International Journal of Engineering Research and General Science Volume 3, Issue 4, July-August, 2015
ISSN 2091-2730

Study on Variation of Conversion Efficiency and Quantum Efficiency with Different Thickness of CIGS Material in Chalcopyrite Thin Film Quantum Well Solar Cells

Atul Kumar Agarwal[1], Prashant Kriplani[2],N.L.Gupta[3], D.R. Mehrotra[4]

1. Department of Physics, Govt. College Nasirabad, Ajmer(India)
2. Department of Chemistry, Govt. Women Engineering College, Ajmer(India)
3. Department of Physics, Govt. College Ajmer (Ajmer)

Email: agarwalatul75@gmail.com : Contact no. : +91-9414007751

ABSTRACT-The possibility of using chalcopyrites of the type Cu(In,Ge)Se_2 in a quantum well solar cells are explored. In view of the goal to decrease manufacturing cost Cu (In,Ga)Se_2 (CIGS) type semiconductors attract much attention in recent era. Management of light in thin-film solar cells, where the thickness of the absorber layer is below one micrometer, is of great importance. Keeping this fact in mind, in this paper we are going to investigate the effect of thickness on conversion and quantum efficiency of CIGS thin film solar cell using Silvaco Atlas software to explore the possibility of efficiency enhancement of QWSC's with CIGS material as well material.

KEY WORDS: QWSC, III-V semiconductors, Chalcopyrite, CIGS material, CIGS Thickness, SILVACO ATLAS, Conversion efficiency, quantum efficiency

INTRODUCTION

The concept of quantum well solar cell [1] was proposed with the goal to provide the possibility to absorb sub-band gap photons. Thereby leading to increase power conversion efficiency. In the quantum well solar cell concept of quantum well with lower band gap is implemented into the intrinsic region of p-i-n structures. Therefore also the photons with lower energy then the band gap of host material can be absorbed which increases the current of the device.

In general GaAs, GaAsP are widely used material for quantum well solar cells, recently nitride material, hybrid (inorganic-organic) materials are also used for quantum well solar cells[2-4].

On the other hand with the goal to decrease manufacturing cost polycrystalline thin-film solar cells such as $CuInSe_2$ (CIS), Cu (In,Ga)Se_2 (CIGS) and CdTe[5-6] type semiconductors are important for terrestrial applications because of their high efficiency, long-term stable performance and potential for low-cost production. Because of the high absorption coefficient (0.105cm^{-1}) a thin layer of 0.2 mm is sufficient to absorb the useful part of the spectrum. Highest record efficiencies of 19.2% for CIGS and 16.5% for CdTe have been achieved. Currently, these polycrystalline compound semiconductors solar cells are attracting considerable interest for space applications, because proton and electron irradiation tests of CIGS and CdTe solar cells have proven that their stability against particle irradiation is superior to Si or III-V solar cells. Moreover, lightweight and flexible solar cells can yield a high specific power (W/kg) and open numerous possibilities for a variety of applications.

Due to the superior light absorption properties of CIGS with an absorption coefficient α of the order of $\sim10^5 cm^{-1}$ in principle also very thin layers effectively absorb the incident radiation[7]. The absorption coefficient of Cu-Chalcopyrites is upto one order of magnitude larger than that of the typically used III-V semiconductors ($\sim10^4 cm^{-1}$), making them potentially viable materials for QWCS application.

Afshar *et.al*[8] explored the possibility of chalcopyrite semiconductor of the type CIGS in a quantum well solar cell structure and provide a basis for the future development of chalcopyrite type QWSC's. Welser *et.al*[9]suggested that CIS or CIGS material with high Indium composition may be employed for the narrow band gap well and CGS or CIGS with high Gallium composition may be used elsewhere in the QWSC's.

Management of light in thin-film solar cells, where the thickness of the absorber layer are below one micrometer, is of great importance. Sufficient light trapping has to be established in the absorber (active) layer of the cell and low optical losses in other layers. Optical modeling combined with numerical simulation has been found as a very useful tool for analysis and optimization of optical properties of thin-film solar cells[10]. These are special optical systems where layer thicknesses are in the range of light wavelength and the interfaces between the layers are usually textured (rough) in order to scatter the light in the structure and prolong its optical path. First issue requires the use of the models where interference effects, occurring between forward and backward going light waves, are taken into account. The second issue requires the light scattering process to be included in the modeling. Since the morphology of rough interfaces is usually random and the lateral sizes of texture features are in the range of light wavelength, light scattering process appears to be complicated and, thus, difficult to model. Empirical approaches are needed to support the modeling and simulations of such kind of optical systems.

