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The Effect of Doping and the Thickness of the Layers on CIGS Solar Cell Efficiency

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Abstract: The main problemswith the use of fossil fuels is the restrictions on their access and the detrimental consequences of their use which causes a threat to human health and quality of life. Consequently, the use of other energy sources has become necessary. Renewable Energy as a permanent and clean energy source is an answer to this problem. One such energy source includes photovoltaic solar energy that is widely available as a reliable energy source. Research and Development of Photovoltaic Energy in general, will reduce costs and improve efficiency in both areas. CIGS solar cells have higher efficiency in comparison with other cells. Ion implantation and doping technique offers the unique structure of a solar cells. This paper will examine the performance of solar cells with Cu In_{1-x} Ga_x Se_2 structure. This willbe performed by Silvaco software. Effect of doping phosphorus (p) and Natrium (Na), as well as the value of x and thethickness of the various layers of the solar cell, on the efficiency of the cell, have been studied.

Keywords: absorber layer, efficiency, ion implantation, solar cells, thin film.

1. Introduction

Copper-Indium-Gallium-Selenium (CIGS) Solar cell is a semiconductor I-III-VI_2 with a direct band gap and high absorption coefficient. The preceding is an alloy between CIS and CGS which is described by the chemical formula $CuIn_{1-x}Ga_xSe_2$,Where x is the ratio between Ga/(Ga+In).By changing x, the concentration of Gallium and Indium will change and as a result would alter the band gap. The value ofband gaps change from 1.04ev for x= 0 for the CIS to 1.68ev for x=1, for the CGS [3].

In these cells, the lowest conduction band has been put against the maximum capacity of the tape and has the highest efficiency compared to other solar cells [2].

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CIGS solar cells as shown in Figure1 is composed of the following layers.

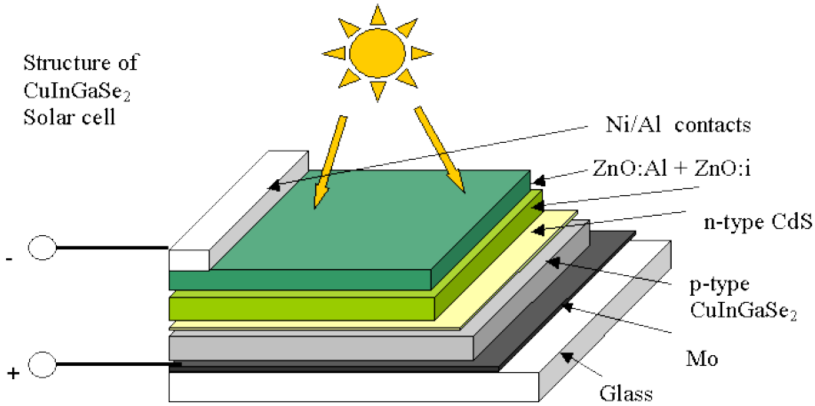

Fig.1. CIGS structure.

Layer1)Impure aluminium with zinc oxide (ZnO: Al) whose duty it is to guide the photons received.

Layer2)Layers of zinc oxide (ZnO: i) As layer TCO (Transparent Conductive Oxide) used. TCO layers have a large band gap to ensure maximum absorption of sunlight. It should be a transparent layer that can absorb maximum photons [4].

Layer3) layers n-CdS(sulphidecadmium) that is n type semiconductor and acts as a buffer layer between CIGS and TCO layers .These layers will result in better performance of the solar cells [5].

Layer4) of the CIGS absorber layer is the core and active layer of the solar cell and a p-type multi crystal semiconductor. It has a direct band gap and its absorption coefficient is about 10^5 cm^{-1}.This layer along with the buffer layer form a p-njunction [3].

Layer5) (Mo) layer is a refractory metal which is used as a rear connection. Its role is to gather the carriers from the absorption layer and to present them to a foreign carrier. As a result, the resistance is low.

Layer6) Solar cell Substrate, is made of a glass (soda) or plastic .This material is highly resistant against corrosion and Its price is reasonable.

Figure2 shows a comparison between the thicknesses of the various layers [6].

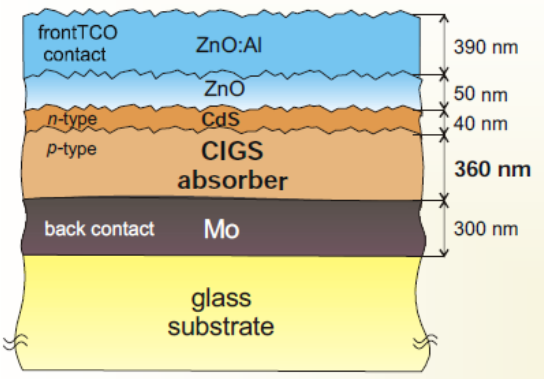

Fig. 2. Comparison between the thickness of the CIGS layer.

This paper examines the CIGS solar cell performance by silvaco software. The effect of changing X and applying Na doping on the solar cell will also be expressed.

