Solid State Science and Technology, Vol. 18, No 1 (2010) 244-250
ISSN 0128-7389

MODELING AND SIMULATION OF HETEROJUNCTION OF InGaAs/GaAs SOLAR CELL BY USING SILVACO SOFTWARE

A. Lennie[1], H. Abdullah[1], A.M. Markom[1], S. Shaari[2] and J.S. Mandeep[1]

[1]*Dept. of Electrical, Electronics and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia*

[2]*Institute of Microengineering and Nanoelectronics (IMEN), Universiti Kebangsaan Malaysia, 43600 Bangi Selangor, Malaysia*

ABSTRACT

In this paper presented a heterojunction of InGaAs/GaAs solar cell is modeled and fully simulated by Silvaco software with demonstrated by two-dimensional analysis. The InGaAs window layers of GaAs heterojunction solar cell help in reducing the surface recombination at the emitter surface of the solar cells resulting in significant improvement in energy conversion efficiency. The fabrication process and simulation of photovoltaic properties are performing by using '*Virtual Wafer Fabrication*' software produced by SILVACO Inc. TCAD tools. Three types of concentration doping of Phosphorus were chose in this work which is 1×10^{17} ion/cm^{-2}, 1×10^{19} ion/cm^{-2} and 1×10^{20} ion/cm^{-2}. These simulations were run in 30°, 60° and 90° of incident light for each doping concentration. The factors affected the efficiencies and performance which consists of concentration doping, angle of incident light and junction depth of solar cell are analyzed and discussed. As the results, the maximum efficiency is 36.48% from 1×10^{17} ion/cm^{-2} doping in 90° incident light, while the electrical characteristics gives lower I_{sc} value and higher V_{oc} value. As a conclusion, the efficiency of 36.48% has produced the thinnest junction depth of InGaAs window layer and GaAs emitter layer.

INTRODUCTION

A solar cell consists of potential energy barriers within a semiconductor material that is capable of separating the electrons and holes that are generated by the absorption of light within the semiconductor [1]. The most common four types of barriers are homojunctions, heteroface structures, heterojunctions and schottkey barriers. Homojunctions is p-n junction within the same semiconductor material, heteroface structures is similar to homojunctions but with a window layer of a larger band gap semiconductor added to reduce surface recombination loss, and heterojunction is p-n junction between two different semiconductor material while schottkey barriers is metal-semiconductors junctions. The use of a heterojunction with larger band gap window means to minimize the surface recombination loss that might otherwise dominate in direct band gap materials [2]. It also expands the semiconductor material possibilities for solar photovoltaic enormously.

Corresponding Author: huda@vlsi.eng.ukm.my

Solid State Science and Technology, Vol. 18, No 1 (2010) 244-250
ISSN 0128-7389

One of goals of solar cells is the calculation of solar efficiency [3]. The current-voltage characteristics as shown in Figure 1 illustrated current-voltage characteristics to define basics solar parameters, light generated current (I_L), short circuit current (I_{sc}) and voltage open circuit (V_{oc}).

