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SIMULATION AND OPTIMIZATION OF HIGH PERFORMANCE CIGS SOLAR CELLS

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Abstract*- Simulation and optimization of high performance three layer CIGS solar cell have been carried-out in this paper using AMPS-1D (Analysis of Microelectronic and Photonic Structure). The use of three stage process in conjunction with composition monitoring facilitates the fabrication of solar cell with efficiency 23.77%. CIGS solar cell simulation performed to find out cell performance on the influence of particular layer material; electrical, optical and geometrical parameters. Here is a description of recent result in reducing absorber thickness. Current tested maximum efficiency of CIGS solar cell is 21%. This proposed model provides simulated efficiency 23.77%.*

Keywords: Cu(In,Ga)Se2 (CIGS), AMPS-1D simulation, open circuit voltage (Voc), short circuit current density (J sc), fill factor.

INTRODUCTION

In a basic structure of CIGS solar cell, Window layer is the top layer of solar cell structure. Sunlight strikes upon this layer. Transparent conducting oxide (TCO) layer, here ZnO layer is window layer.

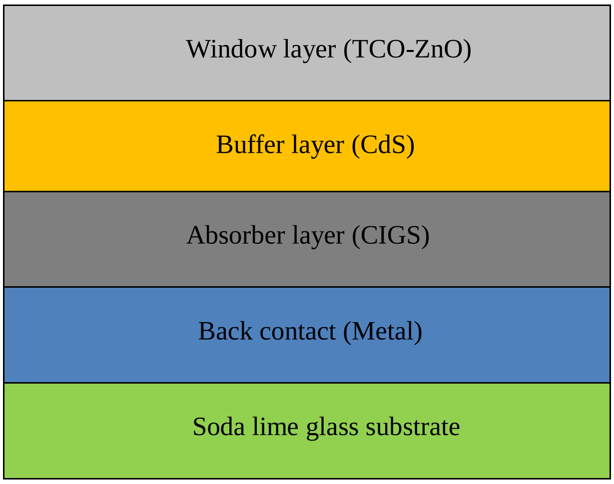

Fig.1: Basic structure of CIGS solar cell

Light partially gets blocked by metallic grid of front contact and partially reflected by TCO layer which is approximately 10-20% because of the differences in index of refraction. ZnO layer has high optical band gap to ensure absorption of incident sunlight. ZnO layer is cheaper than other possible TCO layer and can be easily grown [1]. But high reflection from ZnO layer, lattice mismatch and interface recombination reduces maximum efficiency of solar cell. Hence, buffer layer introduced between P-type absorber layer (CIGS) and window layer (ZnO) to provide lower interface recombination and decrease leakage [2]. N-type CdS layer introduced as buffer layer here. CdS protects absorber layer from damage. The band-gap of CdS is 2.4eV which is high enough to reduce absorption loss of photon in buffer layer. CdS also has less reflection loss in the front surface because it has refractive index which is comparable with ZnO and CIGS [3].Optimum thickness lies around 40-100nm.

The layer after buffer layer and most important layer in the solar cell structure is absorber layer. CIGS is used as absorber layer here. Absorber layer forms p-n junction with buffer layer (CdS) [1]. CIGS layer has lower concentration of electrons. Light absorbed by CIGS layer creates excess electron-hole pair. Then holes to flow towards buffer layer, CdS. As a result net current flows through the hetero Junction.

In three layer solar cell structure back contact is under absorber layer. And its role is to collect carriers from absorber and delivering it to external load [1].

Ni back contact given high performance compared with other metals. The work function and reflectivity at the contact-semiconductor interface is suitable for Ni metal [1]. It has low resistivity, which results flow of majority carriers and holes.

The whole three layer solar cell structure is deposited on soda lime glass substrate. It has thermal expansion coefficient matches with CIGS [4]. It is corrosion resistant and has low price, it also acts as compensating donor.

