*Photovoltaic Science & Engineering*

*PHY-507T*

Assignment Report on

# ***"CIGS Based Multi-Junction Solar Cell"***

*"Simulation"*

*Using*

*Scaps-1D Tools*


Submitted by

**EVD17I009**

**Ranjan Yadav**

Department of ECE

Indian Institute of Information Technology, Design and Manufacturing

Kancheepuram, Tamil Nadu, 600-127

## Acknowledgement:

I would like to thank **Dr. Vivek Kumar sir** for his valuable teaching about photovoltaic science and engineering which served as a starting point and major reference source for my Project.

Additionally, I would like to express my heartfelt gratitude to the Dean Academic Dr. Binsu J. Kailath, Dr. KP Pradhan, Dr. Prerna Saxena and all dear faculties from department of electronics and communication engineering, IIITDM-Chennai, and many TAs for laying the foundation for my engineering background knowledge and laying concepts and providing their valuable insight and guidance at various steps of the development process .

I extend this appreciation towards authors from various other sources who have provided all the relevant information in fields related to my projects that have made the completion of these projects possible.

Furthermore, I would like to thank my family and friends for their continued support and encouragement throughout. Without them, this would not have been made possible, as they have helped push me further and further to reach my desired destination.

Last, but not least, I would like to thank my peers who have lent their support, advice and much appreciated words of encouragement. Their valuable input and suggestions with respect to my project is thoroughly appreciated.

## Abstract:

To enhance the efficiency of earlier presented, CIGS based 3-layer MJ solar cell by inserting the novel back surface field (SnS) layer. Also, to analyze the effects of changing the width parameter for absorber, buffer and back surface field layer and to implement ZnS as buffer layer and establishing it as substitute for CdS.

# BONAFIDE CERTIFICATE

Certified that project report on **"To enhance the efficiency of earlier presented, CIGS based 3-layer MJ solar cell by inserting the novel back surface field (SnS) layer. Also, to analyze the effects of changing the width parameter for absorber, buffer and back surface field layer and to implement ZnS as buffer layer and establishing it as substitute for CdS"** is the bonafide work of Ranjan Yadav who carried out the project work under mentorship of Dr. Vivek Kumar Sir.

## Course Coordinator

Dr. Vivek Kumar Sir
Assistant Professor
IIITDM-CHENNAI

## Head of ECE Department

Dr.Priyanka Kokil
Assistant Professor
IIITDM-CHENNAI

## Dean Academics

Dr. Binsu J Kailath
Associate Professor
IIITDM-CHENNAI

# Introduction:

**Solar Cell:**

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Individual solar cell devices can be combined to form modules, otherwise known as solar panels.

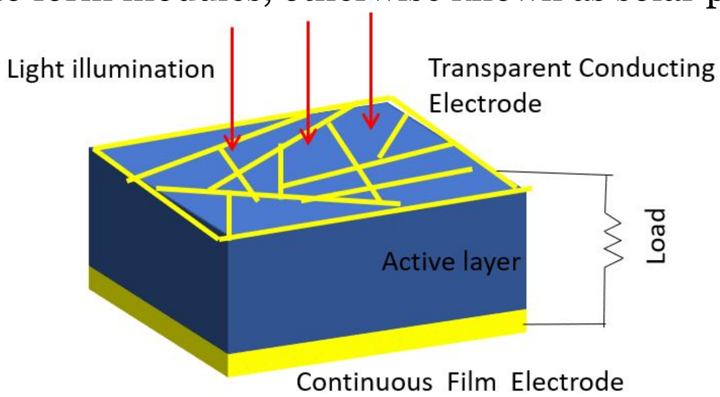



**Fig1: Working of Solar Cell**

**Multi-junction solar cell:**

Multi-junction (MJ) solar cells are solar cells with multiple p–n junctions made of different semiconductor materials. Each material's p-n junction will produce electric current in response to different wavelengths of light. The use of multiple semiconducting materials allows the absorbance of a broader range of wavelengths, improving the cell's sunlight to electrical energy conversion efficiency.

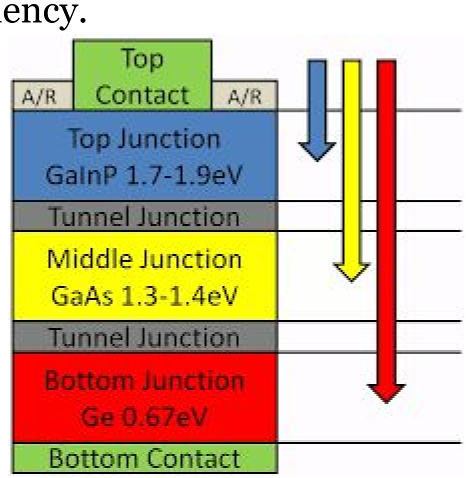



**Fig2: MJSC Example**

**Ideation:**

Cells made from multiple materials layers can have multiple bandgaps and will therefore respond to multiple light wavelengths, capturing and converting some of the energy that would otherwise be lost to relaxation as we know.

For instance, if one had a cell with two bandgaps in it, one tuned to red light and the other to green, then the extra energy in green, cyan and blue light would be lost only to the bandgap of the green-sensitive material, while the energy of the red, yellow and orange would be lost only to the bandgap of the red-sensitive material.

1. Conveniently, light of a particular wavelength does not interact strongly with materials that are of bigger bandgap. This means that you can make a multi-junction cell by layering the different materials on top of each other, shortest wavelengths (biggest band-gap) on the "top" and increasing through the body of the cell.
2. As the photons have to pass through the cell to reach the proper layer to be absorbed, transparent conductors need to be used and also to collect the electrons being generated at each layer.

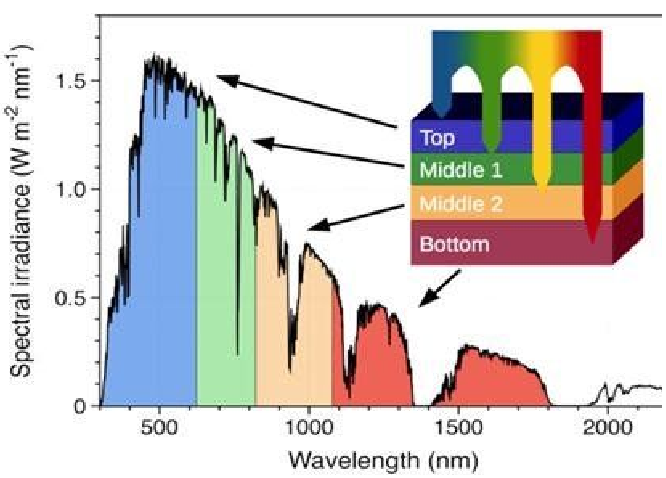



**Fig3: Spectrum Utilization**

**Comparing multi-junction and single-junction solar cells:**

1. **Efficiency:**
   a. A solar cell efficiency is a measure of what percentage of incoming light that hits the cell can be converted to electricity.
   b. In terms of theoretical efficiency, multi-junction solar cells have the potential to significantly outperform traditional single-junction solar cells.
   c. According to the Department of Energy, multi-junction solar cells with three junctions have theoretical efficiencies over 45 percent, while single-junction cells top out at about 33.5 percent. Adding more junctions (potentially up to 5 or 6 junctions) could boost efficiency over 70 percent. For reference, the most efficient solar panels available today have efficiencies around 22 percent.

2. **Materials:**
   a. Single-junction solar cells are typically made using silicon as a semiconductor, while multi-junction solar cells commonly use three separate semiconductors: gallium indium phosphide (GaInP), indium gallium arsenide (InGaAs), and germanium (Ge).

3. **Pricing:**
   a. One thing is for sure: multi-junction solar cell production is a more complicated and difficult process using more expensive materials, so they'll likely cost more than single-junction cells when they hit the mass market.
   b. There aren't commercially-available multi-junction solar cells yet, which means that pricing is mostly speculation.

**CIGS as material:**

CIGS is important material for terrestrial based solar cells applications because of their high efficiency, long-term stable performance and potential for low-cost production. Thin film solar-cells with polycrystalline Cu(In,Ga)Se2 (CIGS ) absorber layers provide a good alternative to wafer based crystalline silicon solar cells, which currently constitute the major share of photovoltaics installed and used worldwide. The CIGS based solar cells exhibit excellent outdoor stability, radiation hardness and highest efficiencies (19.2%).

1. These compounds are direct bandgap semiconductors which minimize the requirement for long minority carrier diffusion lengths.

2. Such p-type semiconductors with high absorption coefficient are the promising absorbing materials for thin film photovoltaic technology.

