. Boundary conditions

- PHIBO = $\Phi_{b0} = E_C - E_F$ at x=0 (eV)
- PHIBL = $\Phi_L = E_C - E_F$ at x=L (eV)

2. Surface recombination speeds

- S_{NO} = electrons at x=0 interface (cm/sec)
- S_{PO} = holes at x=0 interface (cm/sec)
- S_{NL} = electrons at x=L interface (cm/sec)
- S_{PL} = holes at x=L interface (cm/sec)

3. Reflection coefficient for light impinging on front and back surfaces

- R_F = reflection coefficient at x=0 (front-surface)
- R_B = reflection coefficient at x=L (back-surface reflection)

4. Temperature T (K) [7]

2.5.2 BASIC MATERIAL PROPERTIES

a. EPS = relative permittivity ε_r at temperature T
b. NC = effective density of states N C (cm^{-3}) in the conduction band at temperature T
c. NV = effective density of states N V (cm^{-3}) in the valence band at temperature T
d. EG = the mobility bandgap $E_{G\mu}$ (eV) at temperature T
e. EGOP = the optical bandgap E_{Gopt} (eV) at temperature T
f. CHI = electron affinity X_e (eV) at temperature T
g. MUN = electron mobility μ_n (cm^2 /V-sec) at temperature T
h. MUP = hole mobility μ_p (cm^2 /V-sec) at temperature T
i. N_A = Acceptor Concentration (cm^{-3})
j. N_D = Donor Concentration (cm^{-3})
k. N_C = Effective Density of States in the Conduction Band (cm^{-3})
l. N_V = Effective Density of States in the Valence Band (cm^{-3}) [7]

2.6 PARAMETER VALUES

The numerical calculations of this research used a recombination velocity of 10^3 cm/s, which corresponds to the approximately to the thermal velocity of the electrons. It suggests that entire carrier will recombine if they reach the surface.

The front surface reflectivity is set to $R_F = 0.1$ in order to reflect the experimental spectral response data of CdS – CdTe solar cells with typical front layer.

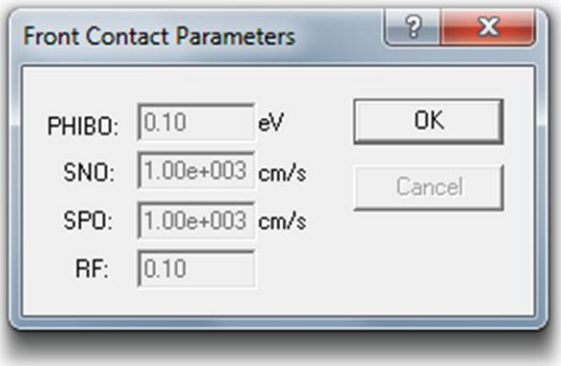

FIG – 2.4: FRONT CONTACT PARAMETERS

The back surface reflectivity parameter is set to $R_B = 0.9$ in order to get the reflected back energetic photons from the back surface.

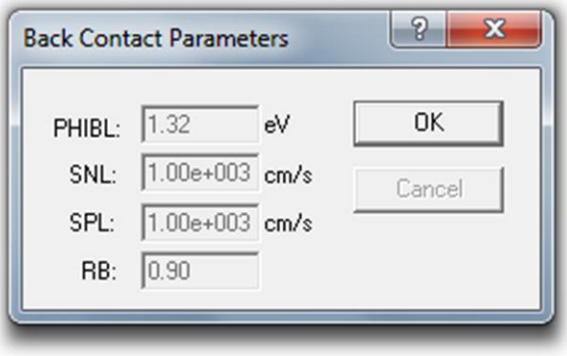

FIG – 2.5: BACK CONTACT PARAMETERS

The voltage biasing window contains the information on the voltage to be applied

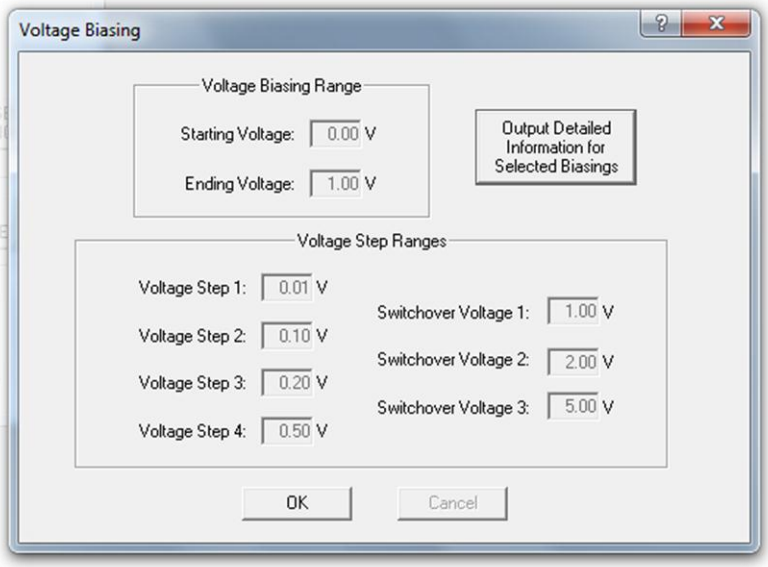

FIG – 2.6: VOLTAGE BIASING

The operating temperature for all cells was set to 300°K [8].

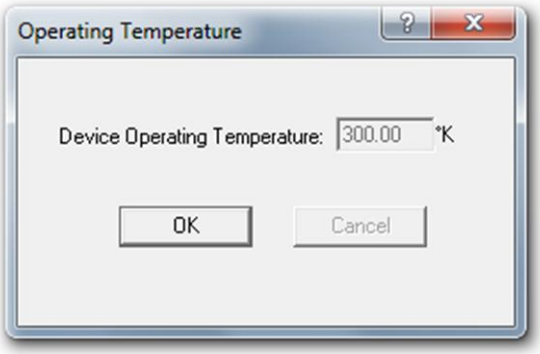

FIG – 2.7: OPERATING TEMPERATURE

CHAPTER 3

SIMULATED RESULTS AND DISCUSSIONS

3.1 INTRODUCTION

This research is done to design a single junction CdS – CdTe solar cell by varying various parameters of the solar cell. Especially, the layer thickness was varied and different back contact materials were used to get the maximum efficiency by minimizing the cost as much as possible. All the necessary parameters and results are discussed in this chapter along the graphs of the important parameters such as efficiency, open – circuit voltage (V_{oc}), short – circuit current density (J_{sc}) and fill factor (FF) of the proposed solar cell.