2. SIMULATION

High performance CIGS solar cell optimization can be determined from following steps:

1. Absorber layer, CIGS optimization
2. Front contact optimization
3. Back contact optimization
4. Buffer layer, CdS optimization

The material properties and absorption spectrum for ZnO, CIGS and CdS have been taken from [6].

Table 1: Material properties for basic CIGS materials [6]

Layer Properties	ZnO	CdS	CIGS
Dielectric Constant	9.0	10.0	13.6
Electron mobility	100 cm^2/Vs	100 cm^2/Vs	100 cm^2/Vs
Hole mobility	25 cm^2/Vs	25 cm^2/Vs	25 cm^2/Vs
Carrier density	$ND=10^{18}$ cm^{-3}	$ND=10^{17}$ cm^{-3}	$ND=2x10^{6}$ cm^{-3}
Band gap	3.3eV	2.4eV	1.12eV
Effective Density NC	$2.22x10^{18}$ cm^{-3}	$2.22x10^{18}$ cm^{-3}	$2.22x10^{18}$ cm^{-3}
Effective Density NV	$1.78x10^{19}$ cm^{-3}	$1.78x10^{19}$ cm^{-3}	$1.78x10^{19}$ cm^{-3}
Electron affinity	4.0eV	3.8eV	4.1eV
Width	50 nm	50 nm	3000 nm

2.1 Absorber Layer CIGS Optimization

Absorber layer CIGS can be optimized by following steps:
1. CIGS band-gap optimization
2. CIGS layer thickness optimization
3. CIGS carrier density (NA) optimization

2.1.1 CIGS band-gap optimization

The optimization of CIGS band-gap can be performed by keeping other parameters fixed. The band-gap of CIGS solar cell can be determined from

$$E(x) = 1.02+0.67x+0.11x(x-1) \quad .... \quad (2.1)$$

The band-gap can be 1.1 to 1.6eV according to equation 2.1 from [7]. By simulating with AMPS-1D it is found that as band-gap increases Voc and Jsc increase with increasing carrier [8]. 1.5eV band-gap is chosen hence it shows highest efficiency 20.7%.

If band-gap lower than that would chosen then In content would increase and though it's costlier than Ga band-gap is chosen 1.5eV which supports the Shcokley-Queisser Limit theory [5].

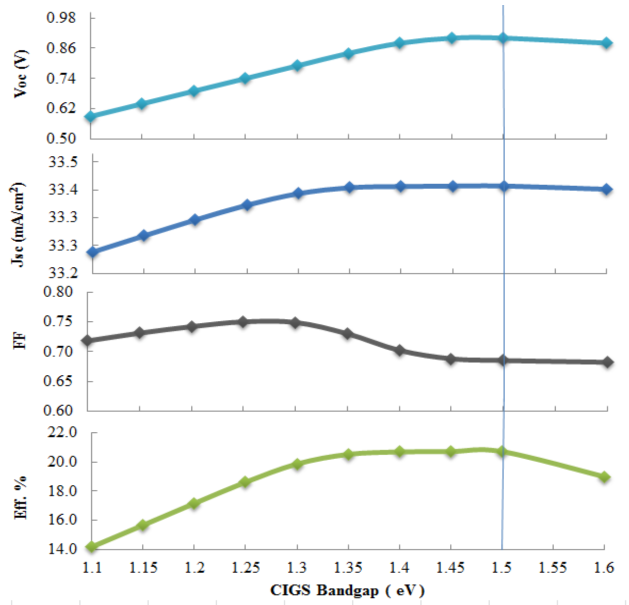

Fig.2: Effect of CIGS band-gap change

2.1.2 CIGS layer thickness optimization

Now keeping the band-gap of CIGS fixed at 1.5eV, then changing the layer thickness from 0 to 5000nm, simulated performance of cell is shown in Figure 3.