2. Simulation

The structure which is intended to simulate the CIGS solar cells is shown in Figure3:

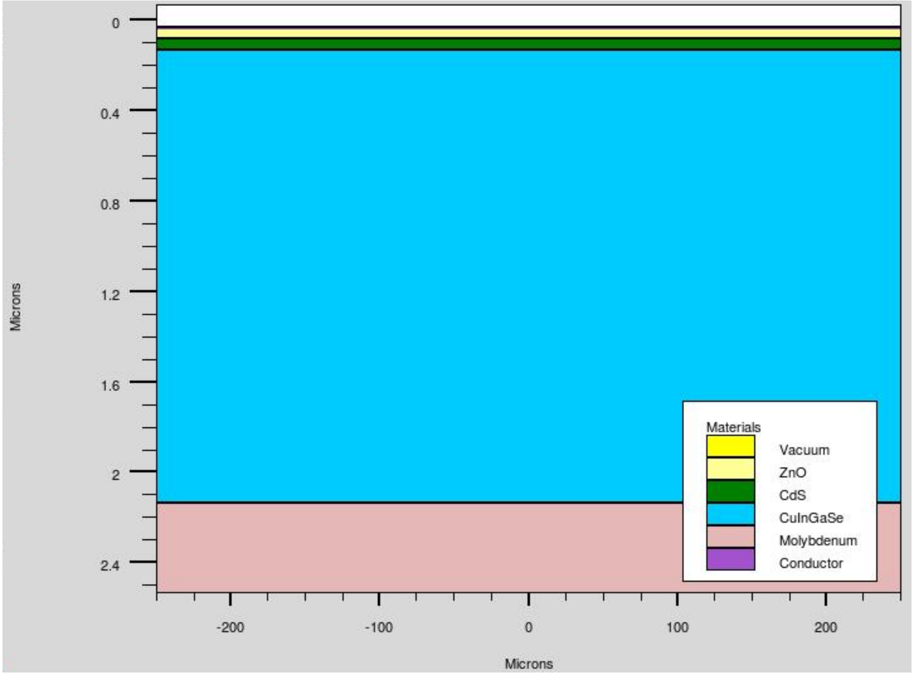

Fig. 3. Structure of CIGS.

Physical parameters used in the simulations Table1 have beenidentified[9].

Table1.Physical Parameters Used In the Simulation

	ZnO	CdS	CIGS
ε_r	9	10	13.6
χ_e (eV)	4	3.75	3.89
μ_n (cm^2/Vs)	50	10	300
μ_p (cm^2/Vs)	5	1	30
N_A (1/cm^3)	0	0	8E+16
N_D (1/cm^3)	$5{\cdot}10^{17}$	$5{\cdot}10^{17}$	$5{\cdot}10^{17}$
NC (1/cm^3)	$2.2{\cdot}10^{18}$	$2.2{\cdot}10^{18}$	$2.2{\cdot}10^{18}$
NV (1/cm^3)	$1.8{\cdot}10^{19}$	$1.8{\cdot}10^{19}$	$1.8{\cdot}10^{19}$
E_g (eV)	3.3	2.4	1.2
Thickness (nm)	55	50	2000

The efficiency of a solar cell is determined by its V- I curve.

This curve using the simulation is shown in Figure4.

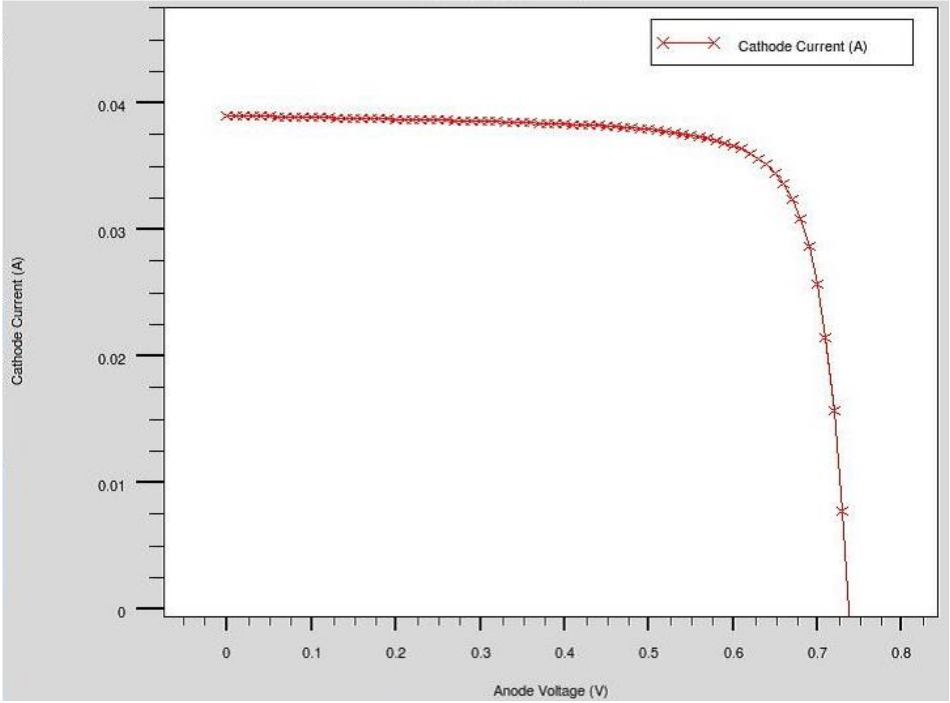

Fig.4. V-I curves of CIGS solar cells.

The energy gap ofCIGS is a function ofthe amount ofitsGallium which is obtained usingRelation1.

$$E_g = 1.010 + 0.626\,x - 0.167x\,(1 - x) \quad (1)$$

The band gap is increased as a result of the increase in Gallium which leads to a relative increase in the open circuit voltage and short circuit current and consequently its efficiency[6]. This software has shown the following results.

By Changing amount of Gallium, different voltages and currents were obtained the results are in shown Figure5. These results show that on the increase of the output voltage, output current decreases.