3. Buffer layer is an intermediate layer film between the absorber and window layers with two main objectives,
   A. to provide structural stability to the device &
   B. to fix the electrostatic conditions inside the absorber layer.

4. Cadmium sulphide (CdS) is a prominent candidate to be used as a buffer layer in Cu(In,Ga)Se2 based solar cells.

**Note that** Cadmium (Cd) is a metal that can cause severe toxicity in humans and the environment.

| |
|---|
| **ZnO{n type}** |
| **Buffer layer(ZnS/CdS){n type}** |
| **CIGS(Absorber layer){p type}** |
| **SnS(Back field Layer){p type}** |

Above table Shows 4-layers arrangement with SnS layer for CIGS based MJ solar cell

**SnS as material:**

1. SnS is a tin compound with desirable qualities such as non toxicity, low cost, and good hydrolytic stability.

2. SnS has been actively studied due to its p-type semiconductor characteristics and remarkable optoelectronic properties. Particularly, the low process temperature of the tin compound is a great advantage. The use of a low process temperature improves the process efficiency, prevents device degradation, and enables application on flexible substrates.

3. Crystallographically, SnS has a double-layered orthorhombic structure under usual process conditions, as shown in Figure 4 . Atoms are covalently bonded in the planar layers, and individual layers are bonded by van der Waals forces. The orthorhombic structure has two carrier paths perpendicular to each other along the basal plane . One path has a zigzag shape, and the other is called the armchair direction. In the case of physical properties, SnS films generally have a carrier concentration of $10^{15}$ to $10^{17}$ $cm^{-3}$, carrier mobility greater than 15 $cm^2/V\text{-}s$, a strong absorption coefficient greater than 104 $cm^{-1}$ in the visible region, and a bandgap of 1.25 eV.

4. SnS is a strong candidate material for various energy devices, such as solar cells, batteries, water splitting devices, and thermoelectrics, due to the excellent optoelectronic properties and stable p-type characteristics.

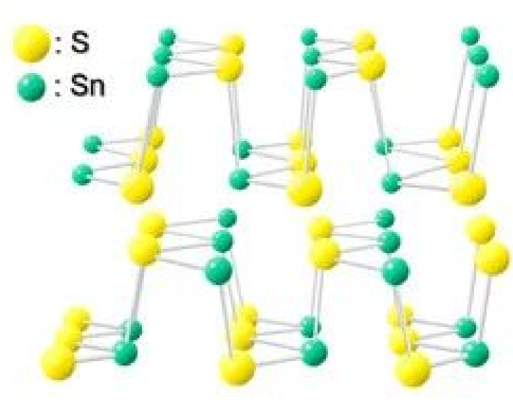



**Fig4: Structure of SnS**

**Importance of having SnS as BSF(back surface field layer):**

1. The BSF layer has a role of the creation of a retarded electric field on the back face which permits the decrease of the effective value of the speed of recombination and therefore improve the electrical characteristics of the solar cell.

2. Thus, adding an electric field in the vicinity of the ohmic contact at the rear surface, makes the minority carriers be pushed towards the space charge zone for a better collection . An improvement is obtained on the current-photon open circuit voltage and photovoltaic conversion efficiency.

3. The low band-gap material (SnS) is inserted as a BSF layer between the absorber layer and the back contact to reduce the barrier height, and to make possible recombination loss at the back contact of the ultra thin CIGS cell.

4. The SnS layer serves as a BSF to reflect back the carriers (electrons) from the CIGS junction and thus would contribute in the enrichment of carriers.

# Simulation Using SCAPS-1D:

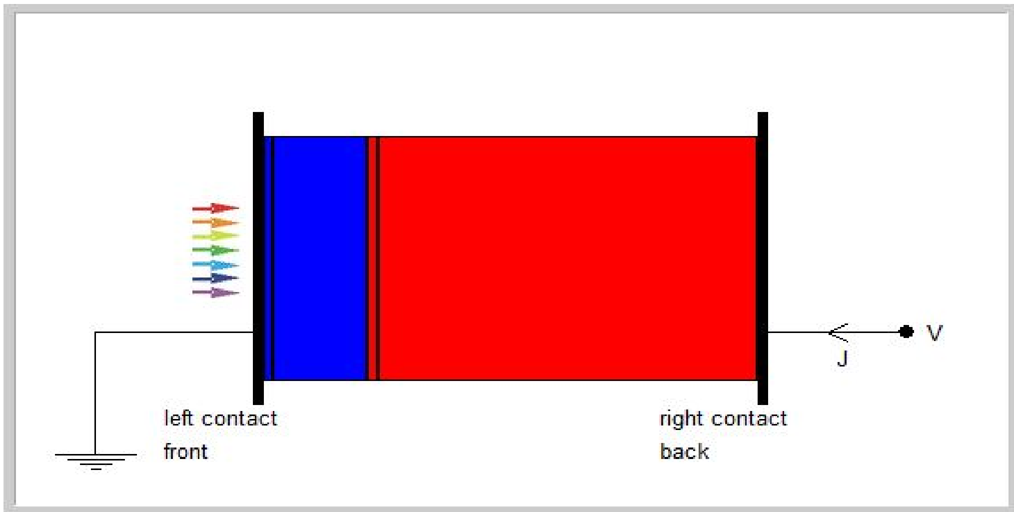



**Fig-5:** Diagram for 4-layer MJ Simulated CIGS based Solar Cell, First layer is ZnO, then Buffer layer(ZnS/CdS) then CIGS layer, SnS layer(moving from left to right).