3.2 ABSORBER LAYER THICKNESS OPTIMIZATION

One of the challenges while creating a solar cell is to keep the cost as minimal as possible by varying the parameters, by using the most materials and at the same time trying to keep the efficiency maximum. For this reason, the layers of the solar cell are optimized and the simulations and results of the optimization will be discussed on the latter parts of this chapter. [8]

3.2.1 RESULTS OF CdTe LAYER THICKNESS OPTIMIZATION

NO.	PARAMETERS	VALUES
1	TYPE	p-CdTe
2	EPS	9.40
3	MUN	500
4	MUP	60
5	N_A (cm^{-3})	5×10^{15}
6	N_D (cm^{-3})	0
7	E_G (eV)	1.50
8	N_C (cm^{-3})	9.08×10^{17}
9	N_V (cm^{-3})	6.33×10^{18}
10	CHI (eV)	4.28
11	CdS Thickness (nm)	200
12	Temperature (°K)	300

TABLE 3.1: PARAMETER VALUES FOR SIMULATION OF CdTe

By keeping the above parameters constant, the thickness of the CdTe layer is varied. The table below shows the results obtained when the thickness of the CdTe is varied.

LAYER THICKNESS (nm)	J_{sc} (mA/cm^2)	EFFICIENCY (%)	FILL FACTOR	V_{oc}
1000	26.176	25.085	-0.887	-1.081
1200	26.295	25.204	-0.887	-1.081
1400	26.371	25.280	-0.887	-1.081
1600	26.422	25.331	-0.887	-1.081
1800	26.458	25.369	-0.887	-1.082
2000	26.485	25.397	-0.887	-1.082

