Modeling and Performance Analysis of Germanium Based p-i-n Solar Cells

Farhan Shadman Chowdhury[1] and Asif Reza Taraque[2]

[1, 2] Department of Electrical, Electronic and Communication Engineering
Military Institute of Science and Technology
Mirpur Cantonment, Dhaka, Bangladesh
[1]farhan.arnab@yahoo.com

***Abstract*—This paper concentrates on the modeling of a Germanium based p-i-n solar cell and analyze the performance of it at different doping concentrations, light intensity and temperature. In this paper a virtual structure of Germanium based p-i-n solar cell was modeled and then a major analysis was done to increase the efficiency of the highly demanding solar cell by changing one of the most important parameters: the doping concentration of the p and n type Germanium doping. The doping concentration of the p-type i.e. the acceptor Germanium has been kept constant and the doping concentration of the donor atom were changed to find the performance of the solar cell. This analysis gives an excellent result with a maximum efficiency of 26.04% and a fill factor of 89.63%.**

Keywords—Modeling, Germanium, Fill Factor, Efficiency, Doping Concentration

I. INTRODUCTION

Generally a p-n junction Germanium solar cell has only one junction. A vast research has been made on this type of solar cell and the energy conversion efficiency has been researched up to its limit. Although a theoretical efficiency in the range 35 to 40% has been achieved for p-n solar cells but the practical solar cells are yet to receive close to it.

In this paper a detailed analysis was made on increasing the efficiency of solar cell which does not deal with the conventional p-n junction solar cell; rather it deals with a comparatively new theme that is designing and analyzing the performance of Germanium based p-i-n solar cell. The current voltage characteristics data has been analyzed for Germanium based p-i-n solar cell to obtain six parameters that completely specify the I-V characteristics curve at open circuit voltage. These parameters are doping concentrations, permittivity, affinity, radiated recombination rate, electron and hole density of states and lattice constants. By changing these parameters the performance of the p-i-n Germanium solar cell can be observes. In this paper among the above mentioned six parameters, varying the doping concentrations was the main objective. A detailed analysis on doping concentrations has given wonderful results. By changing the doping concentrations of the donor atom while keeping the doping concentration of acceptor atom constant different I-V characteristics curve for Germanium p-i-n solar cell was obtained. It was assumed that the permittivity and the temperature remained constant. After analyzing the curves at different doping concentrations the best combination for Germanium based p-i-n solar cell was found to be the acceptor concentration of N_A=1e16 /cm^3 . A variance of N_D in the range of 3e19 to 4e19 /cm^3 three different I-V characteristics curves was obtained. In all three cases the doping concentration of the donor atom was kept constant to N_A=1e16 /cm^3. In this case an assumption was made that the light intensity is at standard 250 W/m^2 with respect to Bangladesh standard. After obtaining three best result for the I-V characteristics curve attention was paid to analyze the performance of the modeled Germanium based p-i-n solar cell. In this paper a good amount of research was also done to observe the effect of temperature and illumination on the modeled solar cell. The range of the temperature taken was the standard range of temperature in Bangladesh which is 293K to 303K. Illumination was varied in the range of 125 W/m^2 to 500 W/m^2. After analyzing the performance of the I-V characteristics curve a maximum efficiency of 26.04% was recorded.

II. EXPERIMENTAL DETAILS

Solar cell is usually a photo diode having a p-n junction. First generation solar cell has single layer p-n junction. In second generation, thin film deposits of semiconductors are used such as amorphous Germanium [1]. Third generation solar cells include hetero structures and p-i-n diodes. A p-i-n diode is a diode with a lightly doped near intrinsic semiconductor between p and n type semiconductor [2]. Generally the p and n type semiconductors are heavily doped. In this paper the doping concentration of the donor atom was considered much higher than that of the acceptor atom [7]. The model picture used for the p-i-n solar cell is shown in figure 1.