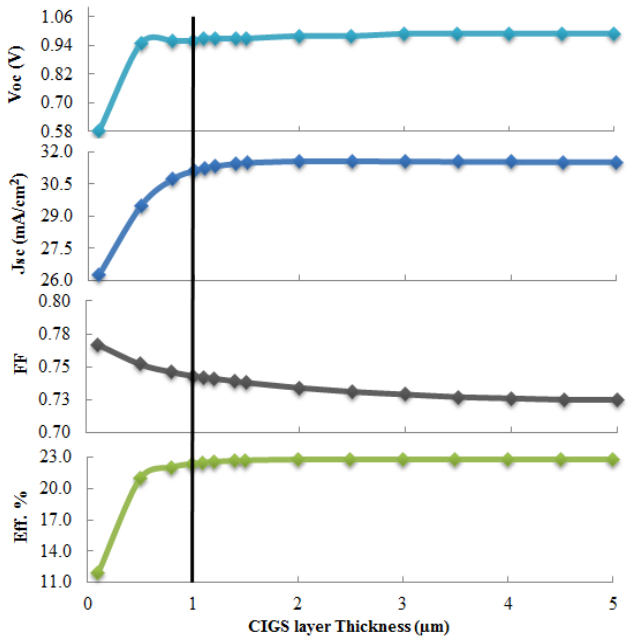

Fig.3: Effect of CIGS layer thickness change

Here from result it is shown that with increasing thickness Voc and Jsc increase and FF decreases. From 1000nm to 5000nm the efficiency variation is negligible, but the material requirement is high. Hence here we selected 1000nm as CIGS layer thickness. Further increase in thickness reduces the overall efficiency by small amount because decrease in fill factor dominates the small increase in Voc and Jsc[13].

2.1.3 CIGS Carrier Density (NA) Optimization

Carrier density, NA in the CIGS absorber can be determined from capacitance voltage measurement [6].

The changes induced by NA can be described by diode equations-

$V_{oc}=kT/q\ln(I_L/I_o+1)$…(2.2)

$I_o=A((qD_e n_i^2)\,/\,L_e N_A+(qD_H n_i^2)\,/L_H N_D)$… … (2.3)

From equation (2.3) increasing NA increases the denominator of Io, hence lowers the saturation current, Io. Since denominator of equation (2.2) decreases so Voc increases with increase in NA [7].

Keeping CIGS band-gap and layer thickness fixed, changing carrier density from $1\times10^{14}cm^{-3}$ to $1\times10^{18}cm^{-3}$ it is found from simulation result that efficiency of CIGS solar cells is highest at $6\times10^{16}cm^{-3}$. And hence selected carrier density is $6\times10^{16}cm^{-3}$.

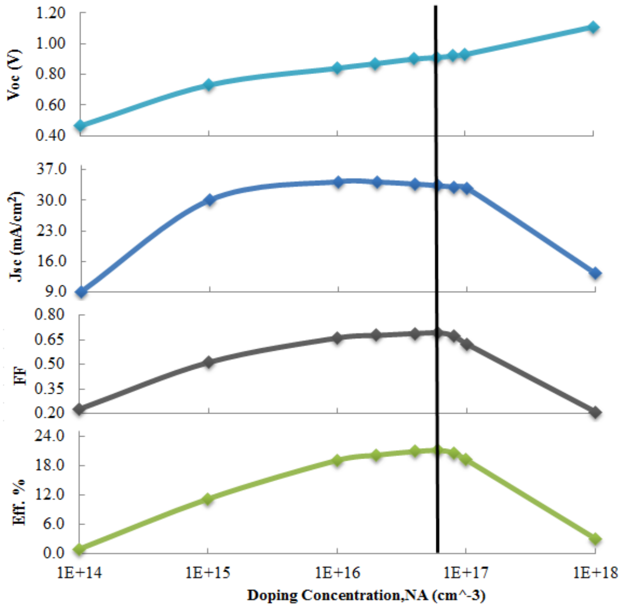

Fig.4: Effect of CIGS carrier density change

2.2 CIGS front contact optimization

Optimum front contact is determined by observing the variation in the performance of solar cells by following steps:

1. Front contact ϕ_{BO} optimization.
2. Front contact reflectivity optimization.

2.2.1 Effect of changing ϕ_{BO} of Front Contact

By changing work function, ϕ_{BO} within 0 to 1eV, it is found from simulation result that Jsc, FF is decreasing and Voc constant. As a result efficiency is also decreasing. Finally selected ϕ_{BO} is 0.2eV for contact-semiconductor interface.