TABLE 3.2: RESULTS OF THE SIMULATION OF CdTe

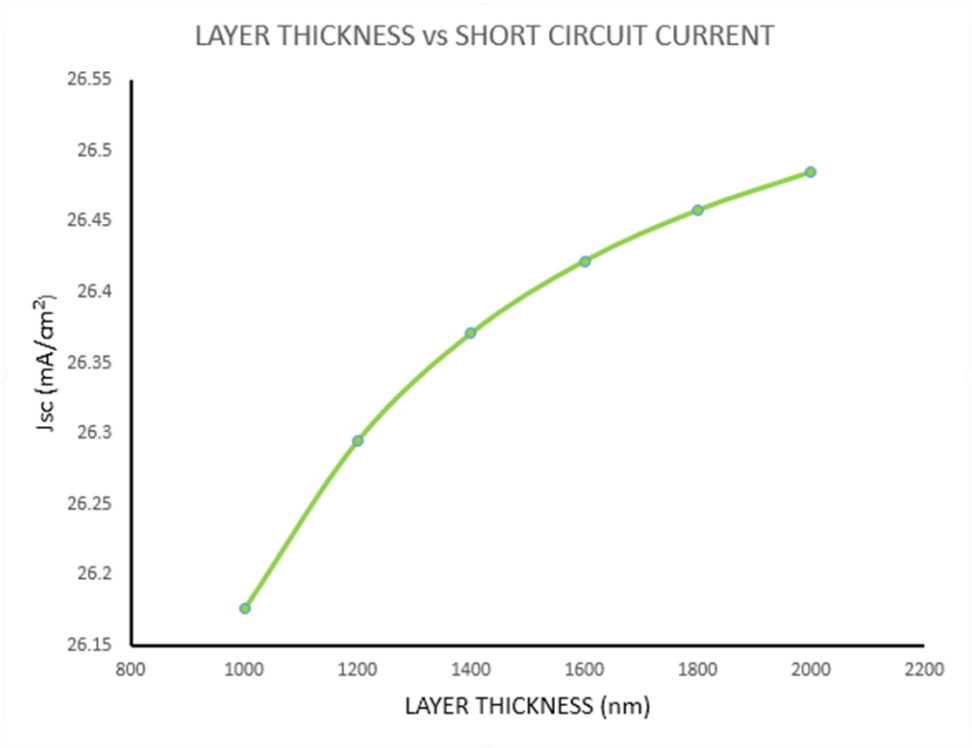

FIG – 3.1: LAYER THICKNESS vs Jsc OF CdTe

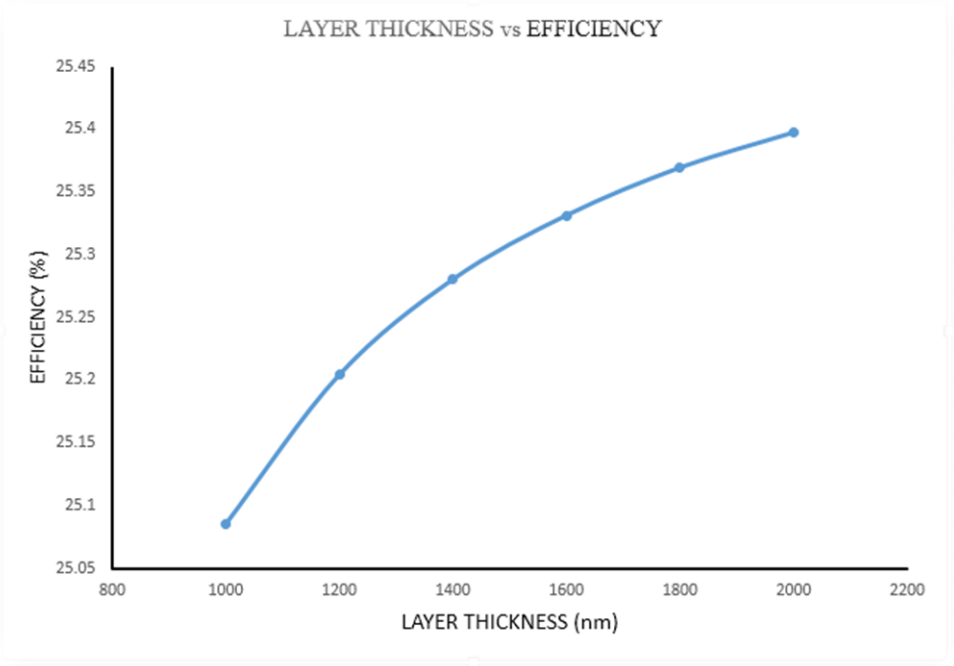

FIG – 3.2: EFFICIENCY VS LAYER THICKNESS OF CdTe

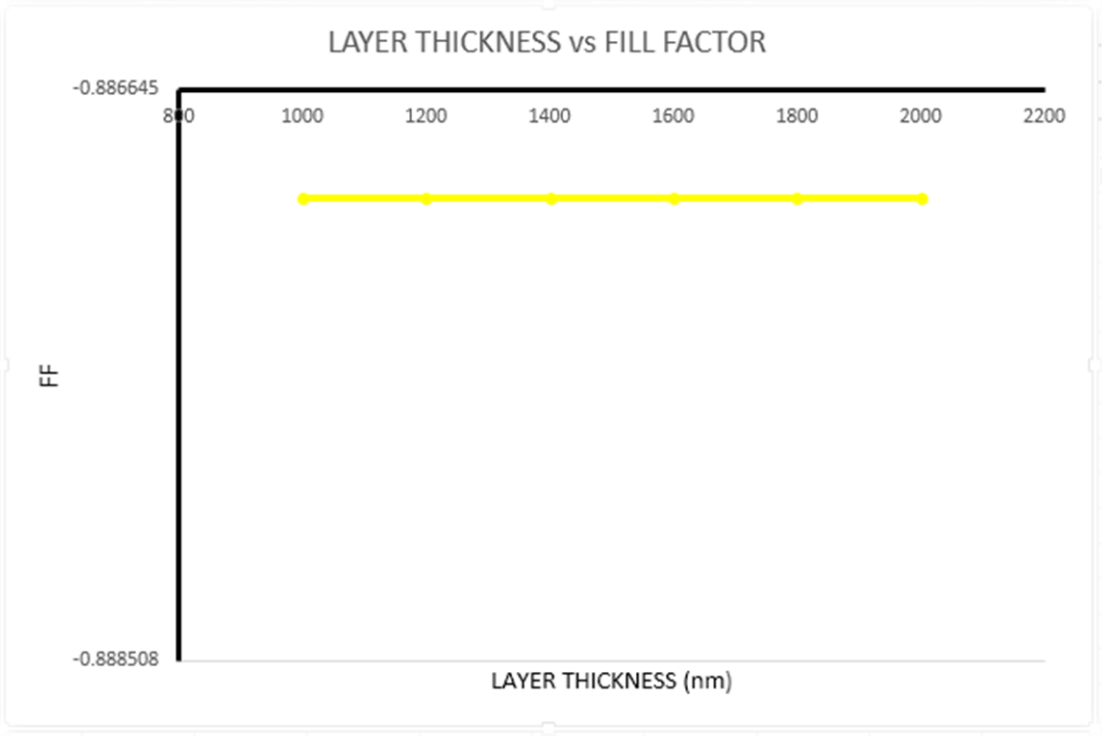

FIG – 3.3: LAYER THICKNESS vs FF (FILL FACTOR) OF CdTe

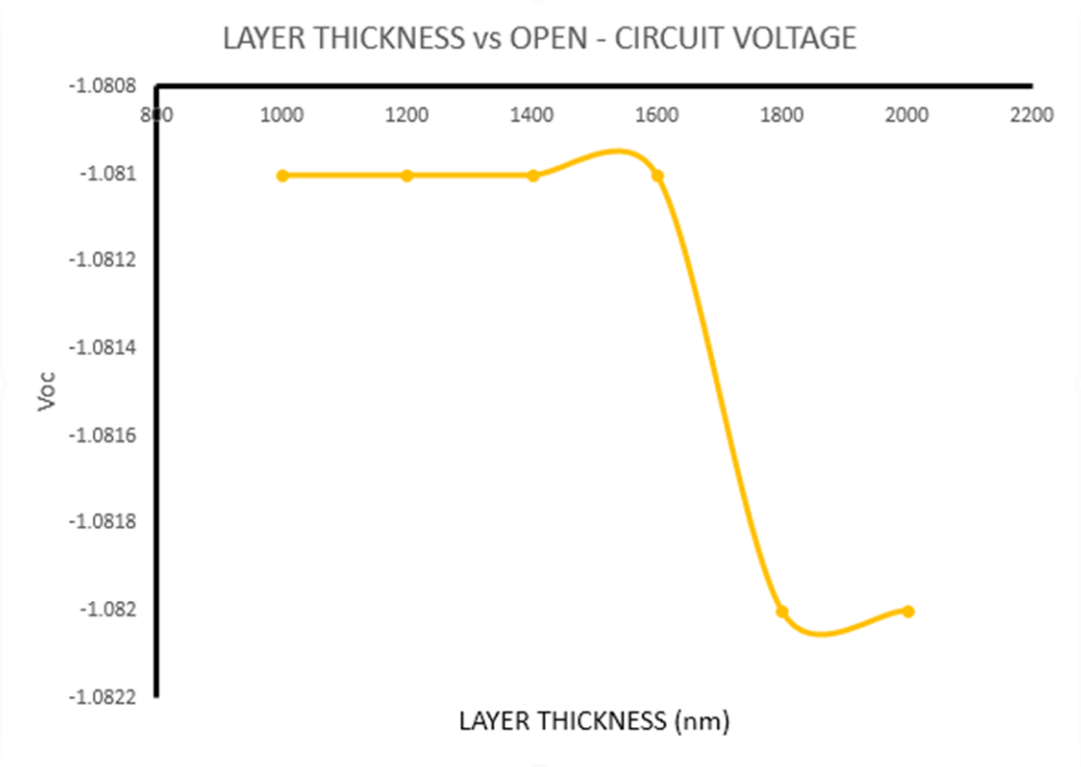

FIG – 3.4: LAYER THICKNESS vs Voc OF CdTe

From the above results and figures (3.1, 3.2, 3.3, 3.4), it can be seen that, the greater the thickness of the CdTe layer, the greater is the efficiency of the solar cell. At the same time it can be seen that J_{SC} also increases with efficiency while FF remains same with little fluctuations in V_{OC}.