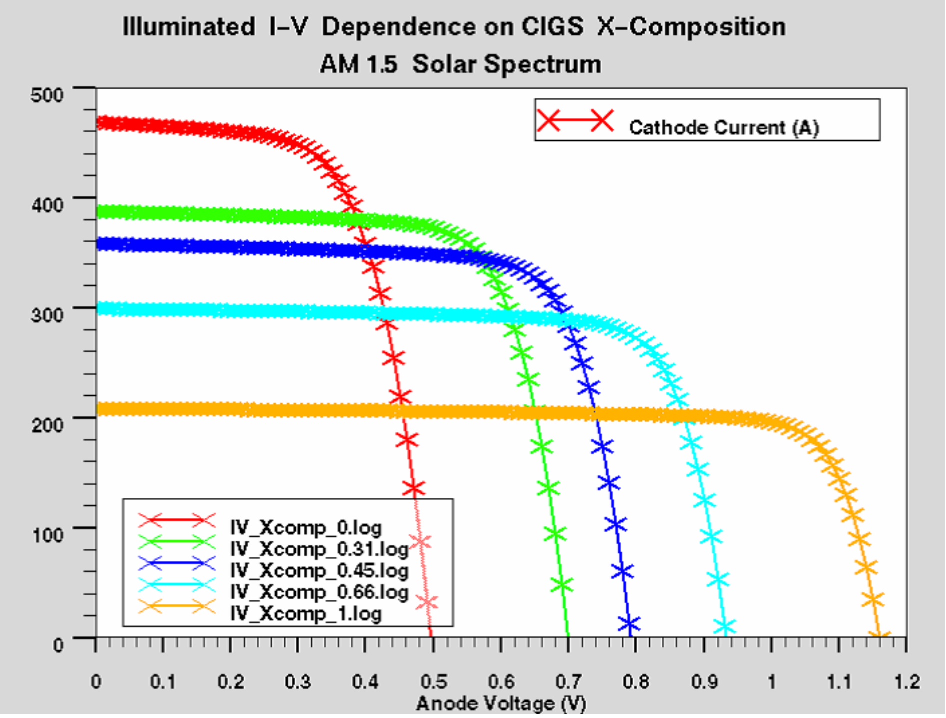

Fig.5. Voltage-Current curve, or different amounts of gallium.

By changing the value of x and enlarging the Band gap energy, thepower of output increase dramatically. Optimum value was found to beatx = 0. 66and is shown in Figure6.

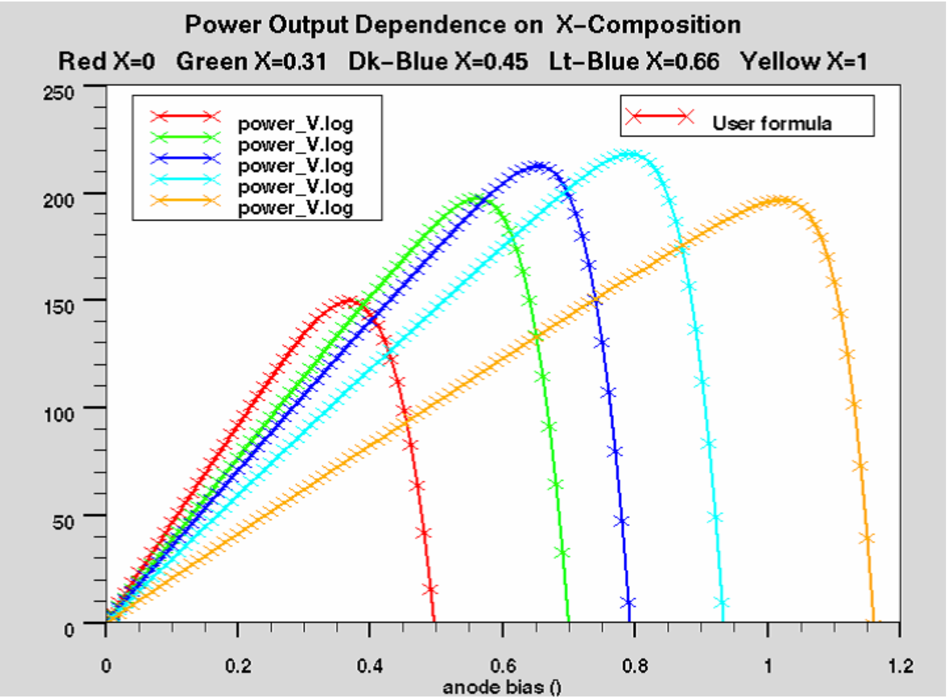

Fig.6. The effect of changes in x on output power.

The effect of doping and Implant:

Phosphorus implant of10^{15} cm^{-3} dose in our solar cell would result the V-Icurve in Figure7 using simulation.

Figure8 shows the power characteristics of our solar cell.

As can be seen, the efficiency has reached 19.1%.

Using simulation method, differentdose ofNa implant were carried out and the Maximum power curve was obtained for the dose of 2×10^{17} cm^{-3}. This is shown in figure9.

Increase in the output voltage would results in the reduction of the current. This would reduce the efficiencies in the long wavelength ranges and is shown in Figure10.