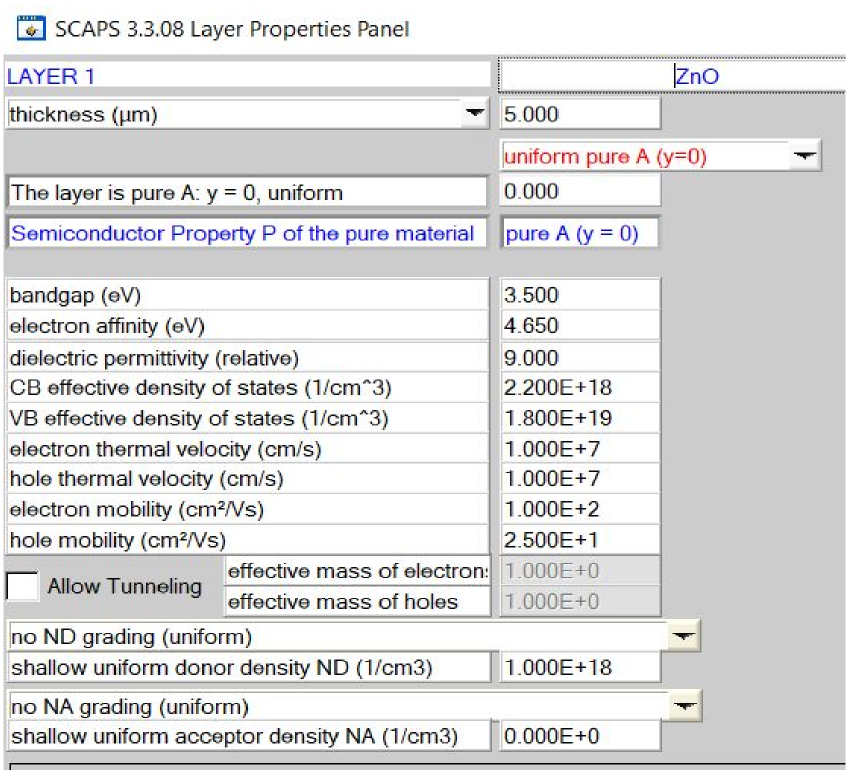



**Fig-6 :** Properties of ZnO layer . N-type surface. Also, this layer will have direct light contact

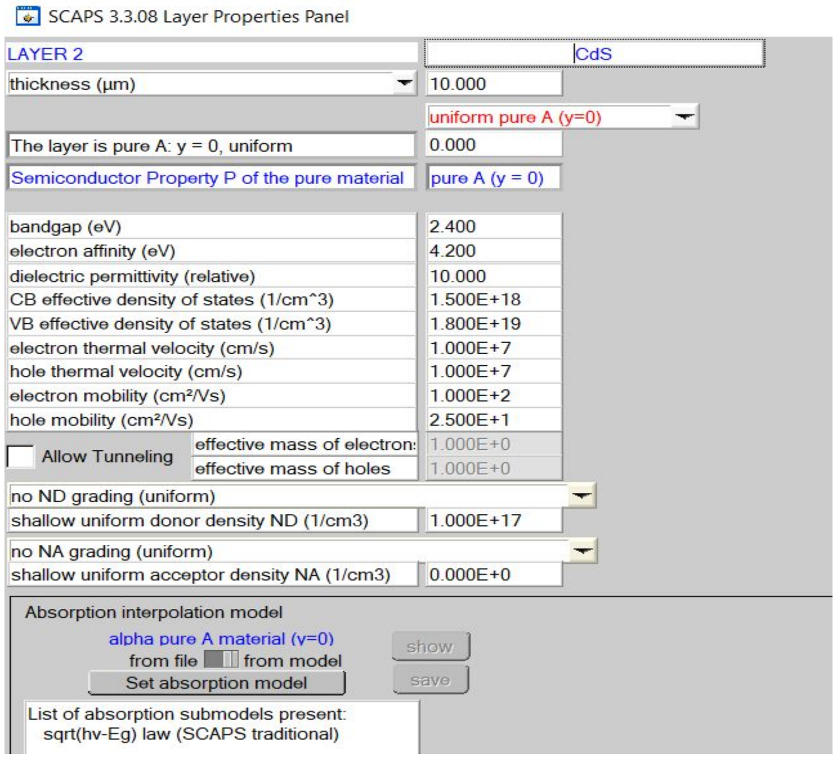



**Fig-7** : Properties of CdS layer . N-type surface. This layer is called a buffer layer.

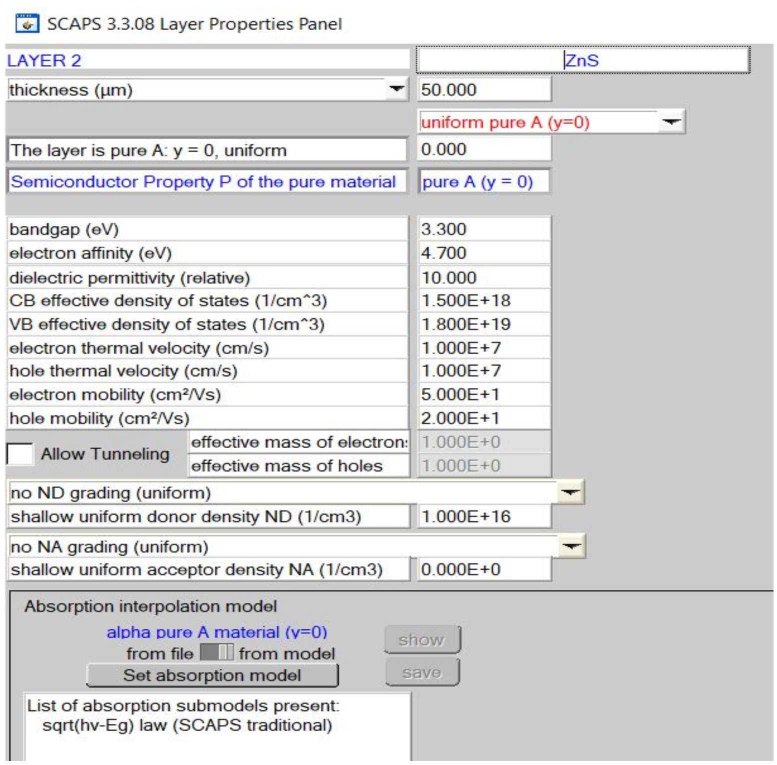



**Fig-8** : Properties of ZnS layer . N-type surface. This layer is called a buffer layer.

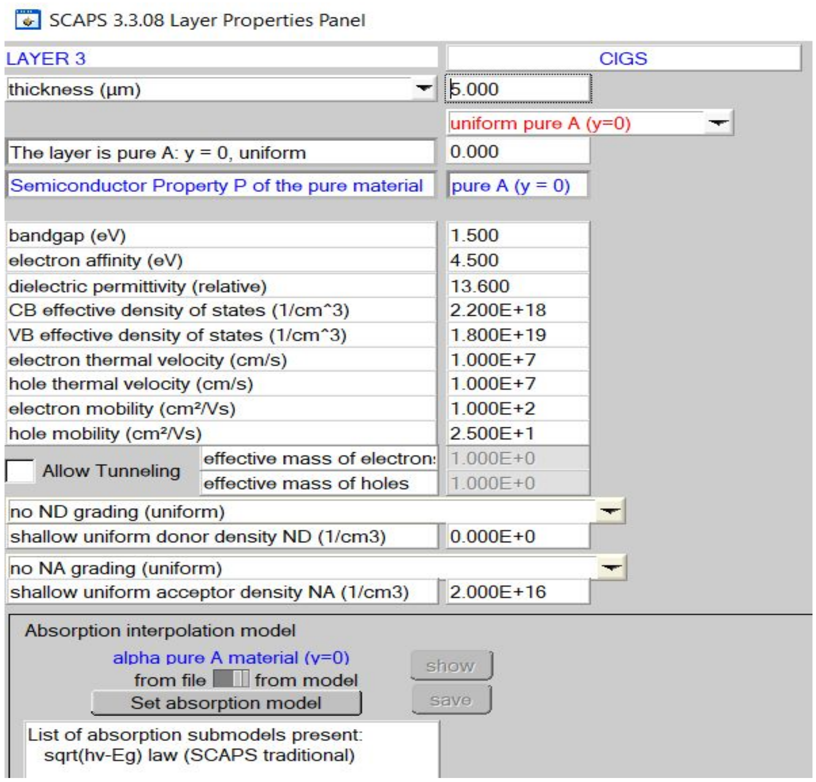



**Fig-9** : Properties of CIGS layer . P-type surface. This layer is called an absorber layer.

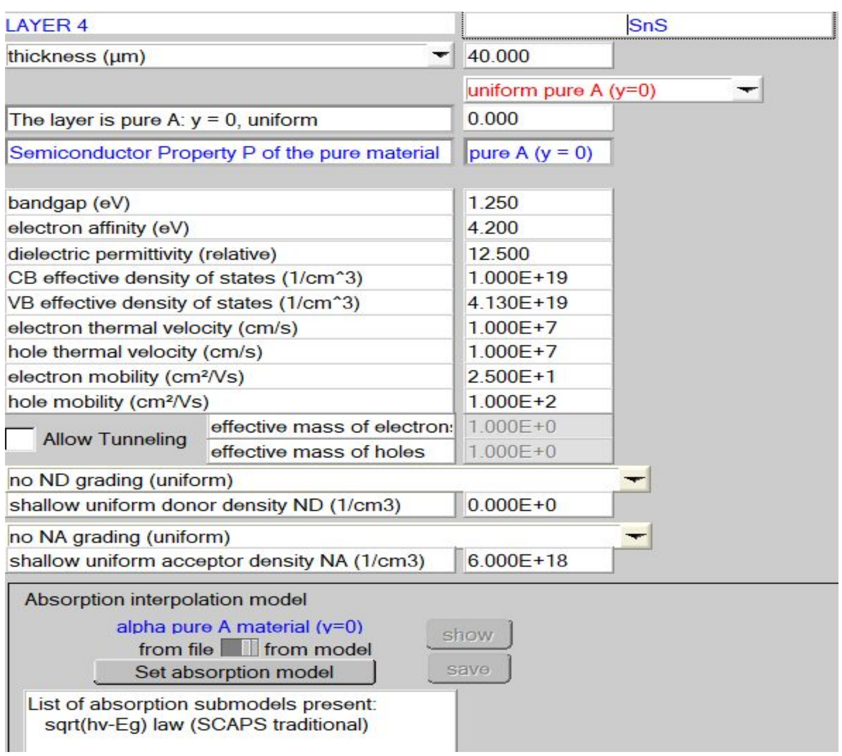



**Fig-10** : Properties of SnS layer . P-type surface. This layer is called the Back field layer.

# Experimental Results:

## Case 1. Effect of Variation of Width of CdS layer("Buffer-layer"), keeping ZnO, CIGS , SnS constant at 5um, 5um, 200um respectively.

| ZnO(um) | CdS(um) | CIGS(um) | SnS(um) | Voc | Isc | FF | Eta |
|---|---|---|---|---|---|---|---|
| 5 | 10 | 5 | 200 | 1.0217 | 36.0764 | 86.37 | 31.84 |
| 5 | 20 | 5 | 200 | 1.0217 | 36.08134 | 86.44 | 31.87 |
| 5 | 30 | 5 | 200 | 1.0217 | 36.081107 | 86.47 | 31.87 |
| 5 | 40 | 5 | 200 | 1.0217 | 36.082282 | 86.48 | 31.88 |
| 5 | 50 | 5 | 200 | 1.0217 | 36.081322 | 86.49 | 31.88 |
| 5 | 60 | 5 | 200 | 1.0217 | 36.087427 | 86.5 | 31.89 |
| 5 | 90 | 5 | 200 | 1.0217 | 36.090402 | 86.51 | 31.9 |
| 5 | 120 | 5 | 200 | 1.0217 | 36.087954 | 86.57 | 31.9 |