Keeping this view in mind, we are going to investigate the effect of thickness on conversion and quantum efficiency of CIGS thin film solar cell using Silvaco Atlas software to explore the possibility of efficiency enhancement of QWSC's with CIGS material as well material.

Solar Cell modeling tool: SILVACO ATLAS

Current solar cell simulation tools typically use discrete components to model one aspect of solar cell operation. These can be very accurate predictors of specific characteristics, but lack the breadth of a complete model and are thereby limited in their usefulness as design tools. The ATLAS software tool was developed by Silvaco to be used for the design of solid state microelectronic devices. ATLAS predicts the electrical characteristics of physical structures by simulating the transport of carriers through a two-dimensional grid. To enter the structure and composition of a solar cell into ATLAS, several parameters must be defined. These include the definition of a fine, two-dimensional grid, called a mesh , a coarser division of the mesh into regions, assignment of materials to each region, identification of electrode locations, assignments of doping levels to each material, and specification of a light spectrum for simulation[11].

Once the physical structure of a solar cell is built in ATLAS, the properties of the materials used in the cell must be defined. A minimum set of material properties data includes: bandgap, dielectric constant, electron affinity, densities of conduction and valence states, electron and hole mobilities, optical recombination coefficient, and an optical file containing the wavelength dependent refractive Index n and extinction coefficient k for a material. The optical file is vital to the simulation of multifunction solar cells as it determines the transmission and attenuation of light passing through the semiconductor.

ATLAS includes a wide selection of models that can be employed in device simulations. These models can be enacted for the entire device or for a specific region. Relevant models include SRH recombination, Auger recombination, optical recombination and concentration-dependent mobility for silicon and gallium arsenide[12-15].

SIMULATION WORK

(i) In this paper simulation work on thin-film Cu(In, Ga)Se_2 (CIGS) solar cells has been reported with the aim for determining the variation in conversion efficiency and quantum efficiency of this solar cells with different CIGS thickness. The base materials used for this simulation work are ZnO, CdS, Molybdinum.

(ii) Region statement for material deposition parameter used **fig.1**:

material = ZnO	bottom thick = 0.44 nm
material = CdS	bottom thick = 0.04 nm
material = CIGS	bottom thick = 0.36 nm
material = Molybdinum	bottom thick = 0.3 nm

(iii) Interface use of defining interface property. Beam statement is used for defining beam normal incidence is used. SOLAR statement is used to perform a wavelength sweep from 0.3 microns to 1.2 microns in 0.01 micron steps. Photo generation rate pattern is shown in **fig.2**

(iv) Conversion efficiency curve and quantum efficiency curve for CIGS thickness of 0.5 micron with wavelength variation are found in **fig. 3** and **fig. 4** respectively

(v) Carrier generation pattern across the device (per unit volume per unit time) is shown in **fig. 5**

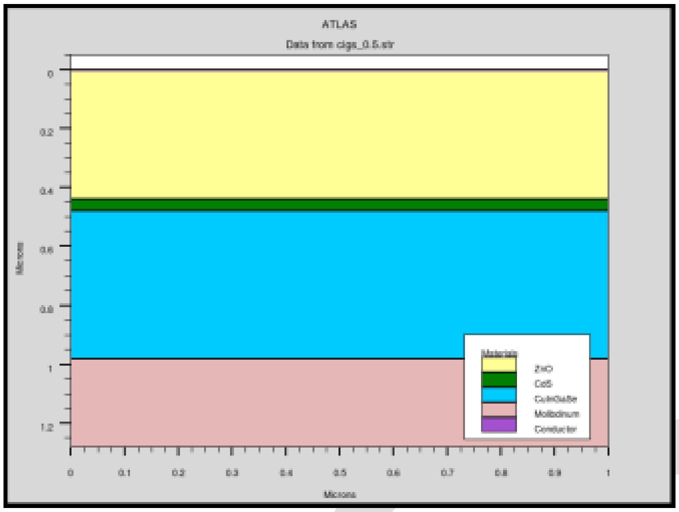

FIG. 1. DEVICE STRUCTURE USED FOR SOLAR CELL SIMULATION USING SILVACO ATLAS SIMULATION SOFTWARE.