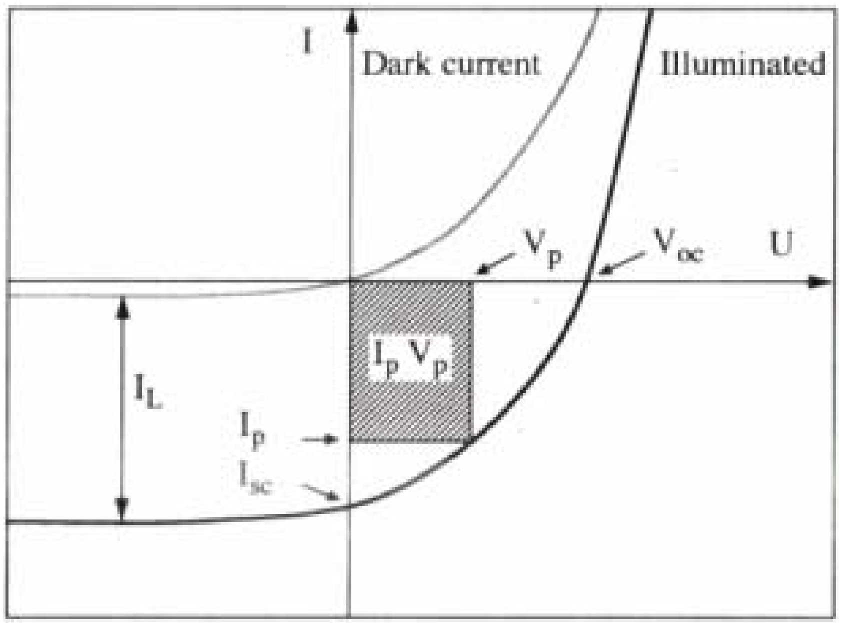


Figure 1: Current-voltage characteristics of p-n junction solar cell in the dark and under illumination.

Fill factor (FF) is defined by the maximum rectangle given by V_{mp} and I_{mp} and such as the Eq. 1:

$$FF = \left(\frac{P_m}{I_{SC} V_{OC}} \right) \quad (1)$$

Typically, the FF is between 0.7 and 0.8 [4]. The solar efficiency of a cell is defined as the ratio maximum power, P_m to the solar power incident on the cell and written as Eq. 2:

$$\eta = \frac{P_m}{P_{in}} \times 100\% = \frac{I_{mp} V_{mp}}{P_{in}} \times 100\% \qquad (2)$$

These parameters are not independent from each other and are controlled by physical processes. The results will allow estimation of the efficiency of a solar cell from perspective of the material properties.

Corresponding Author: huda@vlsi.eng.ukm.my

Two different semiconductors used in this project are GaAs and InGaAs, which GaAs is compound of elements Gallium and Arsenic while InGaAs is compound of Indium, Gallium and Arsenic. In many years, GaAs is known well with the band gap 1.43 eV as produce the highest efficiency of solar cell [5]. GaAs has a direct band gap and a large optical absorption coefficient, absorbing 97% photons within about 2 µm. The near perfect lattice match and absence of interface state recombination of InGaAs/GaAs isotype junction has been used to advantage to remove the front surface recombination loss from heterojunction interface and to yield the highest efficiencies of solar cell. InGaAs is semiconductor which the energy band gap can be change within 1.42 eV from GaAs and 0.36 eV from InAs with changes of ratio In/Ga.

METHODOLOGY

Silvaco software is used to model and simulate as the method of this project with the modules of Athena and Atlas [6]. The fabrication process of solar cell started from the silicon substrate grid selection of 10×50 µm^2 on GaAs wafer with 3.0×10^{14} atom/cm^2 boron concentration and <100> orientation. Then the GaAs growth as substrate p-type with impurity of boron with energy applied at 100 eV. The first layer of 0.10 µm was deposited on the top of substrate by using GaAs as p-type high doping. The implantation of phosphorus was applied to develop n-type layer with different concentration doping of 1×10^{17} ion/cm^{-2}, 1×10^{19} ion/cm^{-2} and 1×10^{20} ion/cm^{-2}. The doped atom is absorbed through annealing process in 60 min with 900°C temperatures. The second layer of 0.05 µm which is window layer for this structure was deposited using InGaAs material followed by formed contact using Aluminum material. Finally, the model structure was applied voltage to extract and analyze the short circuit current output and open circuit voltage of solar cell. The schematic of fabricating layers for InGaAs/GaAs heterojunction solar cell model are as Figure 2 below.