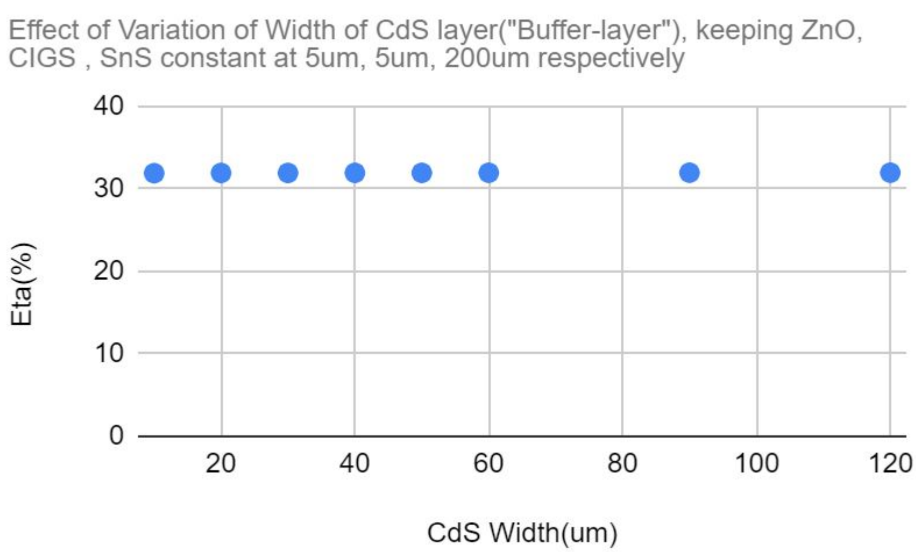
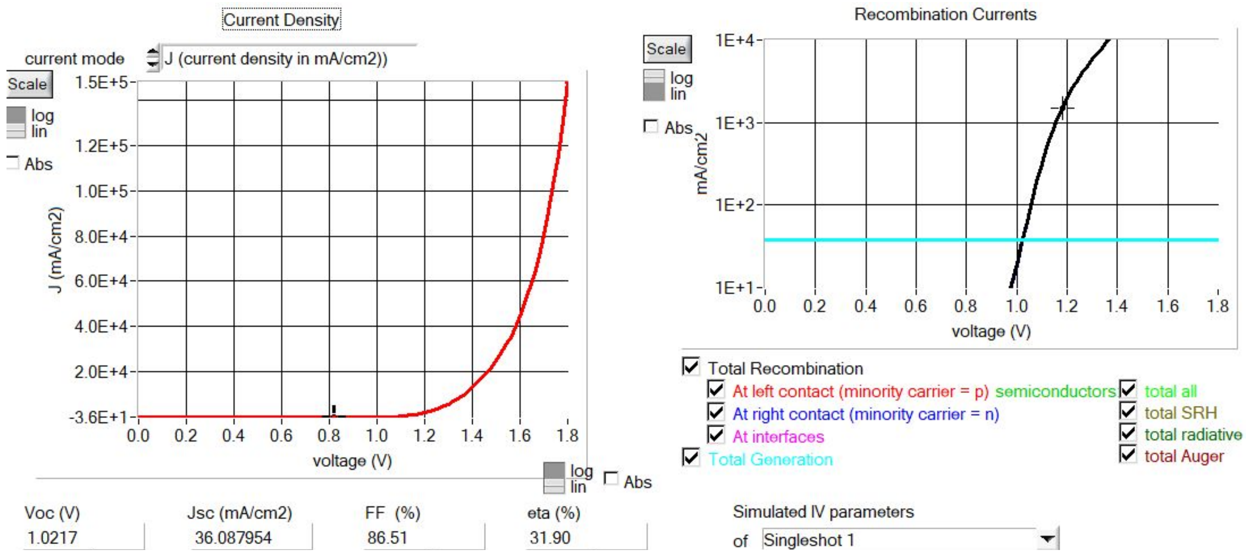
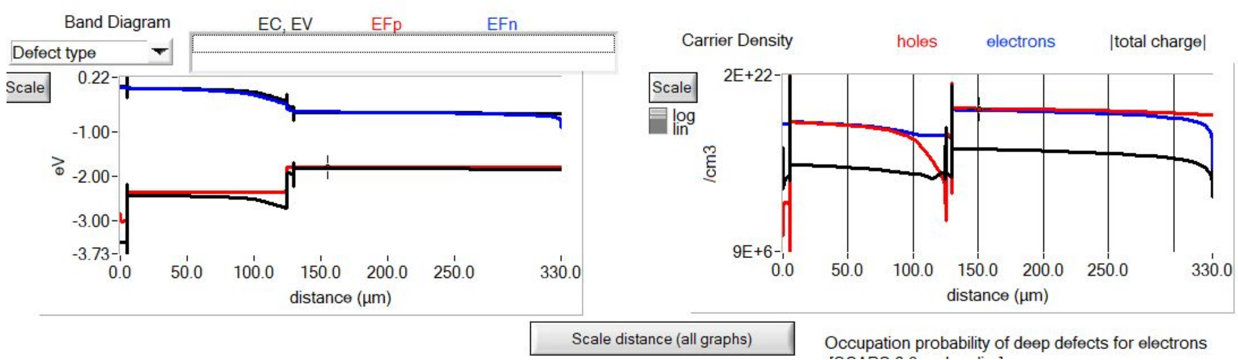
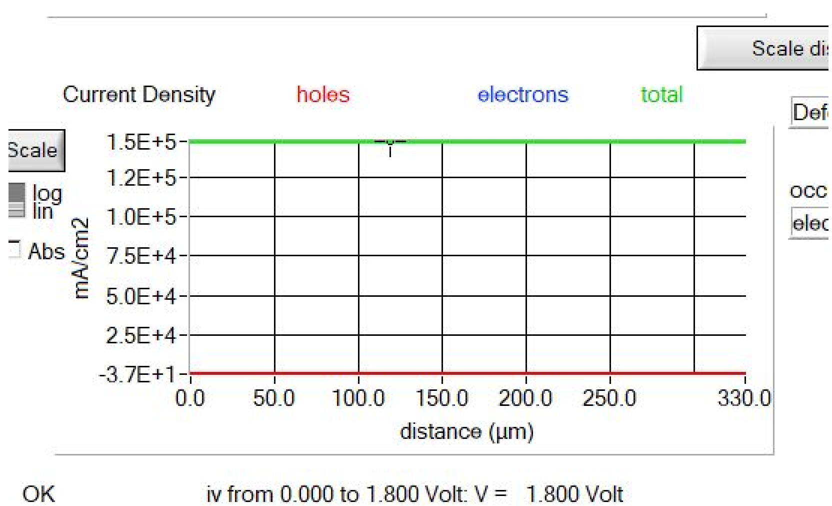



**Fig-11 :** Simulation result on eta vs width of CdS from 10 um to 120 um, shows that eta is almost constant . We can see that by adding SnS layer, the efficiency got boosted by 7-8% which shows the benefit for having MJSC.