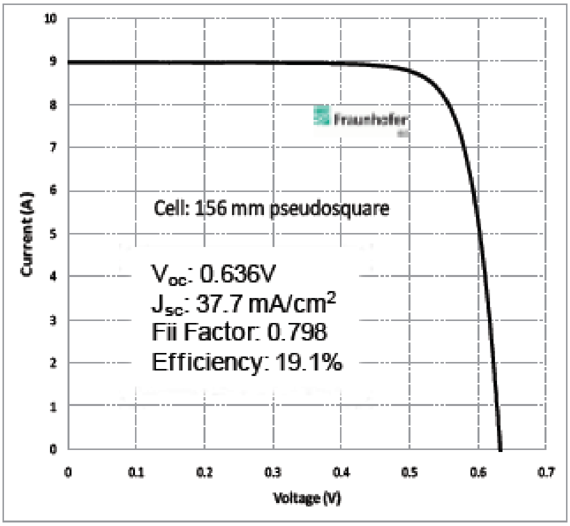

Fig.7. VI curve of a solar cell with P implants.

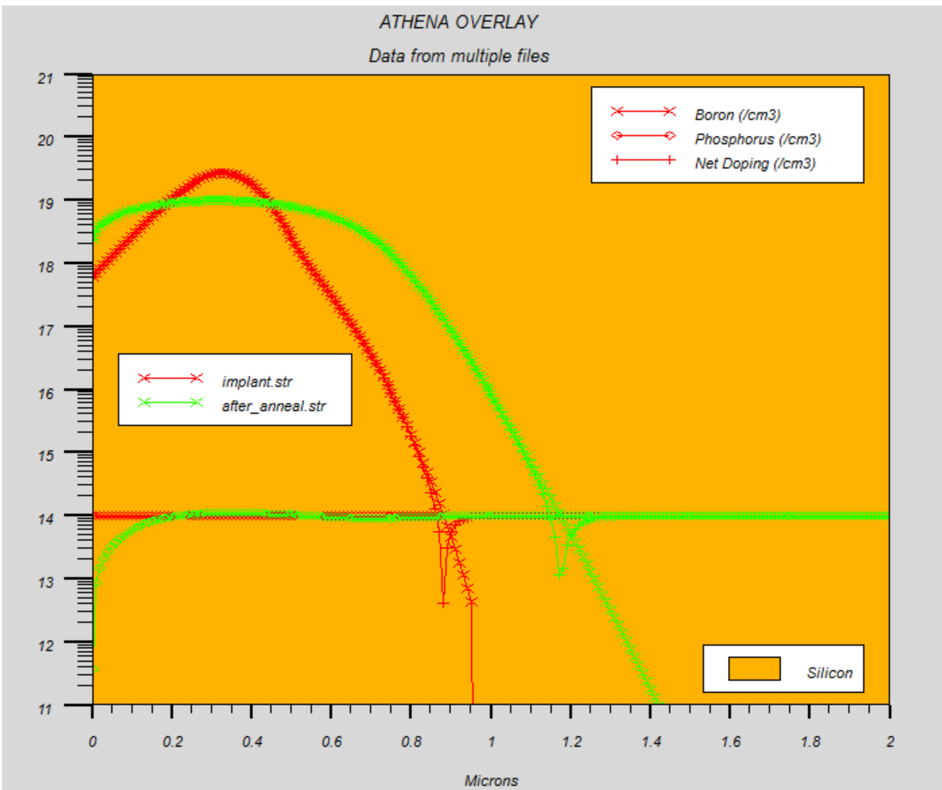

Fig.8. The curve of the solar cell with P implants.

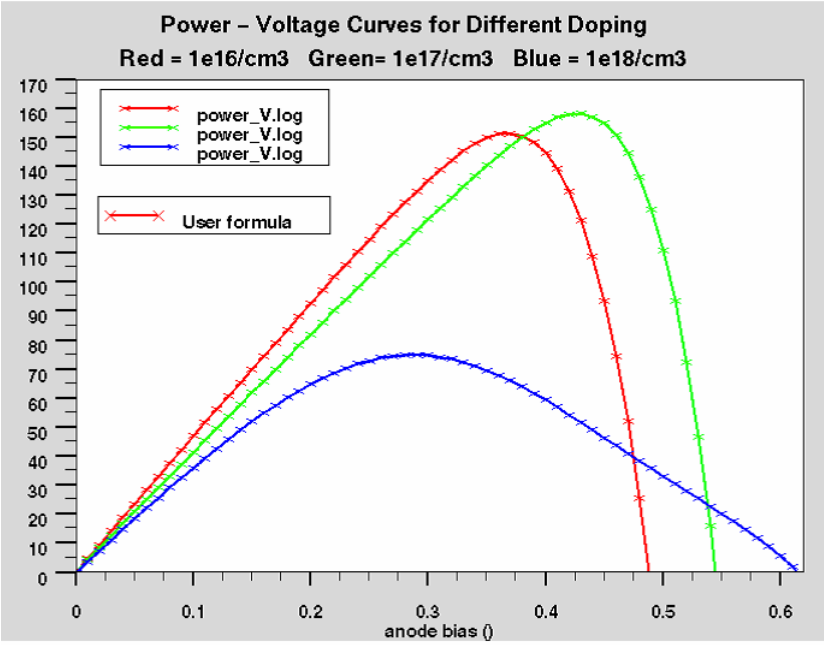

Fig.9. The effect of doping and the Power-Voltage curve.