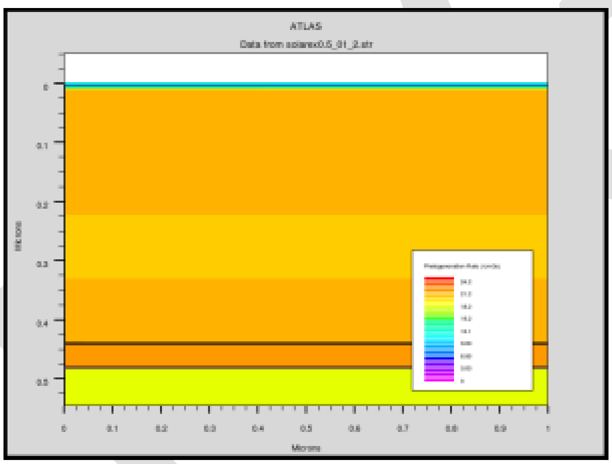

Fig. 2. Photogeneration rates used Silvaco ATLAS simulation software

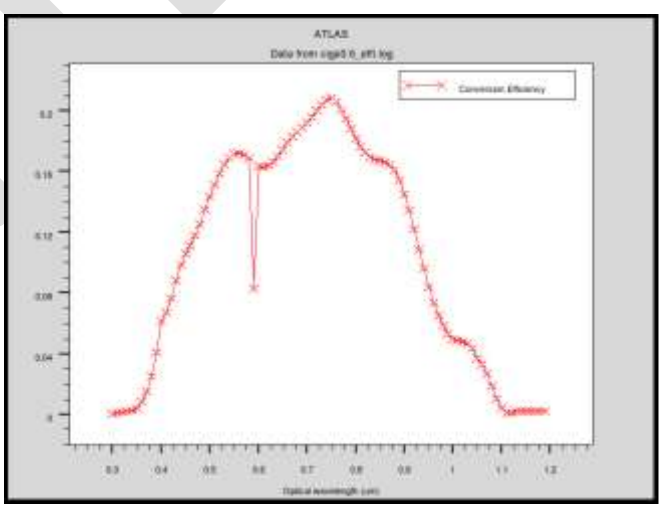

Fig. 3. Conversion efficiency

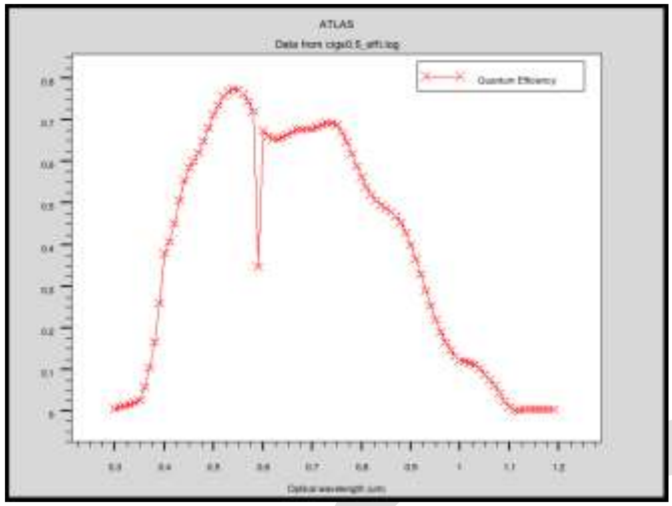

Fig. 4. Quantum efficiency

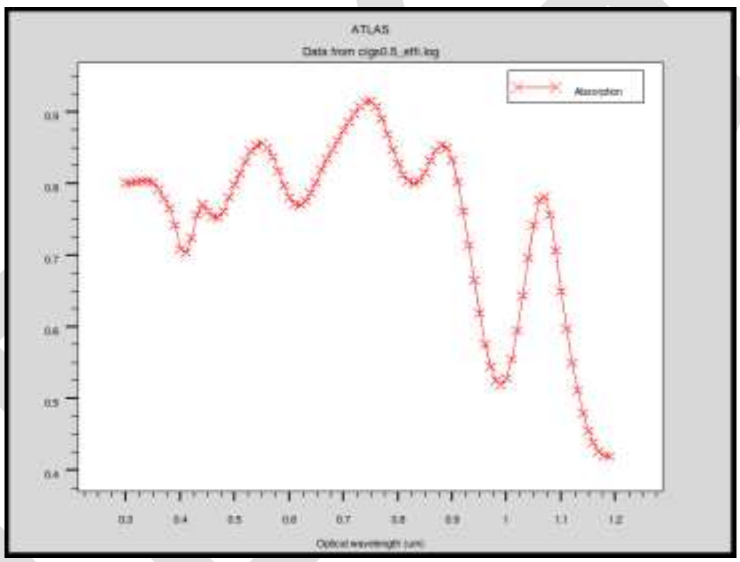

Fig. 5. Carrier generation pattern across the device (per unit volume per unit time)

The results obtained For CIGS solar structure with different CIGS thickness are given in **table 1**:

Table 1

Thickness (micron)	Conversion efficiency	Voc (V)	Isc (Amp)
0.5	0.21	0.46205	16.8092
1.0	0.245	0.47367	9.82356
1.5	0.26	0.43774	1.53777
2.0	0.26	0.48215	6.11232

ACKNOWLEDGMENT

Authors are thankful to Mr. Ambesh Dixit and Mr. Anurag Sahoo, IIT Jodhpur for providing the necessary facility and helpful discussion for simulation works.