2.2.2 Effect of changing reflectivity of front contact

By changing front surface reflectivity Voc, Jsc and FF is decreasing. Generally 15% reflection happens from ZnO front contact [7]. Hence our selected front surface reflectivity is 15%.

2.3 CIGS Back Contact Optimization

Optimization of CIGS back contact can be obtained from

1. Back contact ϕ_{BL} optimization
2. Back contact reflectivity optimization

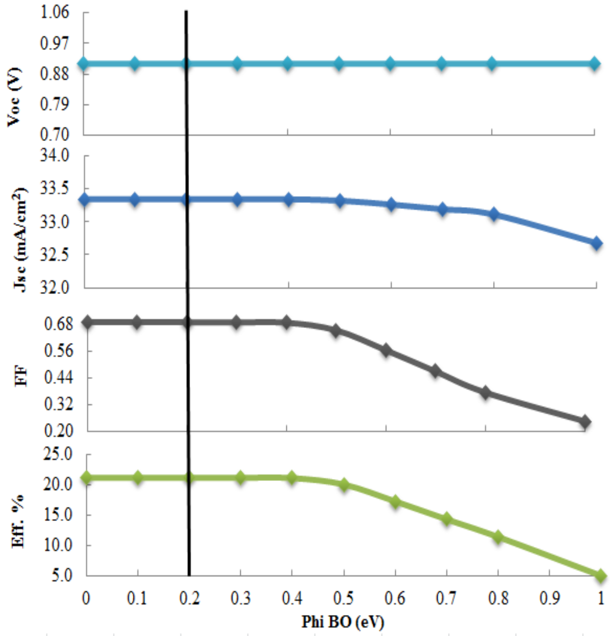

Fig.5: Effect of front contact ϕ_{BO} change

2.3.1 Effect of changing ϕ_{BL} of Back Contact

By changing ϕ_{BL} of back contact from 0.5eV to 1.3eV it is found that efficiency is increasing as a result of Voc, Jsc and FF. Here 1.0eV is selected as work function of back contact and Nickel (Ni) metal is selected as back contact material.

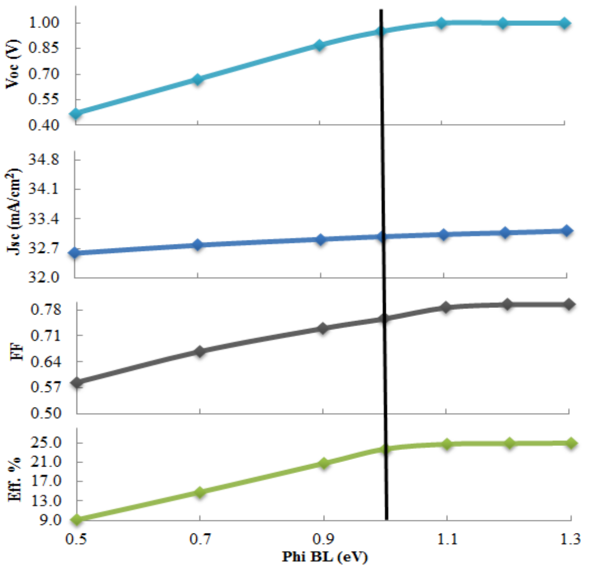

Fig.6: Effect of back contact ϕ_{BL} change

2.3.2 Effect of changing Reflectivity of Back Contact

By changing back surface reflectivity we get from simulated result that efficiency is increasing and selected reflectivity is 80% for Ni back contact metal [10].