# Other plots for maximum efficiency from case 1:



**Case 2. Effect of Variation of Width of SnS layer("Back-layer"), keeping ZnO, CdS , CIGS constant at 5um, 90um, 5um respectively**

| ZnO(um) | CdS(um) | CIGS(um) | SnS(um) | Voc | Isc | FF | Eta |
|---|---|---|---|---|---|---|---|
| 5 | 90 | 5 | 10 | 0.9629 | 32.07 | 85.49 | 26.4 |
| 5 | 90 | 5 | 20 | 0.9781 | 33.3208 | 85.53 | 27.79 |
| 5 | 90 | 5 | 30 | 0.9828 | 34.0018 | 85.59 | 28.6 |
| 5 | 90 | 5 | 40 | 0.9882 | 34.447039 | 85.77 | 29.2 |
| 5 | 90 | 5 | 50 | 0.9926 | 34.76077 | 85.84 | 29.62 |
| 5 | 90 | 5 | 90 | 1.0046 | 35.46107 | 86.08 | 30.67 |
| 5 | 90 | 5 | 120 | 1.0105 | 35.72627 | 86.27 | 31.15 |
| 5 | 90 | 5 | 150 | 1.0154 | 35.907004 | 86.32 | 31.47 |
| 5 | 90 | 5 | 200 | 1.0217 | 36.090402 | 86.51 | 31.9 |

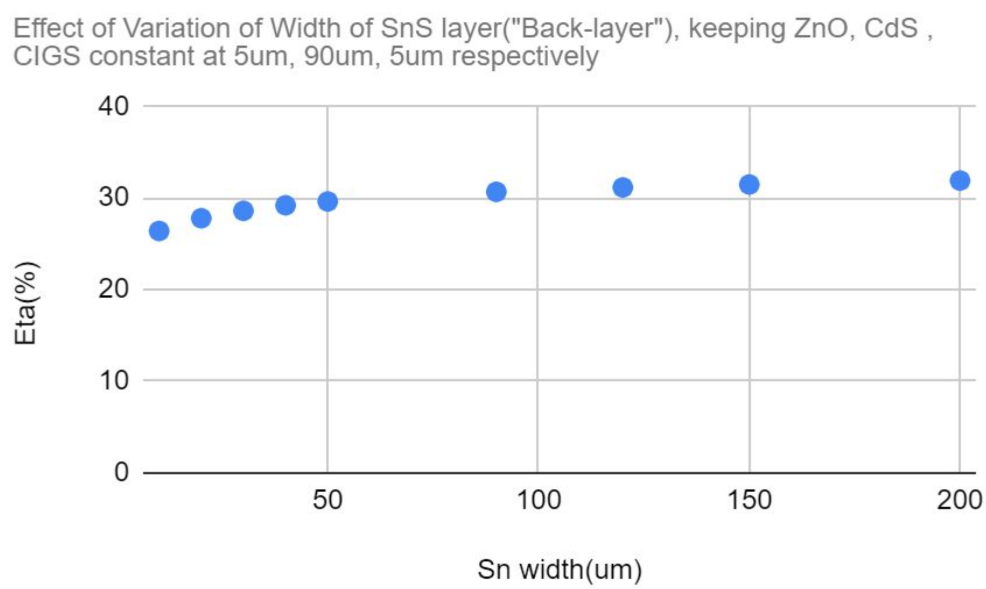
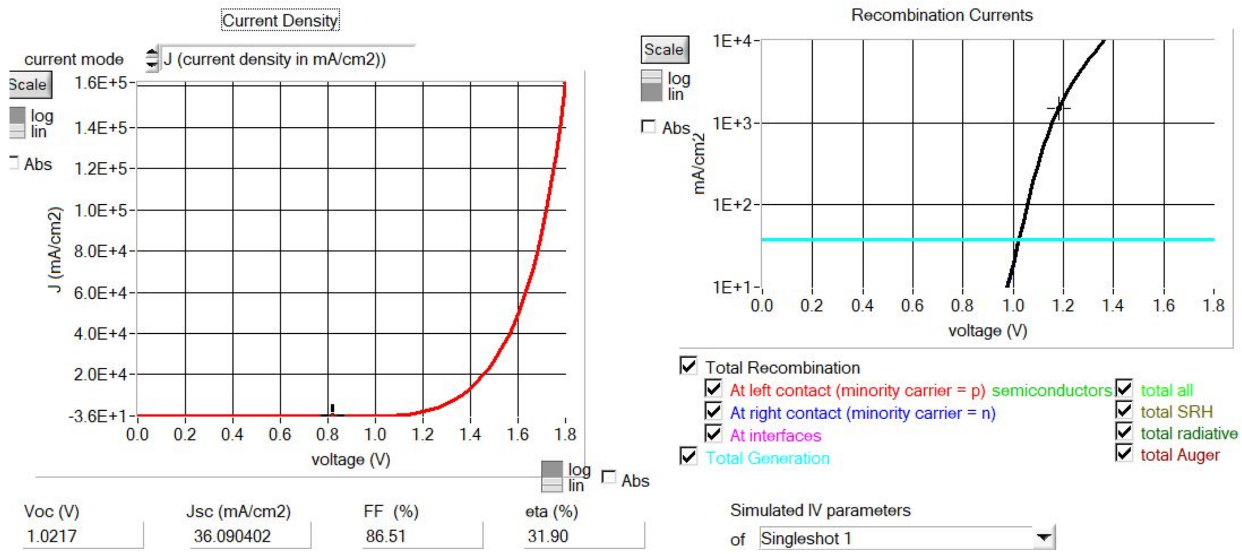
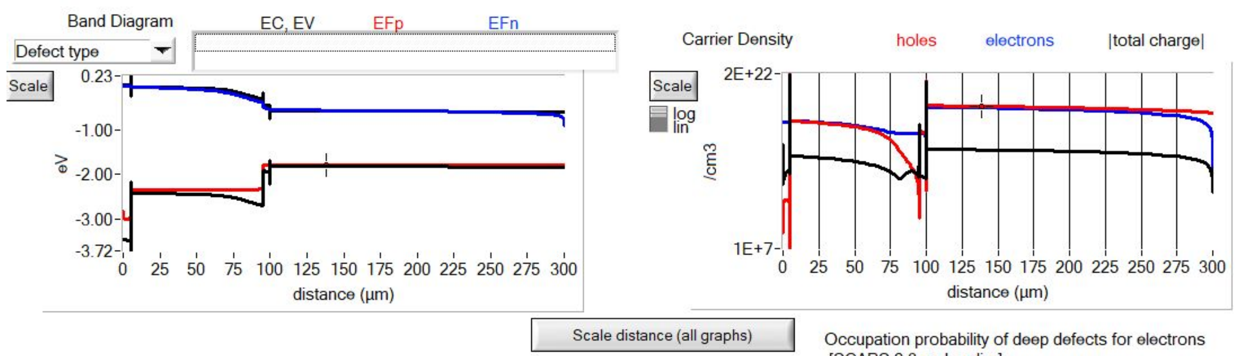
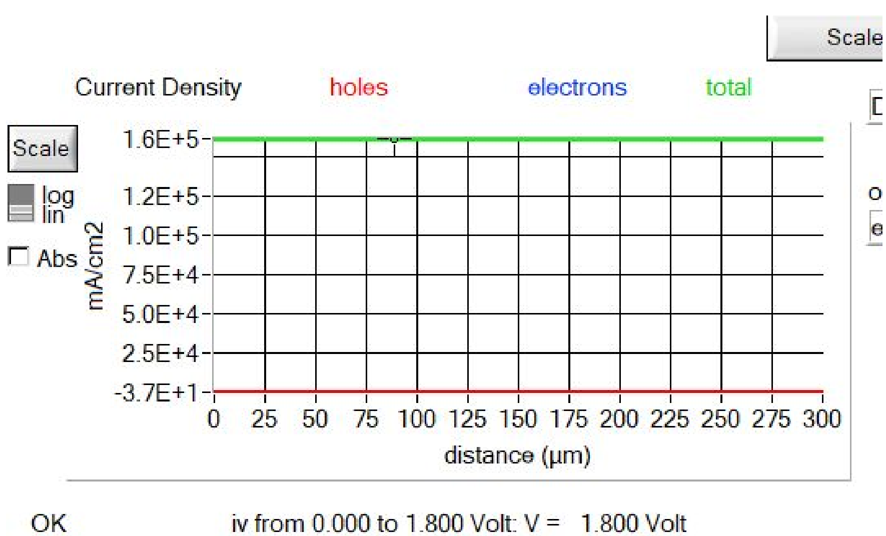



**Fig-12 :** Simulation result on eta vs width of SnS varied from 10 um to 200 um, shows that eta enhancement is almost 6-7%. The eta efficiency is very observable and still for ultra thin efficiency is above 26% which is really good and can be implementable where we need to have a minimum area. However, fabricating upto 200 um which is as similar to size of crystalline Si SC, and efficiency got boosted by 8-10% .