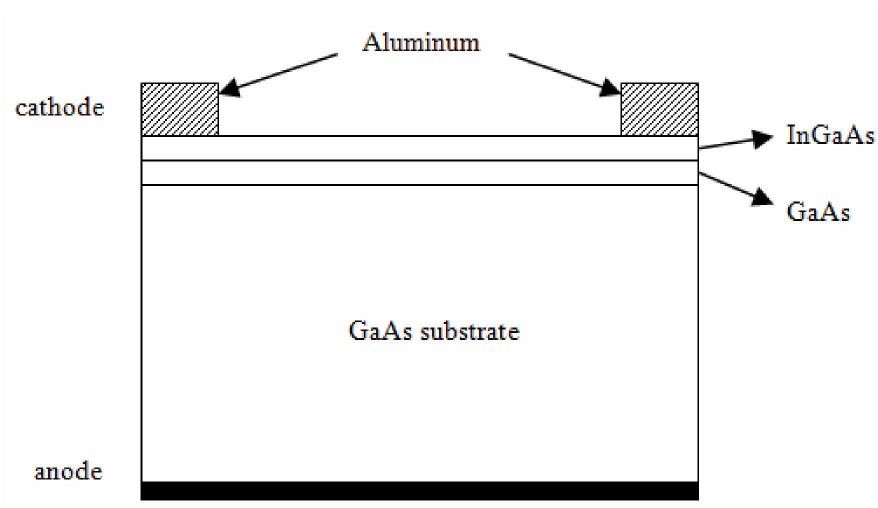


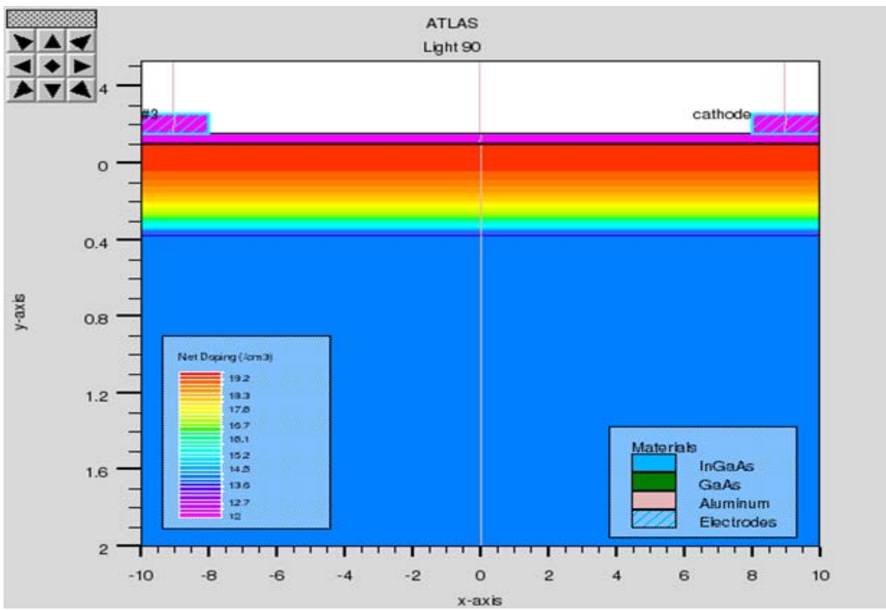
Figure 2: The schematic of InGaAs/GaAs heterojunction solar cell model

Corresponding Author: huda@vlsi.eng.ukm.my

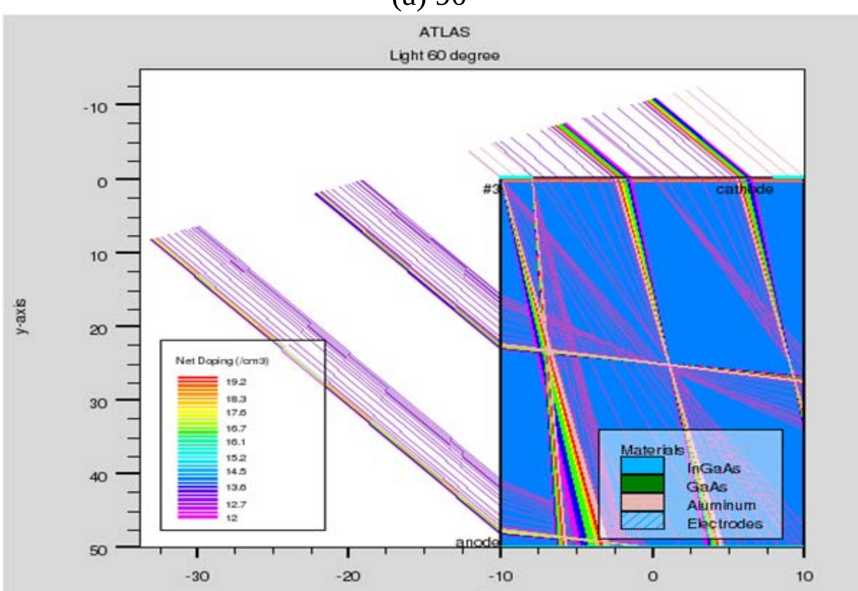
Solid State Science and Technology, Vol. 18, No 1 (2010) 244-250
ISSN 0128-7389

RESULTS AND DISCUSSION

The heterojunction solar cell structure has been done modeled by using Athena simulator in Silvaco software. Figure 3 illustrated heterojunction InGaAs/GaAs solar cell structure with 1×10^{17} ion/cm^{-2} doping at 30°, 60° and 90° incident lights. In 90° incident light figure, the light entering straight into GaAs substrate without reflecting because the structure is even surface. But we can see clearly on the 30° and 60° incident light figures, the light reflected when entering into GaAs substrate region.