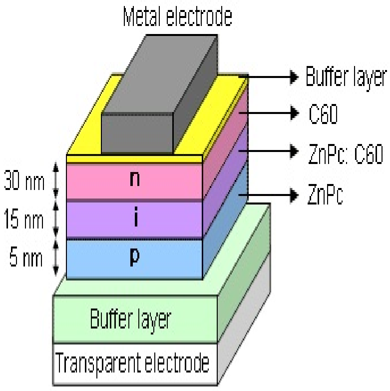

Fig. 1 Model of a Germanium p-i-n Solar Cell

The main difference between a p-i-n and a p-n junction is the wide intrinsic region. This intrinsic region makes the p-i-n an inferior rectifier which has a great role to play in case of analyzing solar cell efficiency. There are mainly two factors to analyze the performance of a solar cell. The ability to produce electrical current when a solar cell absorbs photon from the light is the first factor while analyzing the performance. A Solar cell absorbs photon when sunlight falls on it. During this phenomenon, electron-hole pair is generated. It produces photo current. This photo current acts as an current source. The second factor that is most important in analyzing the performance of a solar cell is the dark current. It is the current passing through a solar cell when it is biased in the dark. I-V characteristic can be achieved by subtracting this dark current from the photo current. So the circulating current will be[1],

$$\mathrm{I} = \mathrm{I_L} - \mathrm{I_F} = \mathrm{I_L} - \mathrm{I_S}\left[e^{\left(\frac{eV}{KT}\right)} - 1\right] \qquad (1)$$

At high-level injection a PIN diode operates. The intrinsic "i" region is flooded with charge carriers from the "p" and "n" regions. the diode conducts current once the flooded electrons and holes reach an equilibrium point. At forward bias, the injected carrier concentration higher than the intrinsic level carrier concentration. Due to this high level injection the electric field extends deeply into the region. This electric field helps in speeding up of the transport of charge carriers from P to N region, which results in faster operation of the diode, making it a suitable device for building a solar cell.

In a PIN diode, the depletion region exists almost completely within the intrinsic region. This depletion region is much larger than in a PN diode, and almost constant-size, independent of the reverse bias applied to the diode. This increases the volume where electron-hole pairs can be generated by an incident photon.

It is a very tough job to calculate the efficiency for analyzing the performance of a solar cell. Fill factor is used as a significant parameter while analyzing the performance and plays a vital role in obtaining the efficiency of a solar cell. The equation of fill factor is as [3],

$$FF = \left[\frac{P_{\mathrm{m}}}{V_{\mathrm{oc}} * I_{\mathrm{sc}}}\right] \times 100\% = \frac{V_m \times I_m}{V_{OC} \times I_{SC}} \times 100\% \qquad (2)$$

Where P_m the maximum power, V_m is the maximum voltage at maximum Power, I_m is the maximum current at maximum power, V_{OC} is the open circuit voltage and I_{SC} is the short circuit current for the designed solar cell.

The input power is calculated by[4],

$$p_{in} = I * A \qquad (3)$$

Where I is the irradiation of sunlight in W/m^2, A is the area of the device.

From P_m and P_{in}, we can evaluate the efficiency [2] with the following equation,

$$= \left(\frac{P_{\mathrm{m}}}{P_{\mathrm{in}}}\right) \times 100\% = \left[\frac{V_{\mathrm{m}} \times I_{\mathrm{m}}}{V_{\mathrm{OC}} \times I_{\mathrm{SC}}}\right] \times 100\% \qquad (4)$$

III. RESULTS & DISCUSSIONS

We discuss the result section in three different categories. In the first part we will discuss the standard properties of the material that has been used while analyzing the performance of Germanium based p-i-n solar cell. In the second category we will consider three different parameters that have been varied through the analysis of the performance of the solar cell that which is being modeled in this paper. Here we will discuss the different characteristics curves that have been established while analyzing the performance. The last section deals with the outcome of this paper.

A. Scheme & Design :

The optical properties of Germanium elements are shown in table I.