# Other plots for maximum efficiency from case 2:



**Case 3. Effect of Variation of Width of CIGS layer("Absorber-layer"), keeping ZnO, CdS , SnS constant at 5um, 50um, 200um respectively.**

| ZnO(um) | CdS(um) | CIGS(um) | SnS(um) | Voc | Isc | FF | Eta |
|---|---|---|---|---|---|---|---|
| 5 | 50 | 2 | 200 | 1.0518 | 36.54361 | 87.27 | 32.4 |
| 5 | 50 | 3 | 200 | 1.018 | 36.419733 | 86.94 | 32.23 |
| 5 | 50 | 5 | 200 | 1.0217 | 36.081332 | 86.49 | 31.88 |

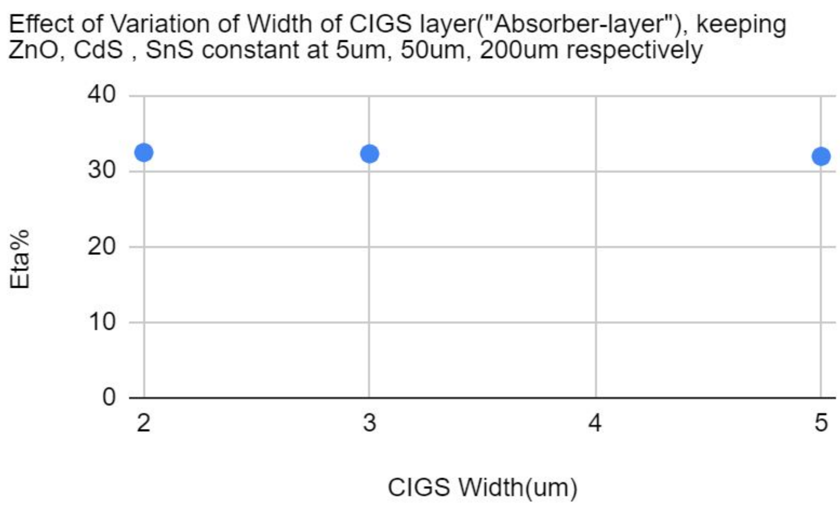
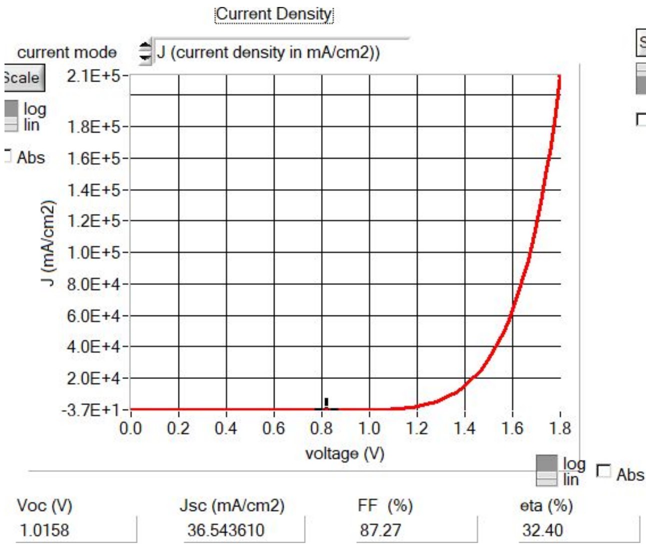
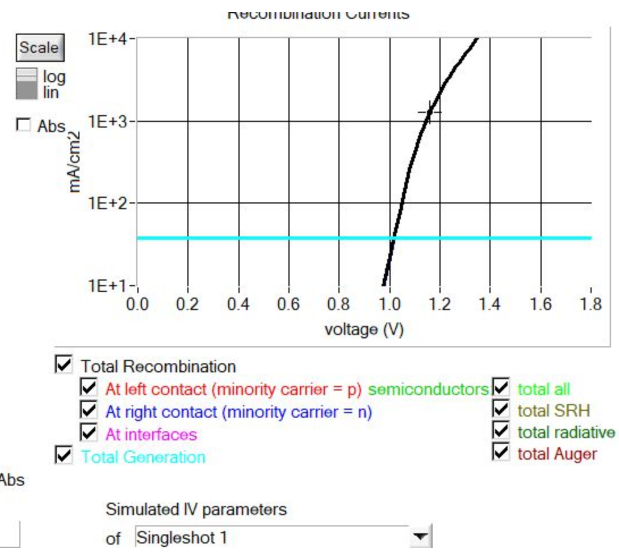
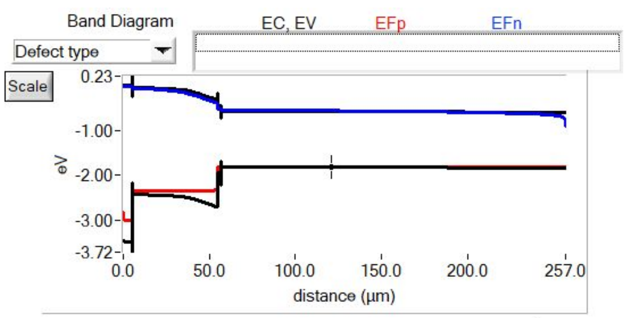


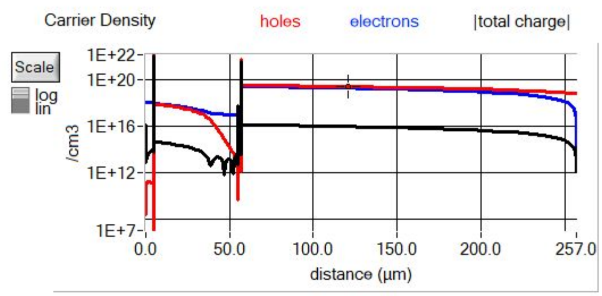

**Fig-13**: Simulation result on eta vs width of CIGS(absorber layer) with CdS as buffer layer, shows that eta enhancement is almost 0.7% . Increase in eta is observable however it is not drastic. We can also see that for 2um we have maximum efficiency out of these 3 cases, which shows the benefit of having ultra thin CIGS to enhance the efficiency. However precision of fabrication in labs matters most so we may have to choose sizing effectively depending upon application.

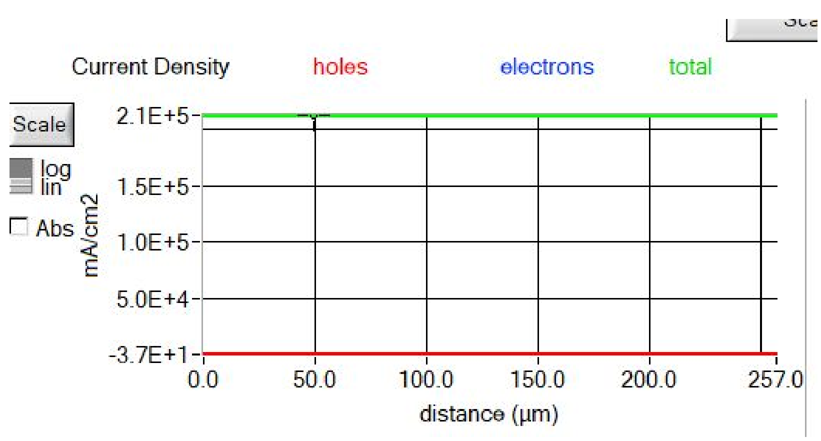
## Other plots for maximum efficiency from case 3:



**Case 4: Effect of Variation of Width of ZnS layer("Buffer-layer"), keeping ZnO, CIGS, SnS constant at 5um, 5um, 200um respectively.**

| ZnO(um) | ZnS(um) | CIGS(um) | SnS(um) | Voc | Isc | FF | Eta |
|---|---|---|---|---|---|---|---|
| 5 | 10 | 5 | 200 | 1.0227 | 36.035934 | 86.45 | 31.84 |
| 5 | 20 | 5 | 200 | 1.0217 | 36.036066 | 86.4 | 31.81 |
| 5 | 30 | 5 | 200 | 1.0217 | 36.036156 | 86.35 | 31.79 |
| 5 | 40 | 5 | 200 | 1.0217 | 36.03629 | 86.25 | 31.75 |
| 5 | 50 | 5 | 200 | 1.0217 | 36.03616 | 86.03 | 31.68 |