These results show that if we go on increasing the thickness of the CdTe layer, the efficiency will simultaneously increase and naturally, the cost will also increase. It can also be seen that when 1µm thickness is increased, only a slight 0.382% efficiency increased, which is very insignificant compared to level to which the thickness of CdTe is increased.

For these reasons, the layer thickness of CdTe is kept 1000 nm (or 1 µm) for which the efficiency is 25.085%.

3.2.2 RESULTS OF THE CdS LAYER THICKNESS OPTIMIZATION

NO.	PARAMETERS	VALUES
1	TYPE	p-CdS
2	EPS	9.00
3	MUN	350
4	MUP	65
5	N_A (cm^{-3})	0
6	N_D (cm^{-3})	1×10^{17}
7	E_G (eV)	2.42
8	N_C (cm^{-3})	2.40×10^{18}
9	N_V (cm^{-3})	1.79×10^{19}
10	CHI (eV)	4.50
11	CdS Thickness (nm)	1000
12	Temperature (°K)	300

TABLE 3.3: PARAMETER VALUES FOR SIMULATION OF CdS

By keepin the above parameters constant, the thickness of the CdS layer is varied. The table below shows the results obtained when the thickness of the CdS is varied.

LAYER THICKNESS (nm)	J_{sc} (mA/cm^2)	EFFICIENCY (%)	FILL FACTOR	V_{oc}
170	26.207	25.116	-0.887	-1.081
140	26.237	25.146	-0.887	-1.081
110	26.264	25.175	-0.887	-1.081
80	26.288	25.201	-0.887	-1.081
75	26.292	25.205	-0.887	-1.081
65	26.298	25.213	-0.887	-1.081
55	26.304	25.220	-0.887	-1.081