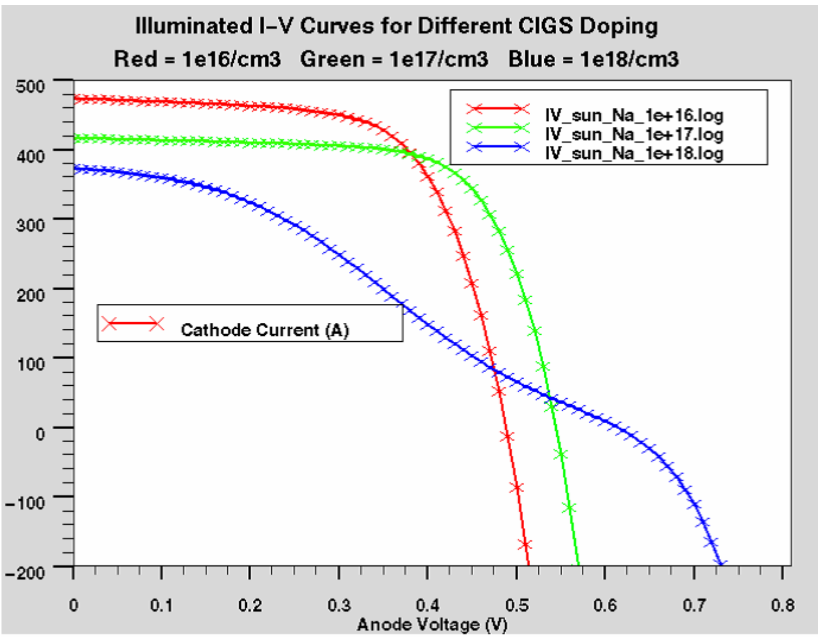

Fig.10. The Current-Voltage curve applied to doping.

Efficiency of 20.3 % is achieved using Na implant of2×10^{17} cm^{-3} dose. This may be due to slight increase in the band gap value. This is demonstratedin figure11 [7].

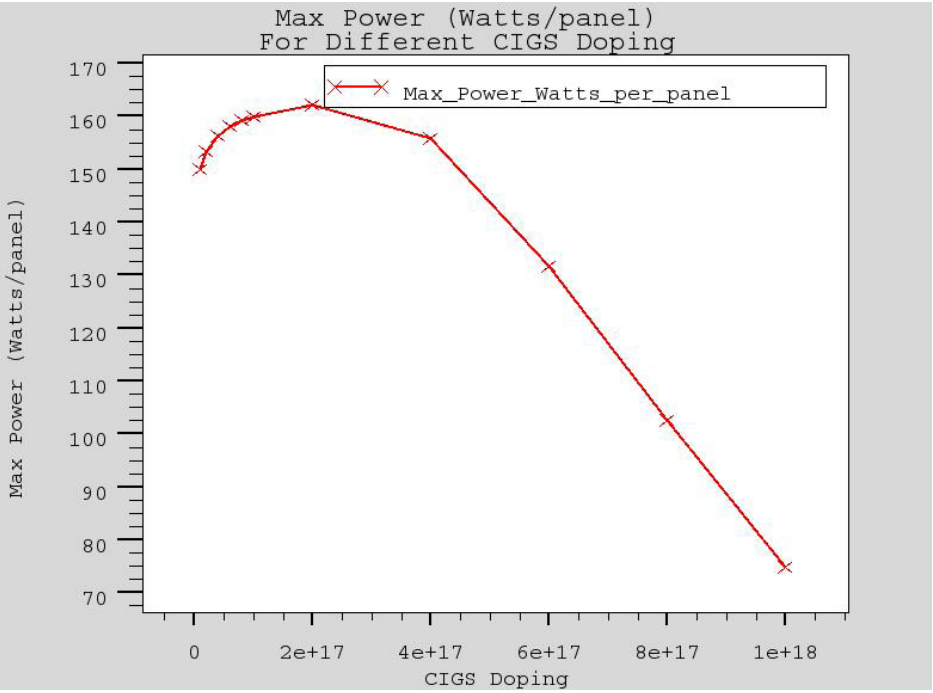

Fig.11. maximum power curve.

Changingthethickness ofthelayers:

The thickness of the solar cell, is an important parameter andis dependent on many factors.

A) *the thickness of the CIGS absorber layer*

Using simulations,the absorber layer of CIGS cell was increased from 0.5 to 3 micrometer andits V-I curve is shown in figure12.

Increasing the thickness of the absorber layer of CIGS, the amount of current and voltage and cell efficiency increases. The reason for this is that, by increasingthethicknessoftheabsorberlayer, thelayerabsorbmore photons and this wouldhelp toproducemoreelectron-hole. Pairs Figure13 shows stream voltage-current curves and figure14 shows efficiency curve by changing the thickness of the absorber layer (I_{SC} = 33.6 mA andV_{oc} = 0.95 v and η=% 26) [7].