TABLE I. Properties of Germanium at T=300K

Properties	**Germanium**
Atoms(/cm^3)	4.42e22
Atomic Weight	72.61
Crystal Structure	Diamond
Density(g/cm^3)	5.33
Lattice Constant(cm)	5.65
Melting point(deg C)	937
Dielectric Constant	16
Band gap Energy(eV)	0.66
Electron Affinity(volts)	4.13
NC(/cm^3)	1.04e19
NV(/cm^3)	6.0e18
Intrinsic Concentration(/cm^3)	2.4e13

Electron Mobility(cm^2/V-s)	3900
Hole Mobility(cm^2/V-s)	1900
Electron Effective Mass	0.55
Hole Effective Mass	0.37

Germanium is a chemical element with the symbol Ge and atomic number 32, atomic mass 72.61 amu, number of protons/electrons 32 and number of neutrons 41. Classification is metalloid, crystal structure cubic and color grayish. Germanium has 4 valance electrons. Germanium is group IVA element.

Germanium is an indirect semiconductor. Thus to make transitions from the valence band to the conduction band with the least amount of energy an electron must absorb a photon and a phonon. Germanium is indirect band gap material.

B. Characteristics Curves:

With the help of the device simulator TCAD we have established the I-V characteristics of the Germanium based p-i-n solar cell at different doping concentrations while keeping the temperature and light intensity constant. The demonstration of an I-V characteristics curve of Germanium solar cell [6] in TCAD is shown in fig.2

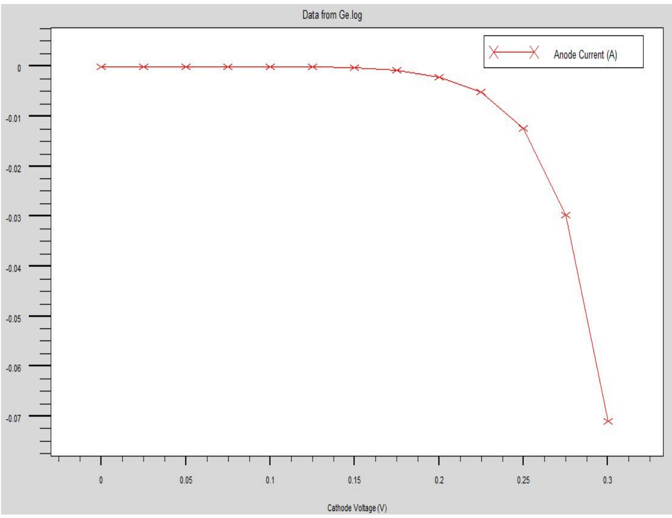

Fig. 2 Germanium based p-i-n solar cell I-V curve

This I-V curve in figure 2 is for an acceptor doping concentration of N_A=1e16 /cm^3 and a donor concentration of N_D=3e19 /cm^3. In this paper three best possible doping concentrations were considered to analyze the I-V characteristics of the Germanium based p-i-n solar cell and to achieve maximum outcome.

Figure 3 represents the I-V characteristics curve of Germanium based p-i-n solar cell for three different doping concentrations. The short circuit current is 0.038A for N_D=3e19 /cm^3 and N_A=1e16 /cm^3; 0.034 A for N_D=3.5e19 /cm^3 and N_A=1e16 /cm^3; 0.027A for N_D=4e19 /cm^3 and N_A=1e16 /cm^3. The open circuit voltage is 0.68V for these short circuit currents.