TABLE 3.4: RESULTS OF THE SIMULATION OF CdTe

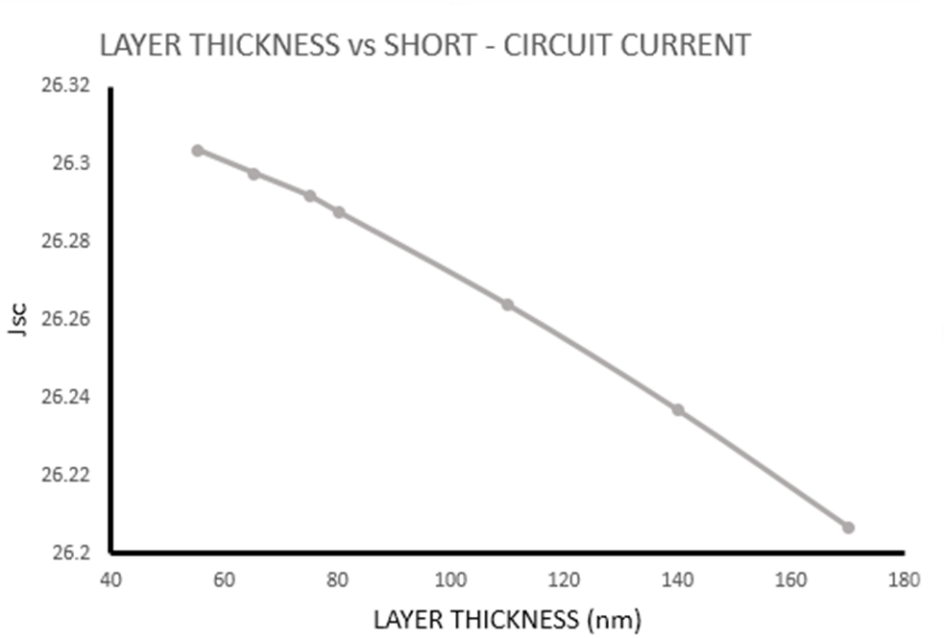

FIG – 3.5: LAYER THICKNESS vs Jsc OF CdS

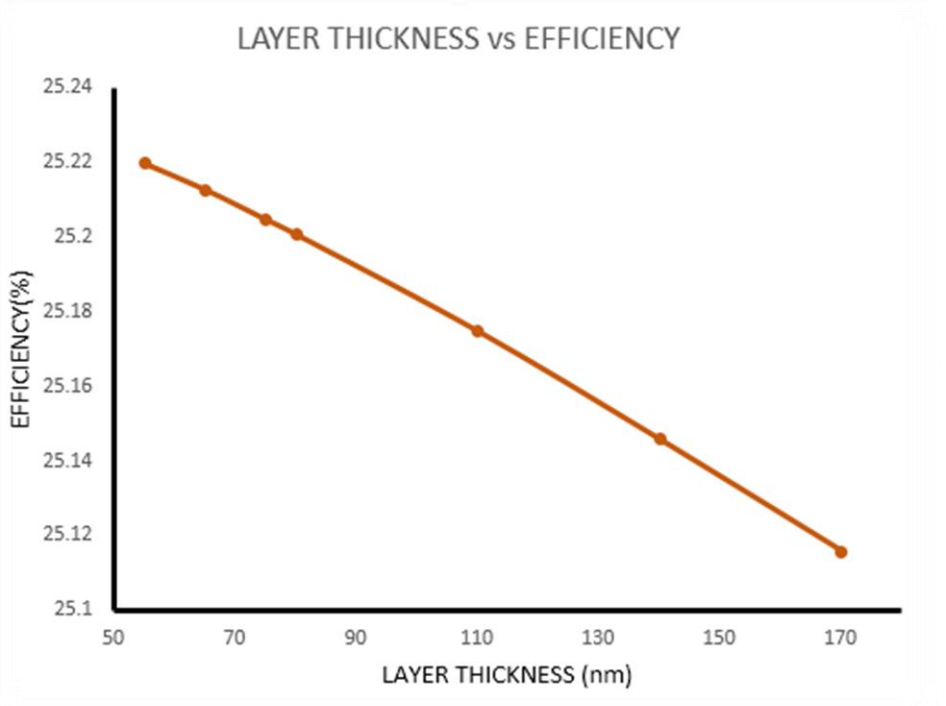

FIG – 3.6: LAYER THICKNESS vs EFFICIENCY OF CdS

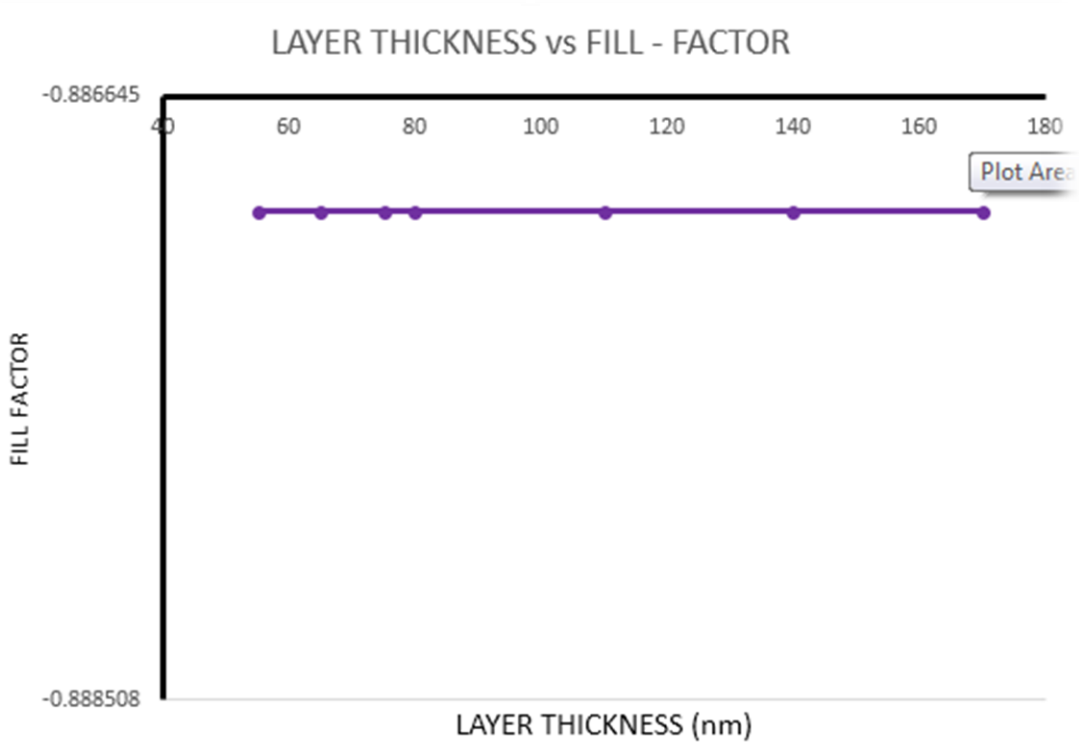

FIG – 3.7: LAYER THICKNESS vs FF (FILL FACTOR) OF CdS

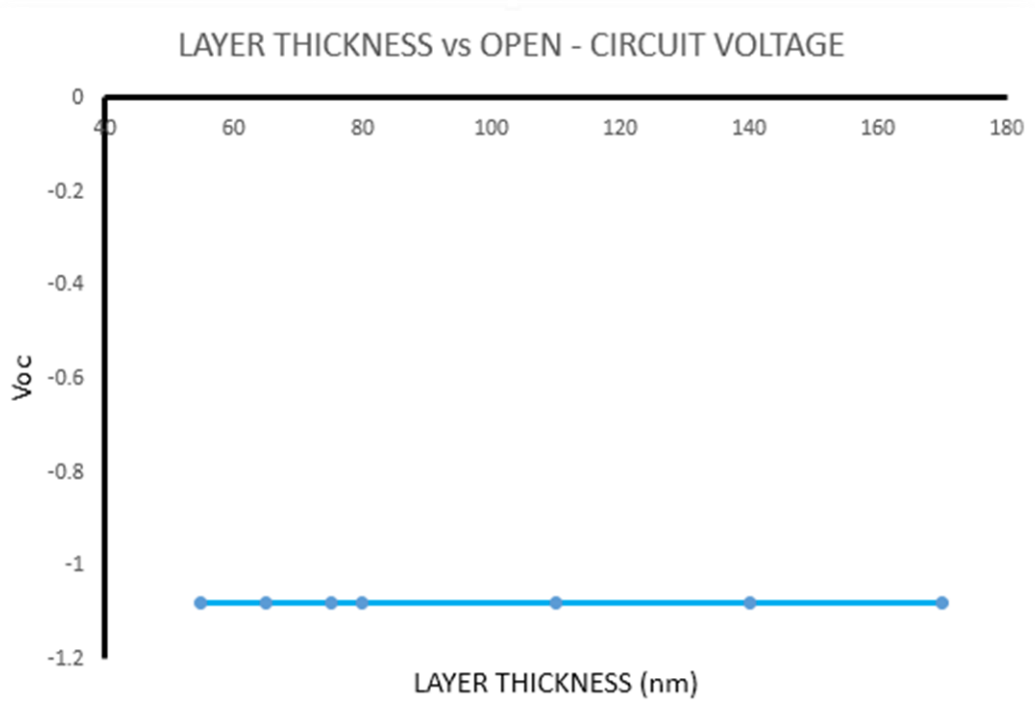

FIG – 3.8: LAYER THICKNESS vs Voc OF CdS

From the above resuts and figures (3.5, 3.6, 3.7, 3.8), it can be seen that as the layer thickness of CdS decreases, the efficiency of the solar cell increases; also, the J_{SC} increases whereas the FF and the V_{OC} remains same.