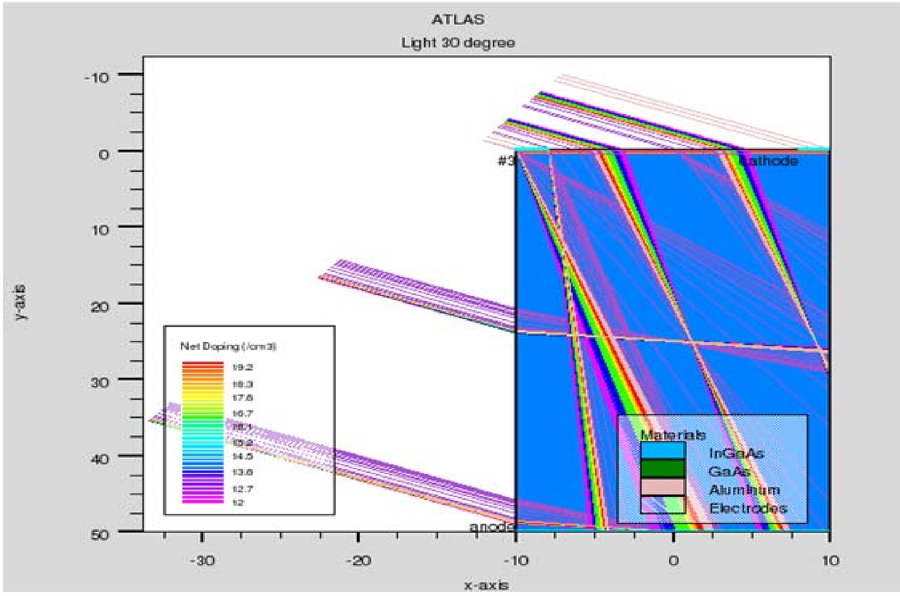


(a) 90°



(b) 60°

Corresponding Author: huda@vlsi.eng.ukm.my



(c) 30°

Figure 3: The solar cell structure with incident light of (a) 90°, (b) 60° and (c) 30°

Atlas simulator enables device technology engineers to simulate the electrical, optical, and thermal behavior of semiconductor devices [6]. ATLAS has the capability to provide a wide variety of illustrative results for use in solar cell design [7]. The simulation result of short circuit current (I_{sc}), open circuit voltage (V_{oc}), emitter junction depth (GaAs) and window layer junction depth (InGaAs) on InGaAs/GaAs heterojunction solar cell for variables concentration doping in 90° incident light were extracted and recorded in Table 1 below.

Table 1: Simulation result for variable phosphorus doping

Phosphorus Doping (atom/cm^2)	$\mathbf{1 \times 10^{17}}$	$\mathbf{1 \times 10^{19}}$	$\mathbf{1 \times 10^{20}}$
J_{sc} (nA)	4.80	5.02	5.00
V_{oc} (mV)	9.50	8.70	8.60
GaAs junction depth (μm)	0.34	0.42	0.45
InGaAs junction depth (μm)	2.86	2.87	2.89

Figure 4 described the histogram of efficiency for variable doping concentration when different angle of incident light hits on InGaAs/GaAs heterojunction solar cell surface. In overall the increasing of doping concentration resulted of decreasing efficiency solar cell, and this situation because of hot electron effect and depletion region from increasing number of electron and their momentum and velocity. This result can be concluded the efficiency of 1×10^{17} ion/cm^2 at 90° incident light is higher than others concentration doping in different incident light angle which has η of 36.48%.