CONCLUSION AND FUTURE ASPECT

The simulation results for a thin CIGS solar cell deposited with different inorganic material were presented. The average absorption of the devices is ~ 85% for all thicknesses considered for investigations and quantum efficiency is in the same range over entire wavelength. Yet strong dependence may be seen for Voc and Isc, as explained in the table. We found that uniform thin layer is suitable for such applications with high saturation current with respect of open circuit voltage which in less sensitive to the layer thickness. Thus for optimum power, smaller thickness of CIGS - 0.5 micron may be better for light to energy conversion. The reduction in open circuit voltage is found as the main limitation in efficiency enhancement GaAs/GaAsP QWSC's. Our simulation results shown that the open circuit voltage is not very much affected by thickness of CIGS material. Therefore, if CIGS material is used in QWSC's the open circuit voltage may not lower down We may also found the optimal thickness of CIGS layer for achieving enhancement in conversion and quantum efficiency.

REFERENCES:

1. K. Barnham, I.Ballard, J.Connolly,P.Graffin,B.Kluftinger, J.Nelson, E. Tsui, A. Zachariou, *Appl. Surf. Sci.* **1997**, 113, 722.
2. N. Tansu, J. Y. Yeh, L. Mawst, J. Phys. Cond. Mat. Phys. **2004**,16, S3277.
3. D. Jackrel, S. Bank, H. Yuen, M.Wistey, J.J.S. Harris,A. Ptak, S. Jhonston, D. Friedman, S. Kurtz, J. Appl. Phys. **2007**, 101, 114916.
4. J. Geisz, D. Friedman,J. Ward, A. Duda, W. Olavarria, T. Moriarty, J. Kiehl, M. Romero, A.Norman, K. Jones, Appl Phys. Lett. **2008**, 93, 123505.
5. P. Jackson, D.Hariskos, E. Lotter, S. Paetel, R. Wuerz, R.Menner, W.Wischmann, M. Powalla, Prog. Photovolt :Res. Appl. **2011**, 19, URL http://dx.doi.org/10.1002/pip.1078
6. I. Repins, M. Contreras, B.Egaas, C.DeHart, J.Scharf, C. Perkins B.To, R. Noufi, Prog. Photovolt: Res. Appl **2008**, 16,235.
7. Q. Guo, S. J. Kim, M. Kar, W. N. Shafarman, R. W. Birkmire, E. A. Stach, R. Agarwal, H. W. Hillhouse, Nano Letters, **2008**, 8, 2982.
8. M. Afshar, S. Sadewasser, J. Albert, S. Lehmann, D. Abou-Ras, D. Fuertes Marron, A. A. Rockett, E. Rasanen, M. C. L. Steiner, Adv. Energy Mater**. 2011**,1,1109.
9. R. E. Welser, A. K. Sood, United State Patent, US008921687B1, Dec. 30,**2014**
10. J. Krc, M. Sever, M. topic, IEEE Journal of Photovoltaics, **2013**,3(4), 1156.
11. Atlas User's Manual, vols. 1-2, software version5.6.0.R, Silvaco International, Sunnyvale, CA, **2003**.
12. R. R. King, N. H. Karam, J. H. Ermer, N. Hadded, P. Colter, T. Isshki, H. Yoon, H. L. Cotal, D. E. Joslin, D. D. Krut, R. Sudharshan, K. Edmondson, B. T. cavicchi, D. R. Lillington, "Next Generation, high efficiency III-V multijunction solar cells", Proc. Twenty-Eight IEEE Photovoltaic Specilists Conference, **2000**, 998.
13. P. Michalopoulous, "A novel approach for the development and optimization of state-of-the-art photovoltaic devices using Silvaco", Master's Thesis, Naval Postgraduate School, **2002**.
14. J. Malmstrom, Ph D Thesis, Uppsala University, **2004**.
15. M. Burgelman, J. Verscraegen, S. Degrave, P. Nollet, Prog. Photovolt. Res. Appl.**2004**, 143