Therefore, the layer thickness of CdS can be kept at 55 nm and the layer thickness of the CdTe can be kept at 1µm to proceed further for the optimization of the back contact.

3.2.3 RESULTS OF THE OPTIMIZATION OF THE BACK CONTACT

FRONT CONTACT PARAMETERS	BACK CONTACT PARAMETERS
PHIBO = 0.10	PHIBL = 1.25 (1.30, 1.32, 1.37)
SNO = $1.00*10^3$	SNL = $1.00*10^3$
SPO = $1.00*10^3$	SPL = $1.00*10^3$
RF = 0.10	RB = 0.90

TABLE – 3.5: FRONT AND BACK CONTACT PARAMETER VALUES

The PHIBL of the back contact is defined by the following equation

$$\text{PHIBL} = \text{work function}_{\text{back contact}} - \text{electron affinity}_{\text{semiconductor in contact}}$$

The electron affinity of CdTe is assumed to be 3.9 eV [11]. The metals with work functions higher than the electron affinity of CdTe is used as the back contact to achieve the results.

PHIBL	Element	Jsc (mA/cm^2)	Efficiency(%)	FF	V_{oc}
1.25	Nickel	26.257	23.803	-0.878	-1.032
1.30	Silver	26.304	25.220	-0.887	-1.081
1.32	Cobalt	26.310	25.755	-0.889	-1.101
1.37	Iridium	26.315	27.056	-0.893	-1.151