2.4 Buffer Layer CdS Optimization

Optimization of the buffer layer of CIGS solar cells can be determined by following steps:

1. By optimizing the thickness of buffer layer, CdS.
2. By optimizing carrier density (ND) of CIGS solar cells.

In the first step by changing the thickness (nm) of buffer layer, CdS from 0-300nm, Voc is constant and efficiency is a result of Jsc and FF. Highest efficiency is found 90nm. Hence our selected optimum thickness of CdS buffer layer is 90nm.

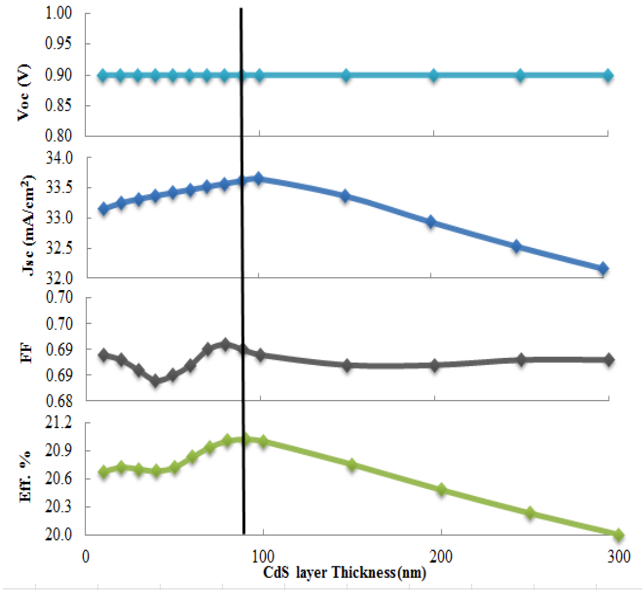

Fig.7: Effect of CdS layer thickness change

Now keeping fixed the thickness of CdS buffer layer, carrier density changed from $1x10^{14}cm^{-3}$ to $1x10^{20}cm^{-3}$. We get highest simulated efficiency at $1x10^{19}cm^{-3}$[6]. Hence optimum doping concentration is selected at $1x10^{19}cm^{-3}$.

3. RESULT

The I-V curve of final CIGS solar cell in Figure 9. The performance of final CIGS solar cell with operating temperature is shown in Figure 10. Here after simulating and optimizing different layer properties of CIGS solar cell, we get final I-V curve using AMPS-1D software. Here Voc = 0.96volts, Jsc = $32.982mA/cm^2$ and FF=0.744. The efficiency of final cell at 298K is 23.77%. This is higher than previously achieved efficiency for CIGS solar cells.

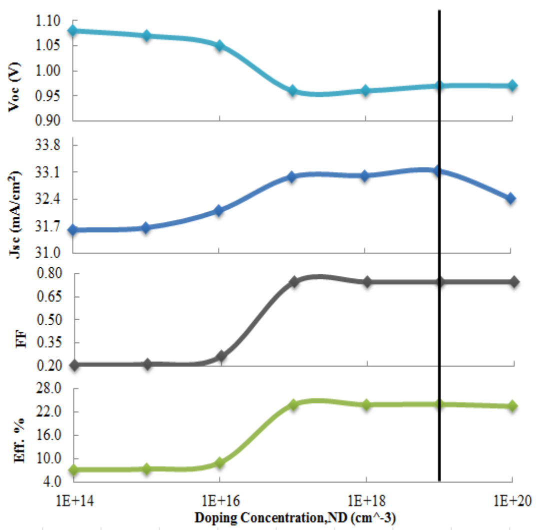

Fig.8: Effect of CdS doping concentration change

The variation of CIGS solar cell performance with temperature is simulated from 0-100 degree celsius using AMPS-1D. The Jsc is not strongly temperature dependant[13]. Light absorption increase since semiconductor band-gap decrease as a result Voc and FF also decrease.
Here the efficiency decreases with increase in operating temperature.