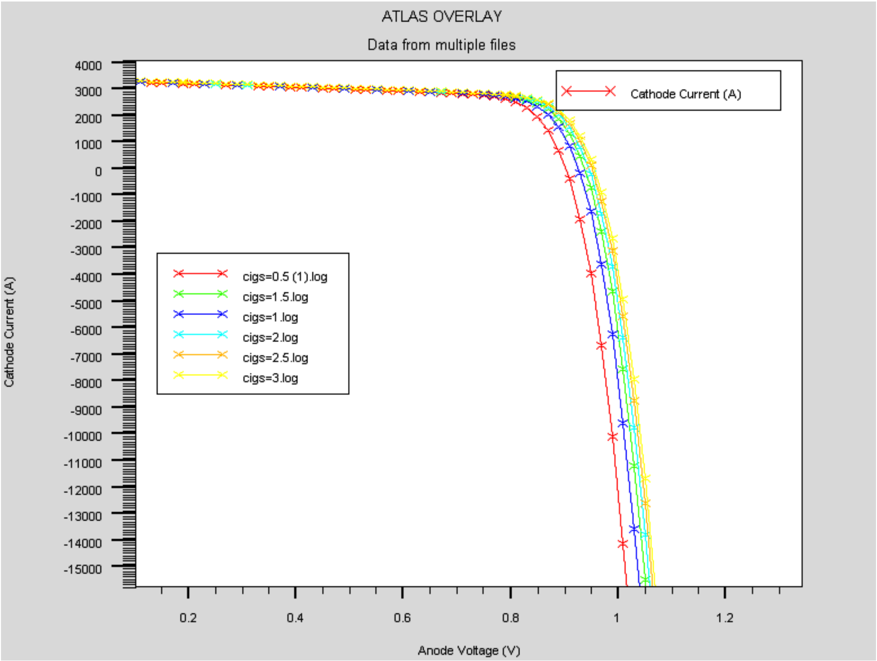

Fig. 12. Curve voltage-currentthe CIGS absorber layer with a thickness change.

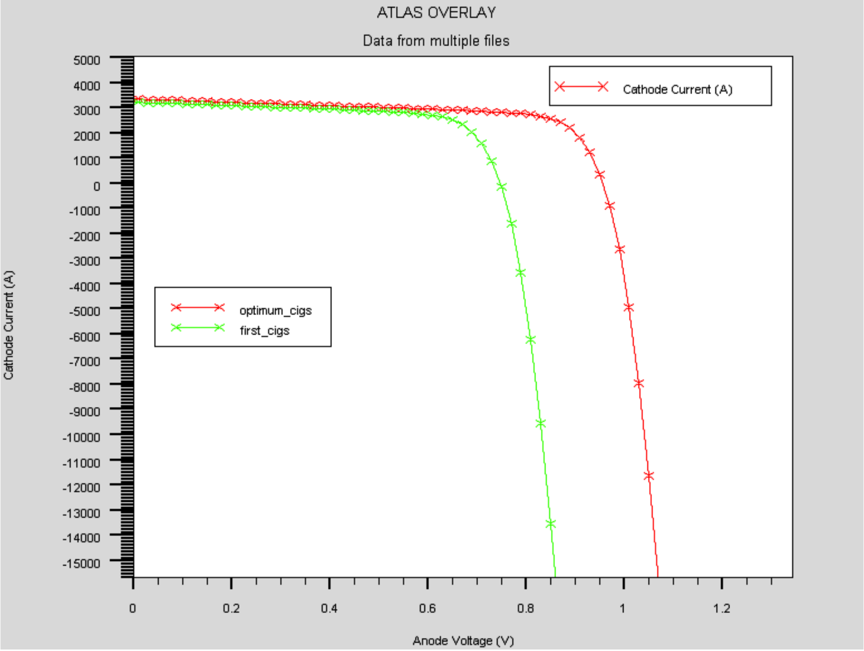

Fig. 13. in the current-voltage curve is improved.

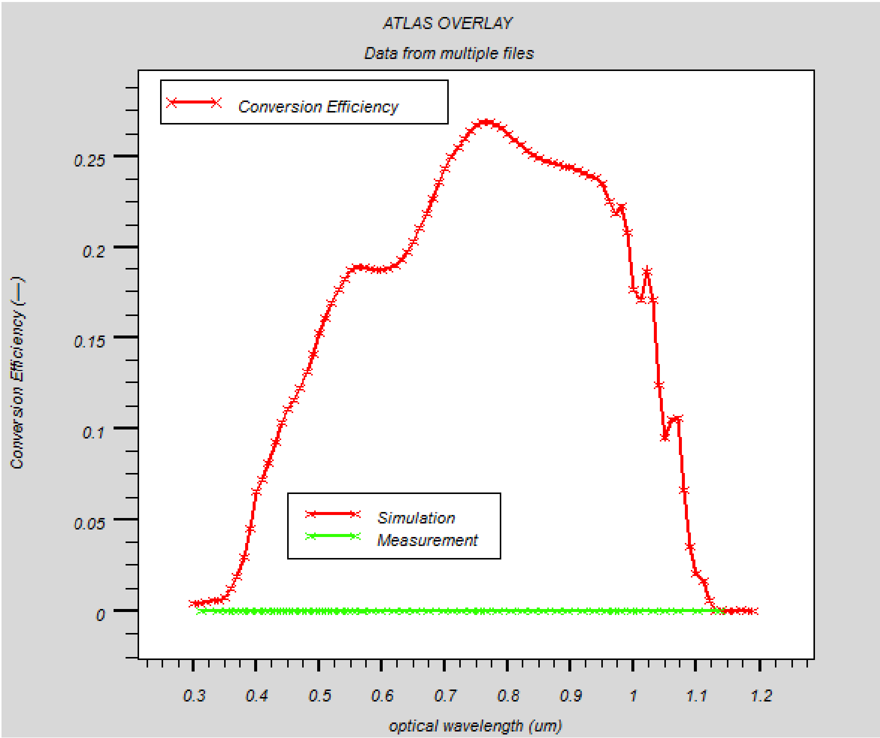

Fig.14.Efficiency curve by changing the thickness of the absorber layer.