TABLE – 3.6: RESULTS OF THE SIMULATION OF THE BACK CONTACT

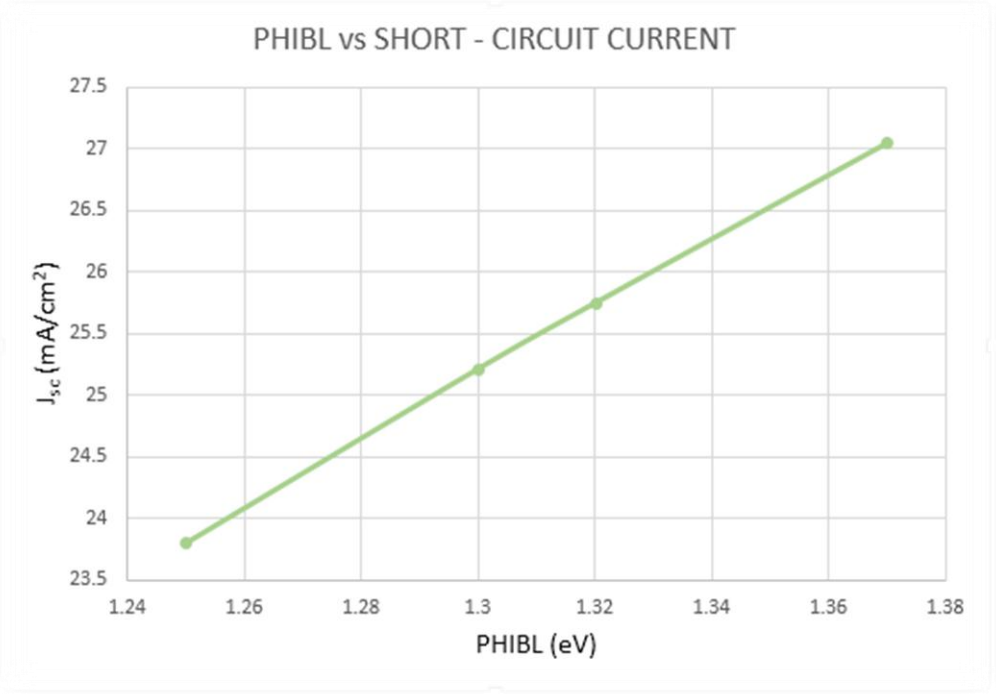

FIG – 3.9: PHIBL vs SHORT CIRCUIT CURRENT

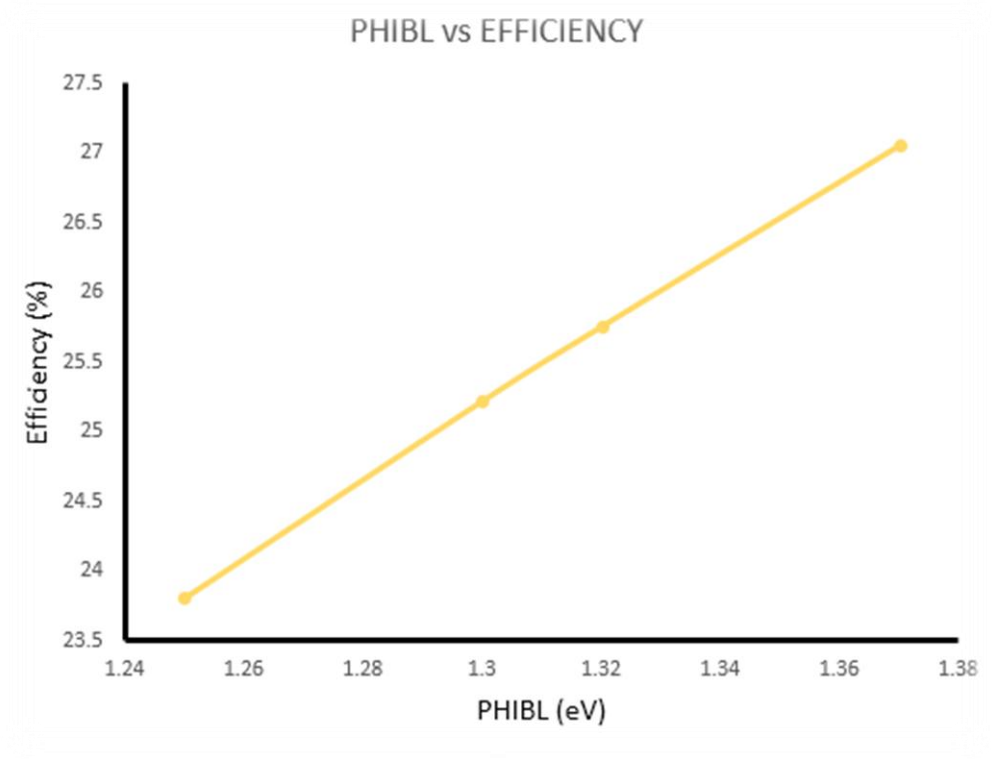

FIG – 3.10 PHIBL vs EFFICIENCY

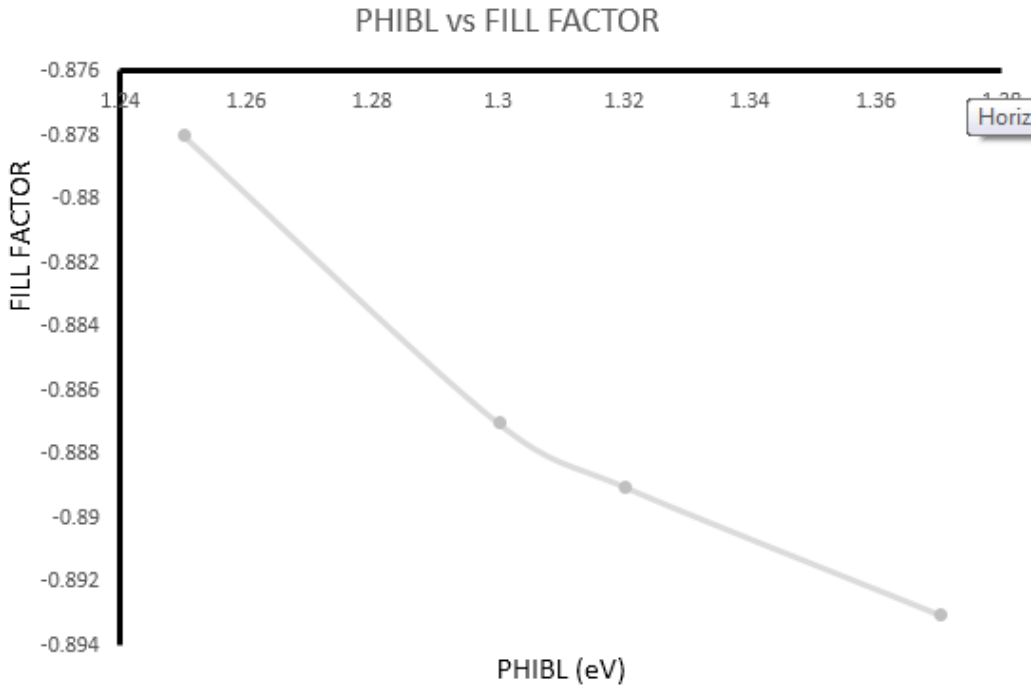

FIG - 3.11: PHIBL vs FF

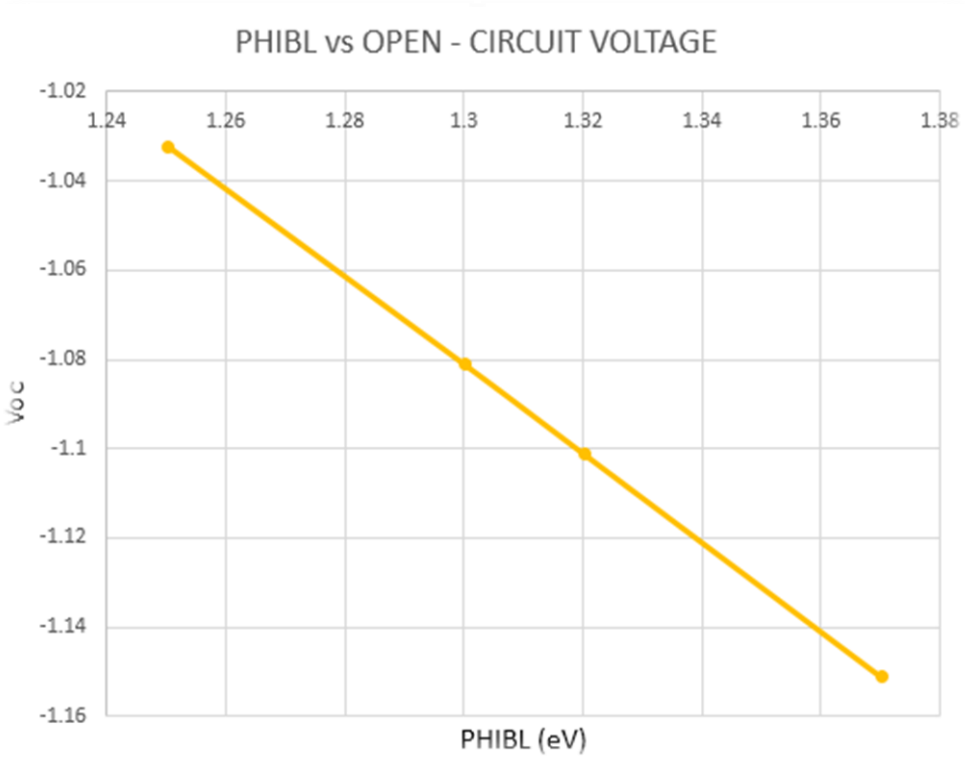

FIG – 3.12: PHIBL vs Voc

From the above results and figures (3.9, 3.10, 3.11, 3.12), it can be seen that as PHIBL increases, the efficiency and the J_{SC} increases even though the FF and the V_{OC} decreases.