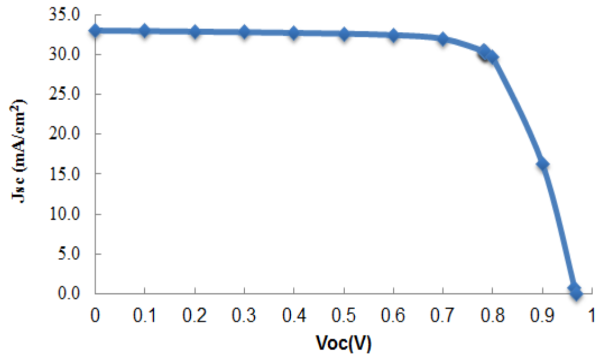

Fig.9: Final I-V curve of CIGS solar cell

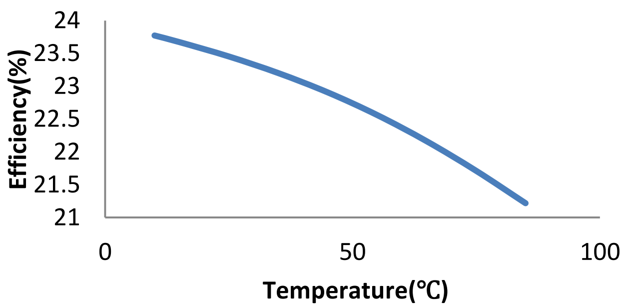

Fig.10: Temperature Vs efficiency curve of CIGS solar cell

4. CONCLUSION

Proposed structure of high performance CIGS solar cell shown bellow

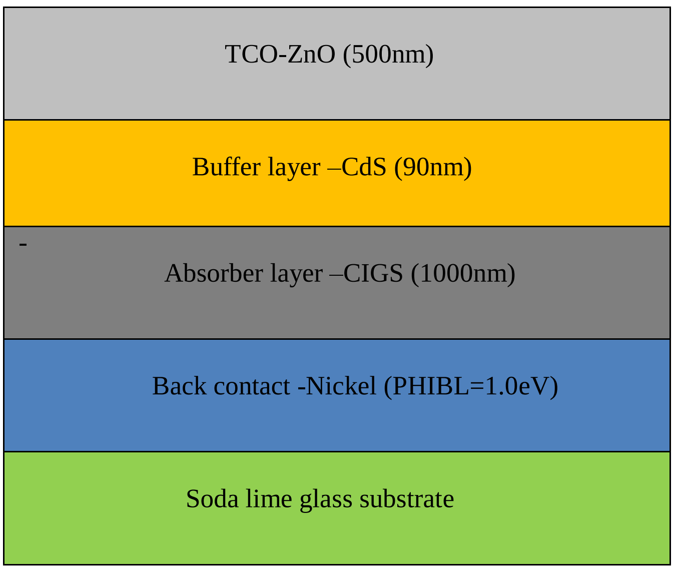

Fig.11: Structure of proposed CIGS solar cell

Final simulated high performance CIGS solar cell has Voc = 0.96volts, Jsc = 32.982mA/cm^2 and FF=0.744. The efficiency of final cell at 298K is 23.77%.

Table 2: Comparison of performance parameters of simulated baseline case from [10] and proposed model

Performance parameter	**Baseline CIGS**	**Proposed model**
Open circuit voltage	0.64 volts	0.96volts
Short circuit current dens.	34.6mA/cm^2	32.982mA/cm^2
Fill factor	0.795	0.744
Efficiency	17.7%	23.77%

The efficiency of CIGS solar cell will rise if back contact material work function can be increased.

5. ACKOWLEDGEMENT

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7. NOMENCLATURE

Symbol	**Meaning**	**Unit**
Voc	Open circuit voltage	(V)
Jsc	Short circuit current density	(mA/cm^2)
FF	Fill factor	Dimensionless