B) ***The thickness of the transparent layer TCO:***

As zno is a material that absorbs the maximum amount ofphotons and also is economical. ThereforeZno is selected and used as ourTCO material. At first thickness layer of0.44 for Zno was considered and using simulation in figure15, efficiency wasobtained to be approximately 19%.

Considering 0.03 micrometers thickness (thickness reduction) for Zno, the result of figure16 were obtained. Efficiency in this case is 19.5 %.

By comparing the two figure of 14 and 15, it is observed that the cell efficiency has increased. This is because that once the thickness of transparent layer is reduced, less light is reflected and consequently more of it would reach the absorber layer. This in turn improve the efficiency of the cell.

Considering the amount of thickness 0.6 mm (increasing), the result is shown in figure17. The efficiency of this mode is approximately 19.5 %.

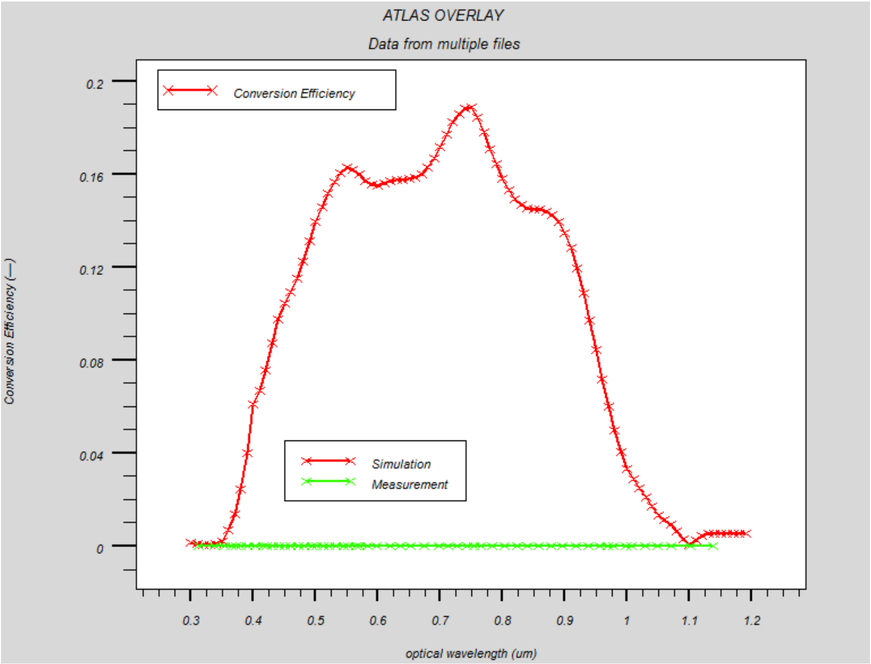

Fig. 15. Solar efficiency curve zno layer thickness in the 0.44 micrometer.

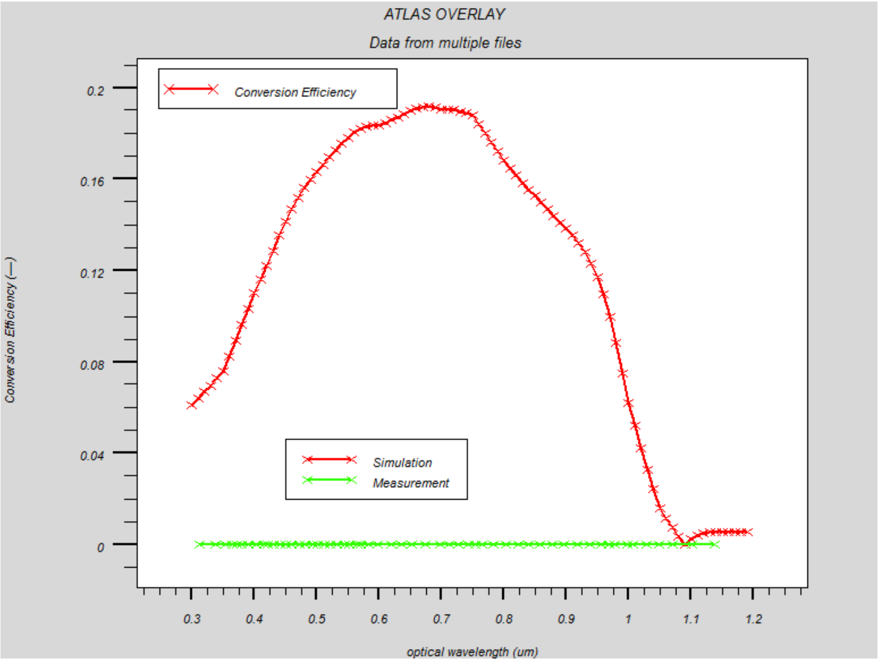

Fig. 16. Solar efficiency curve zno layer thickness in the 0.3 micrometer.