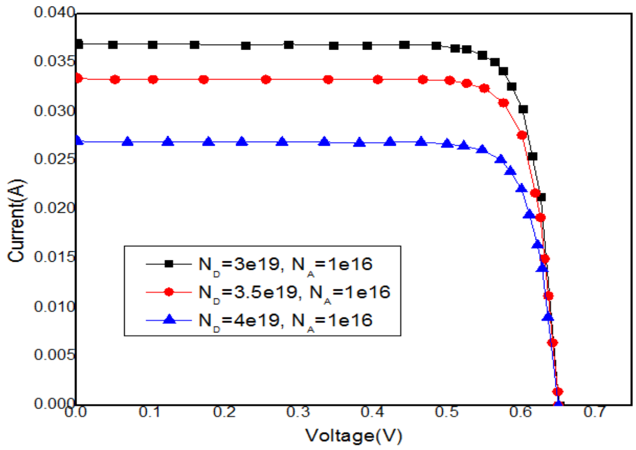

Fig. 3 Germanium based p-i-n solar cell I-V curves at different concentrations

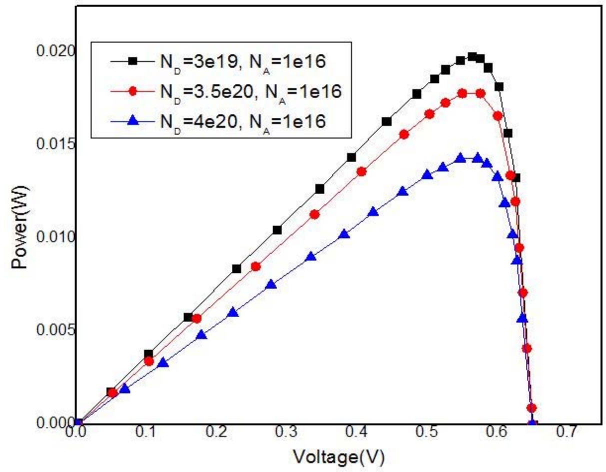

Fig. 4 Germanium based p-i-n solar cell power curves at different concentrations

Figure 4 shows the output power for different concentric combinations. The power curve is shown with respect to voltage. The maximum power for N_D=3e19 /cm^3 and N_A=1e16 /cm^3 is 0.02W and for N_D=3.5e19 /$cm^3$and N_A=1e16 /cm^3 is 0.018W. Whereas the maximum power for N_D=4e19 /cm^3 and N_A=1e16 /cm^3 is 0.014W.

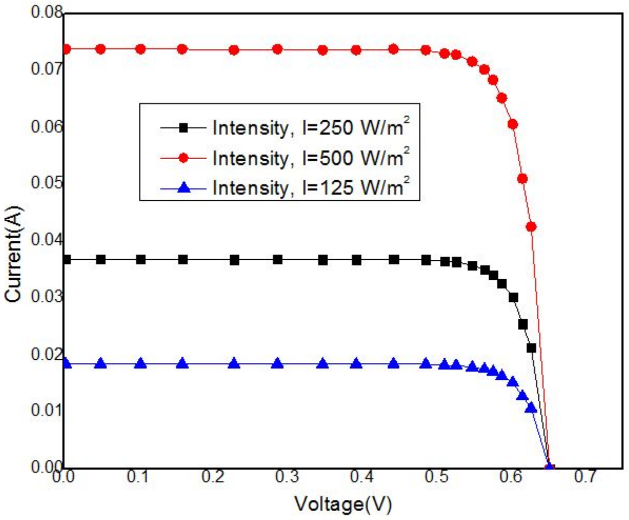

Fig. 5 Effect of illumination on the current of Germanium solar cell

The effect of illumination on Germanium based p-i-n solar cell is shown in figure 5. When intensity of light is doubled the photo-current is doubled. When the intensity is half then photo-current becomes half of its previous value.

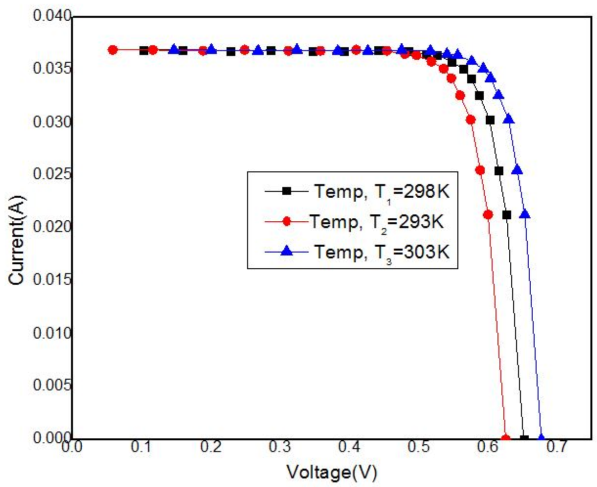

Fig. 6 Effect of temperature on the voltage of Germanium solar cell

The effect of different temperature on Germanium based p-i-n solar cell is shown in figure 6.The temperature we have considered are 293K, 298K, 303K respectively. This figure clearly depicts the effect of temperature on open circuit voltage.

The above curves clearly show that there is a major effect on the performance of Germanium based solar cell in terms of doping concentrations, temperature and light intensity.