It can be clearly seen that Iridium is the clear winner based on these results.

Therefore, a 55 nm p - CdS layer, 1 µm n - CdTe layer, with a J_{SC} of 26.315 mA/cm^2, FF of -0.893 and V_{OC} of – 1.151with an efficiency of 27.056% has been selected for the proposed structure of the solar cell.

3.3 PROPOSED STRUCTURE OF THE SOLAR CELL

In the proposed CdS – CdTe solar cell structure, a p-type layer (which acts as an absorber layer) and a n-type layer is connected to form a single – junction solar cell. A transparent and conducting oxide is staged which acts as the front contact of the cell, generally deposited on high quality glass substrate. Sunlight strike at the p-type material over which a transparent conductor is connected as the front contact. A metal conductor, Iridium is connected as the back contact material. The designed solar cell shown below is a typical structure of CdS – CdTe based solar cell.

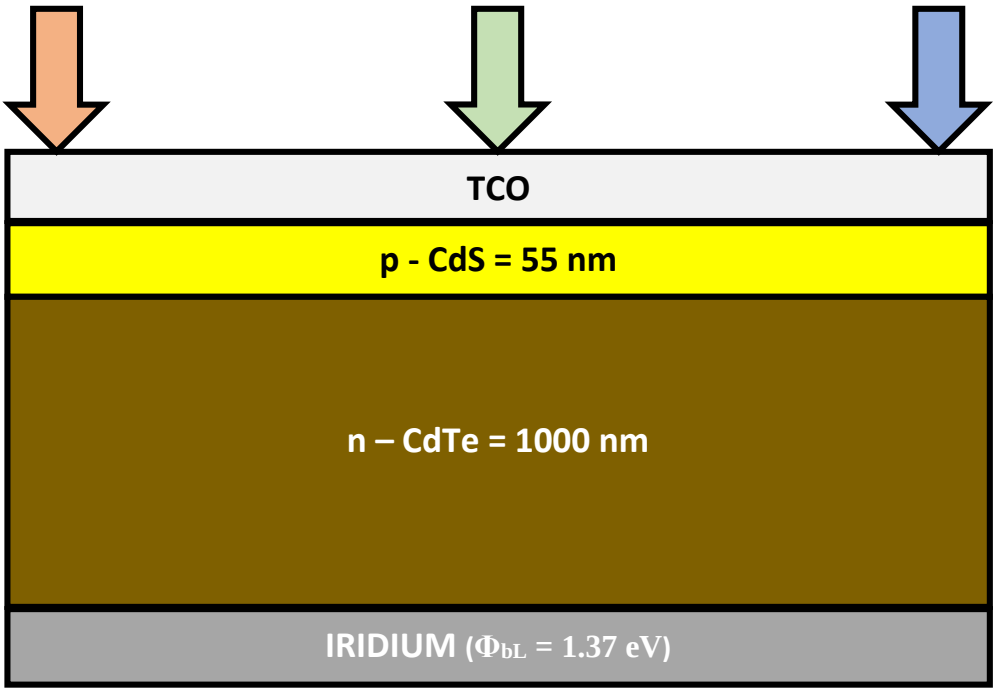

FIG – 3.13: PROPOSED STRUCTURE OF THE CdS – CdTe SOLAR CELL

An optimum silicon solar cell with light trapping and very good surface passivation is about 100 µm thick. However, to get an efficiency of about 25%, thickness between 200 and 500µm are typically used, partly for practical issues such as making and handling thin wafers, and partly for surface passivation reasons. The back contact in the case of silicon solar cells is much less

important than the front contact since it is much further away from the junction and does not need to be transparent.

The design of the rear contact is becoming increasingly important as overall efficiency increases and the cells become thinner [14]. That's why, when CdS – CdTe cells are compared to silicon solar cells, it can be seen that these solar cells requires much less material (about 1/100 of the thickness of silicon) and in these solar cells, the back contact also have impacts on the overall efficiency of the solar cell.

CHAPTER 4

CONCLUSION AND FUTURE WORKS

4.1 CONCLUSION

As the world is suffering from impending death of fossil fuels and serious pollution resulted from the fuels, solar energy is now regarded as one promising solution to the global energy crisis. Thin film CdS/CdTe has long been regarded as one promising choice for the development of cost-effective and reliable solar cells.

In this thesis, a single junction CdS – CdTe solar cell has been designed and simulated by using AMPS 1D simulator. Optimization of layer thickness of p – CdS and n – CdTe was analyzed. Also, different metals were used to analyze the most suitable metal for the back contact. In this research, the temperature was kept constant at 300°K.

A highly efficient 27.056% (V_{oc} = -1.151 V, J_{sc} = 26.315 mA/cm^2, FF = -0.893) ultra – thin CdS – CdTe solar cell has been obtained with the CdS thickness of 55 nm and CdTe thickness as 1µm with a back contact made up of Iridium. The thickness is reduced than other conventional cells as it will reduce the cost effectively.

4.2 FUTURE WORKS

1. The designed cells of this work needs to be fabricated for further investigation
2. This model may be used for further research on tandem solar cells
3. Further studies can be done using other factors that are constraints in the reduction of thickness

LIST OF ABBREVIATIONS

AMPS	ANALYSIS OF MICROELECTRONIC AND PHOTONIC STRUCTURE
CdTe	CADMIUM TELLURIDE
CdS	CADMIUM SULFIDE
T	TEMPERATURE
R_F	REFLECTION COEFFICIENT OF FRONT SURFACE
R_B	REFLECTION COEFFICIENT OF BACK SURFACE
E_G	ENERGY BAND GAP
EPS	RELATIVE PERMITTIVITY
MUN	ELECTRON MOBILITY
MUP	HOLE MOBILITY
FF	FILL FACTOR
J_{SC}	SHORT CIRCUIT CURRENT DENSITY
Voc	OPEN CIRCUIT VOLTAGE
N_A	ACCEPTOR CONCENTRATION
N_V	DONOR CONCENTRATION

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