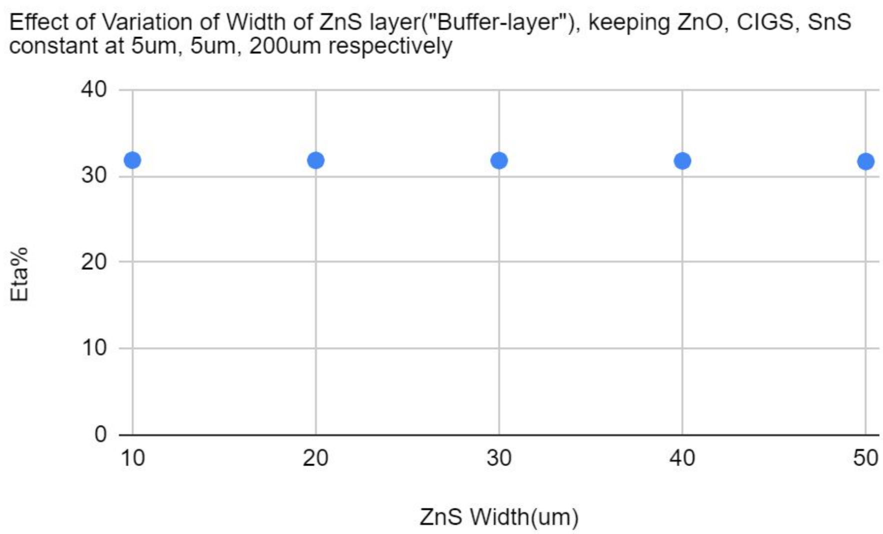
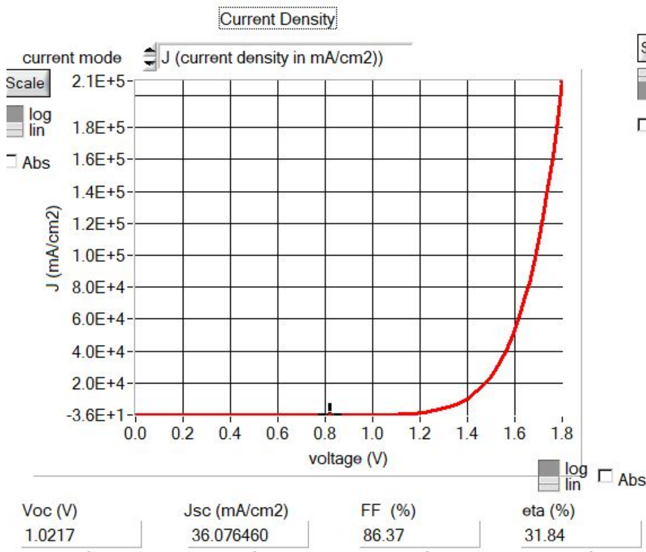


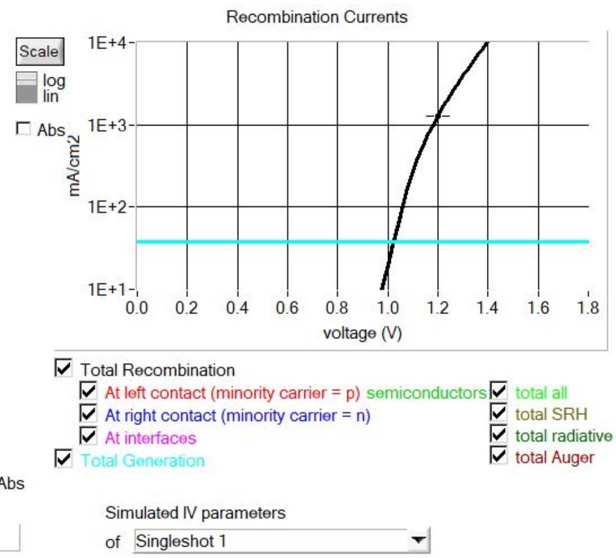

**Fig-13 :** Simulation result on eta vs width of ZnS(buffer layer), shows that eta is almost constant. Eta practical value is around that of CdS. Hence it is good substituting material for CdS.

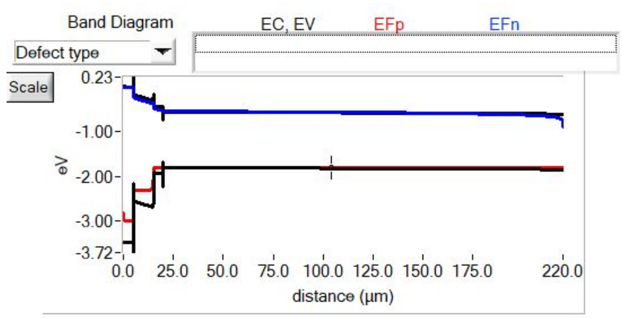
**Note**: Cd is highly toxic in nature for humans as well as the environment.

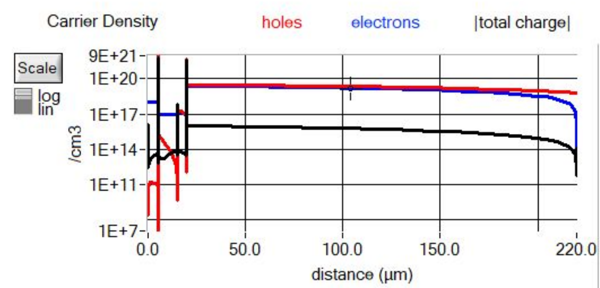
As similar to case 1, We can see efficiency got boosted by around 7-8%, which can be generated by adding a SnS layer of 200 um.

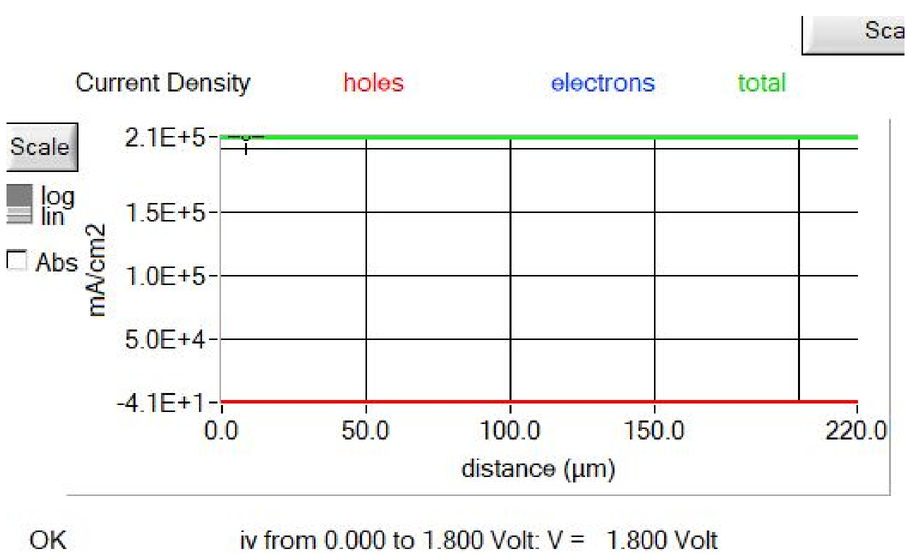
# Other plots for maximum efficiency from case 4:



## 5. Effect of Variation of Width of CIGS layer("Absorber-layer"), keeping ZnO, ZnS , CIGS constant at 5um, 10um, 200um respectively.

| ZnO(um) | ZnS(um) | CIGS(um) | SnS(um) | Voc | Isc | FF | Eta |
|---|---|---|---|---|---|---|---|
| 5 | 10 | 2 | 200 | 1.0517 | 36.498109 | 87.19 | 32.32 |
| 5 | 10 | 3 | 200 | 1.0179 | 36.372253 | 86.47 | 32.16 |
| 5 | 10 | 5 | 200 | 1.0277 | 36.035934 | 86.55 | 31.03 |