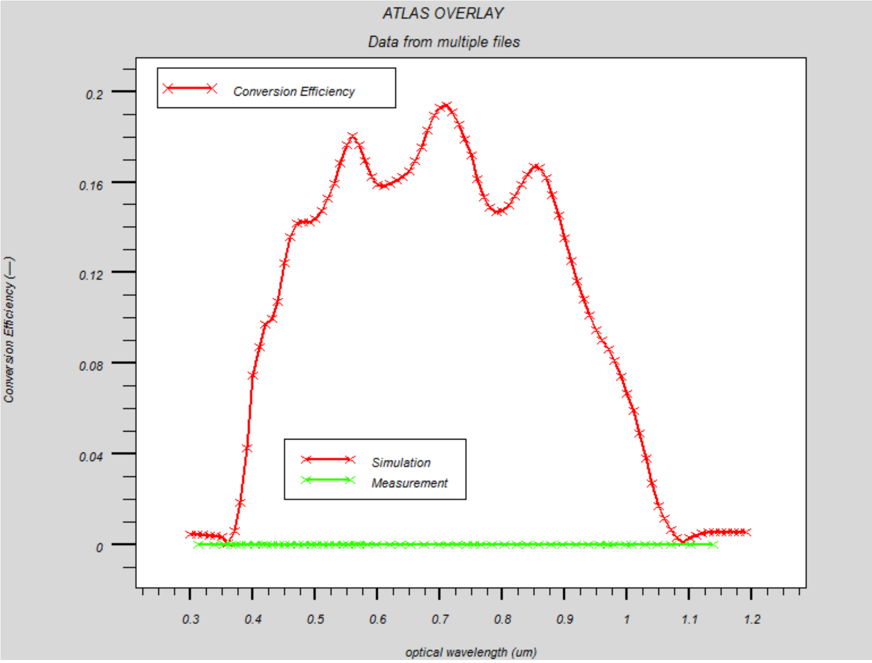

Fig.17. Solar efficiency curve with a value of 0.6 micrometer thickness zno.

3. The Results of The Simulation

Preliminary results of simulations and samplemodels in a state-ofCIGS in this paper, shownin Table2.

Tabel2. Comparison of the parameters of the original model and improved model

Parameter	The basic model	Change x (Ga concentration)	Change Layer Absorbent	Change Layer TCO	doping Na	doping P
$j_{sc}(mA/cm^2)$	32.2	47	33.6	35	33.6	37.7
$V_{oc}(v)$	0.74	0.52	0.95	0.85	0.95	0.63
$E_g(ev)$	1.16	1.4	1.4	1.4	1.4	1.4
x	0.3	0.66	0.66	0.66	0.66	0.66
η(%)	16.6	23.2	26	19.5	22.57	19.1

4. Conclusion

Firstly, in this paper, an initial state for solar cell CIGS with physical parameters given in Table (1).Were considered andlater by changingthe amount ofGallium and Indium (value x). The optimumconditionfor x = 0.66 was obtained.

In Ion Implantation part of the work phosphors was used but implantation ofphosphors did not improve the efficiency considerably. Later Na implantation with different dosages were investigated. Their effect on varying voltage and current and the power of the cell were observed. The maximum power was obtainedwith the dose of 2×10^{17} cm^{-3}. The increase in the efficiency is due to depth penetrationofNa. Therefore, Na was chosenbecause of its better performance at lower temperature and higher concentration ofholes.

This phenomena is ideal at shorter wavelength ranges butreduces the efficiency at higher wavelength ranges. It is therefore concluded in order to obtain a higher efficiency junction, suitable dose of implant should be used.

Later the thickness of the absorber layer of CIGS were consideredandideal value for its thickness was obtained. The thickness of TCO layer were also reduced and later increased in order to find its effect on the efficiency of the cell. Therefore considering all factors such as (doping, thickness of the layer andvalue of X) in solar cell junction which can effect and determine theefficiencies of the solar cell. These were investigated in order to obtain the optimum CIGS cell.

5. References

[1] M. I. Hoffertet, K. Caldeira, A. K. Jain, E. F. Haites, L. D. Danny Harvey, S. D. Potter, M. E. Schlesinger, S. H. Schneider, R. G. Watts, T. M. L. Wigley, D. J. Wuebbles, *Energy Implications of Future Stabilization of Atmospheric CO2 Content.*Nature, 395 (1998) 881-884. Bp Global, Bp Statistical Review of World Energy June 2007.

(http://www.bp.com/statisticalreview(last accessed August 2007).

[2] C.Huang, *Effects of Ga content on Cu(In,Ga)Se_2 solar cells studied by numerical modeling studied bynumbericmodeling*, J. Phys. Chem. Solids, 96 (2002) 330-334.

[3] I. Repins, S. Glynn, J. Duenow, T. J. Coutts, W. K. Metzger and M. A, Contreras, *Required Material Properties for High-Efficiency CIGS Modules*, National Renewable Energy Laboratory, 2009, 1-14.

[4] P. Chelvanathan, M. Hossain, N.Amin, *Performance analysis of copper-indium-gallium- deselenide(CIGS) solar cell with various buffer layers by SCAPS*, Curr. Appl. Phys, 1 (3) (2000) 323-390.

[5] J. Lu, W. Liu, A. Y. Kovalgin, Y. Sun, J. Schmitz, S. Member. *Integration of solar cells on top of CMOS chip*, IEEETrans. Electron. 58 (8) (2011) 2620 - 2627

[6] A.Luque.and, S. Hegedus, *Handbook of Photovoltaic Science and Engineering*, Wiley, Usa, 2003, 1st.

[7] J. T. Heath,J. D. Cohen ,W.N.Shafarman,D.X. Liao, andA.A.Rockett, *Effect of Ga content on defect states in $CuIn_{1-x}Ga_xSe_2$ photovoltaic devices*, Appl. Phys. Lett, 80 (2002) 4540-4542.

[8] P.D.Paulson, R. Birkmire,andW.N.Shafarman., *Optical Charactrization Of Cu* ln_{1-x} Ga_x Se_2*AlloyThinFilms by Spectroscopic Ellipsometry*,J.Appl.Phys. 94 (2003) 879-888.