Corresponding Author: huda@vlsi.eng.ukm.my

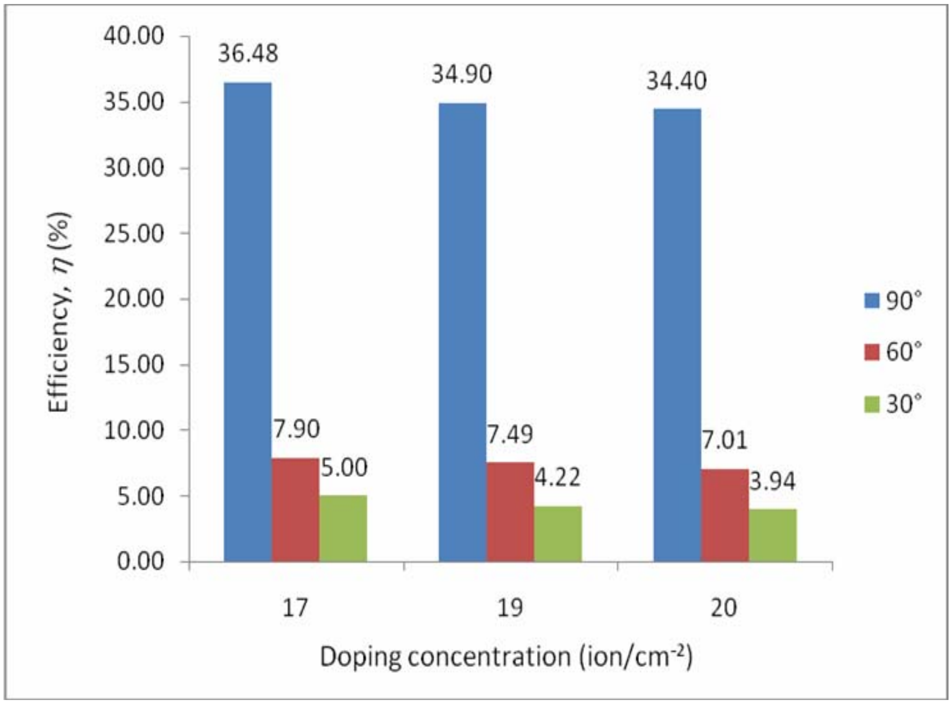


Figure 4: The histogram of efficiency for variable doping concentration in 30, 60 and 90° incident lights on InGaAs/GaAs heterojunction solar cell

CONCLUSION

The ability of the ATLAS device simulator [6], to accurately model solar cell characteristics has been shown. Using these tools, a model of InGaAs/GaAs/GaAs cell was designed and simulated showing junction depth and *I-V* characteristics in line with expectations. Theory of efficiency solar cell promising the increasing of efficiency and performance cells when the values of current and voltage increased. As the results, the maximum efficiency is 36.48% from 1×10^{17} ion/cm^{-2} doping in 90° incident light. While the electrical characteristics gives lower I_{sc} value and higher V_{oc} value. As a conclusion, the efficiency of 36.48% has produced the thinnest junction depth of InGaAs window layer and GaAs layer.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Ministry of Science, Technology and Innovation Malaysia, for sponsoring these research activities through the fund 03-01-02-SF0385. Also thanks Photonics Laboratory, Institute of Microengineering and Nanoelectronics (IMEN), Universiti Kebangsaan Malaysia for providing the facilities.

Corresponding Author: huda@vlsi.eng.ukm.my

REFERENCES

[1]. Othman, M.Y. and Sopian, K. (2002). *Teknologi Tenaga Suria*, (Penerbit Universiti Kebangsaan Malaysia, Bangi).

[2]. Sze, S.M. (2002). *Semiconductor Devices – Physics and Technology*, (2nd Edition, John Wiley & Sons, Inc., United States of America).

[3]. Moller, H.J. (1993). *Semiconductor for Solar Cells*, (Artech House Inc., United States of America).

[4]. Neamen, D.A. (2006). *An Introduction to Semiconductor Devices*, (Mc Graw Hill, New York).

[5]. Sze, S.M. and Kwok, K.Ng. (2007). *Physics of Semiconductor Devices*. (3rd Edition, John Wiley & Sons, Inc., United States of America).

[6]. SILVACO. (2009) *Process Simulation 2-D – ATHENA and ATLAS Overview*, (Silvaco International Inc., Sunnyvale, CA)

[7]. Micheal, S., (2005). *IEEE*. p. 719.

Corresponding Author: huda@vlsi.eng.ukm.my