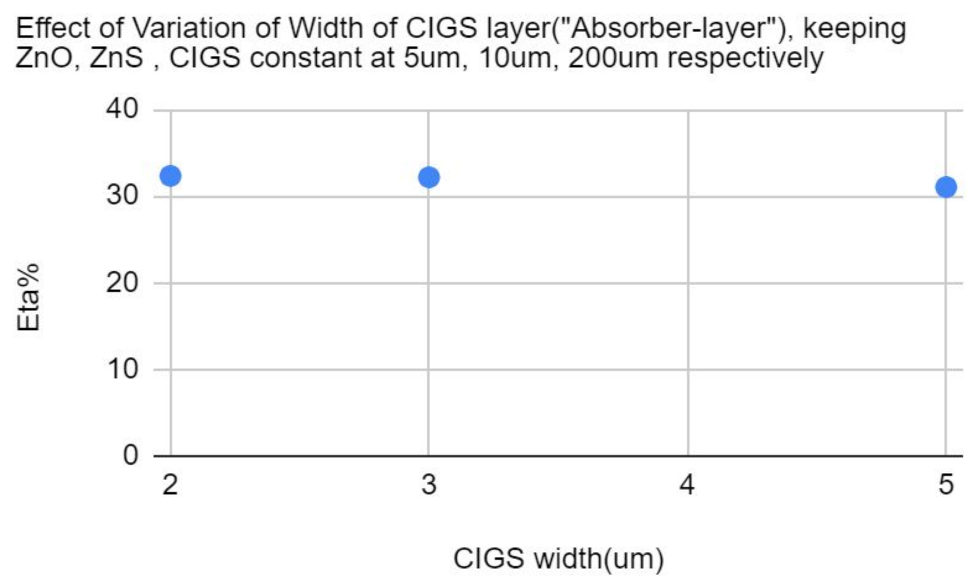
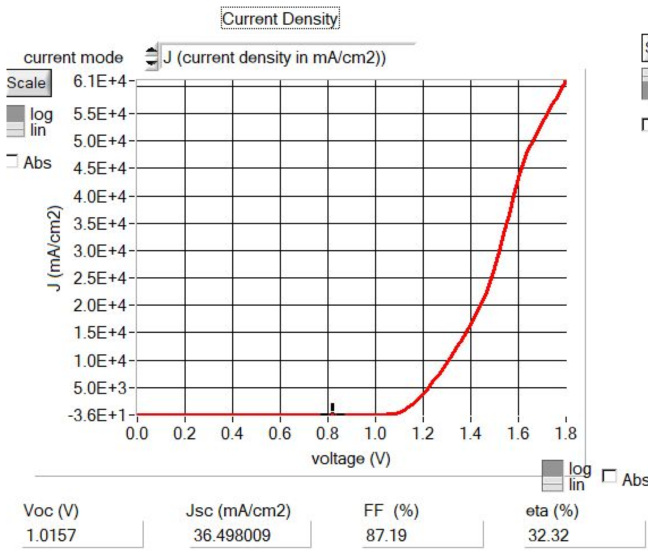
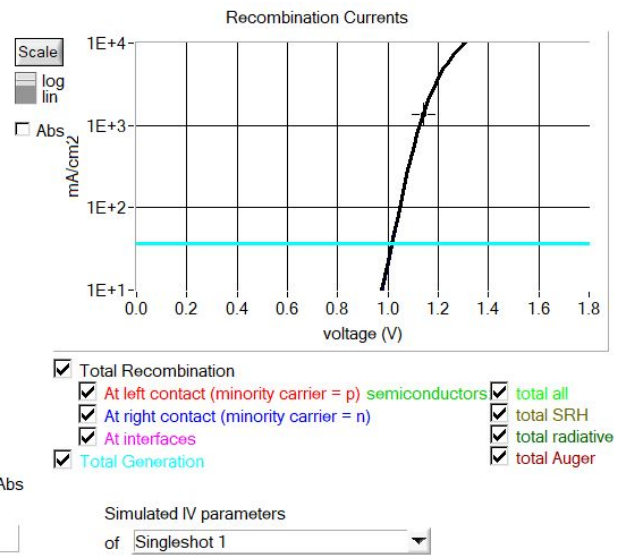
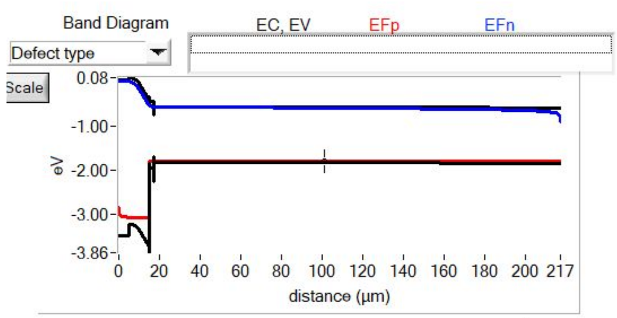


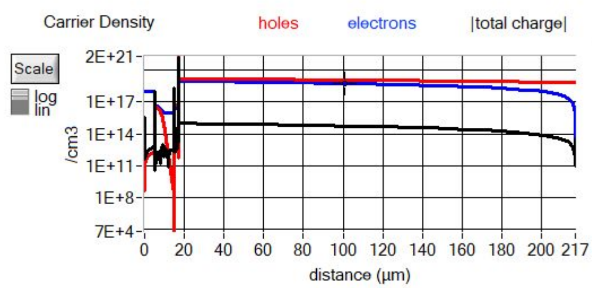

**Fig-14** : Simulation result on eta vs width of CIGS(absorber layer) with ZnS as buffer layer, shows that eta enhancement is almost 0.3% . Increase in eta is observable however it is not drastic. We can also see that for 2um we have maximum efficiency out of these 3 cases, which shows the benefit of having ultra thin CIGS to enhance the efficiency. However precision of fabrication in labs matters most so we may have to choose sizing effectively depending upon application.

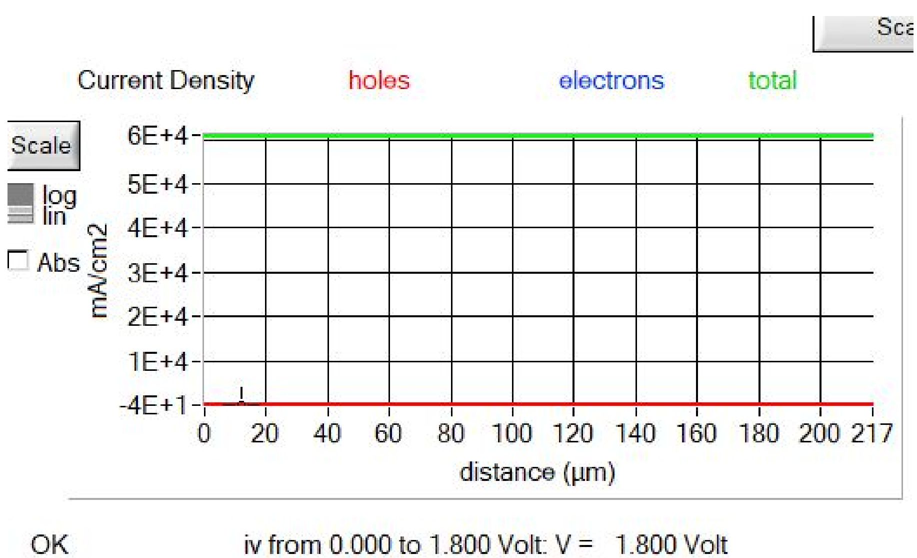
# Other plots for maximum efficiency from case 5:



**Result:**

Simulated the 4 layer MJ Solar cell and plotted the efficiency vs Width for various cases. By inserting SnS as a back field surface layer, the efficiency got boosted significantly. Also with this we can reduce the width of CIGS to make it ultra thin.I chose CdS as buffer layer initially and wanted to find substituting material for CdS due to its toxic nature without compensating the efficiency, Hence found the material ZnS which is good material for environment , easy to manufacture and non-toxic in nature as well with almost same efficiency.

**Conclusion:**

1. In this investigation, I studied the performance of the CIGS-based solar cells. The CdS buffer layer is replaced by other materials like Zinc Sulphide (ZnS) and Zinc Selenide (ZnSe). We concluded that ZnS can be used as alternative material to CdS to attain almost the same efficiency.

2. Multi junction Solar cells , if properly fabricated along with optimum design and best material selection without causing any ill effect on the environment can serve potential sources of renewable energies, with better efficiency rates.

3. *A*. With CdS as a buffer layer, max efficiency I found was 32.4% when ZnO: 5um, CdS: 50um, CIGS: 2um, SnS: 200um.

   *B*. With ZnS as buffer layer, , max efficiency I found was 32.32% when ZnO: 5um, CdS: 50um, CIGS: 2um, SnS: 200um.

In summary, a novel back surface field (BSF) SnS layer has been inserted , the results show that the structure with the layer BSF (ZnO/(CdS/ZnS)/CIGS/SnS) in the cell gives an efficiency upto 32.5%% . This also improves the electrical efficiency with respect to earlier reported ones and reduces the cost due to the reduction of the thickness of the absorber layer.

**References:**

1. https://en.wikipedia.org/wiki/Multi-junction_solar_cell.
2. Repins I, Contreras M, Egaas B, DeHart C, Scharf J, Perkins C, To B, Noufi R. 19.9%-efficient ZnO/CdS/CuInGaSe Solar cell with 81.2% fill factor. Prog Photovolt Res Appl, 2008, p 235–239.
3. J.Lindahl , U.Zimmermann , P.Szaniawski , T.Törndahl , A.Hultqvist , P.Salomé , C.Platzer-Björkman and M.Edoff , Inline Cu(In,Ga)Se2 Co-evaporation for high efficiency solar cells and modules IEEE J.Photovolt , 2013, p1100–1105.
4. M.Powalla , P.Jackson , W.Witte , D.Hariskos , SPaetzle , C.Tschamber and W.Wischmann , High-efficiency Cu(In,Ga)Se2 cells and modules Solar Energy Mater. Solar Cells,2013, p 51–58.
5. A.Chirila et al , Highly efficient Cu(In,Ga)Se2 solar cells grown on flexible polymer films , Nature Mater, 2011, p 857–861.
6. The role of back surface field SnS layer in improvement of efficiency of CdTe thin film solar cells Sabrina Benabbasa), Zahir Rouabaha), Nadir Bouarissab) , Nacereddine Chelalia) .