C. Germanium Based p-i-n Solar Cell Efficiency:

The analytical values which are found by different concentrations of Germanium based p-i-n solar cells are shown in table II.

TABLE II. Efficiency calculation of Germanium solar cell

Parameter	**Values**		
	Germanium		
N_D(cm^{-3})	3e19	3.5e19	4e19
N_A(cm^{-3})	1e16	1e16	1e16
V_{OC}(V)	0.68	0.68	0.68
I_{SC}(A)	0.0702	0.0569	0.0473
V_{MAX}(V)	0.67	0.66	0.65
I_{MAX}(A)	0.038	0.034	0.027
P_{MAX}(W)	0.02	0.018	0.014
I(W/m^2)	250	250	250
Area(m^2)	5e-04	5e-04	5e-04
Fill Factor (%)	89.63	88.04	85.37
Efficiency (%)	26.04	24.01	22.03

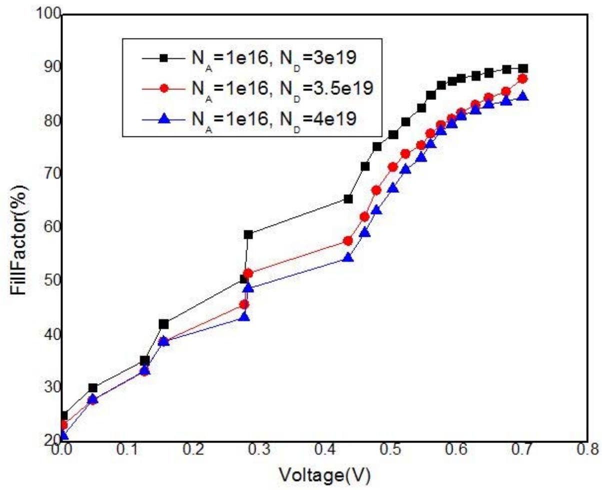

Fig. 7 Fill Factor of different concentration of Germanium solar cells

Figure 7 depicts the fill factor of the designed solar cell at different doping concentrations. The fill factor curve is shown with respect to voltage. The fill factor for N_D=3e19 /cm^3 and N_A=1e16 /cm^3 is 89.63% and for N_D=3.5e19 /cm^{3}and N_A=1e16 /cm^3 is 88.04%. Whereas the fill factor for N_D=4e19 /cm^3 and N_A=1e16 /cm^3 is 85.37%. This excellent fill factor curve opens up the path of having a solar cell of very high efficiency. In this paper, our concentration was to achieve a fill factor at a certain doping concentration to achieve maximum performance of the designed solar cell.

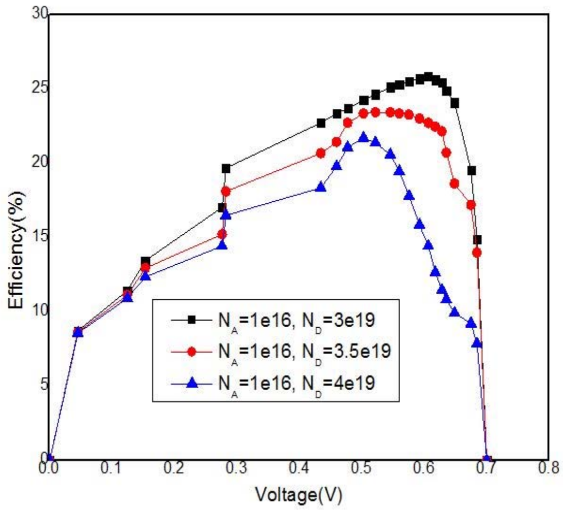

Fig. 8 Efficiency of different concentration of Germanium solar cells

The characteristics of the efficiency versus voltage of Germanium based p-i-n solar cell is shown in figure 8. The efficiency for N_D=3e19 /cm^3 and N_A=1e16 /cm^3 is 26.04%. The efficiency for N_D=3.5e19 /cm^3 and N_A=1e16 /cm^3 is 24.01%. The efficiency for N_D=4e19 /cm^3 and N_A=1e16 is 22.03%. In this paper we could achieve a maximum conversion efficiency of 26.04% which is a very good performance with the present researches that has been done on this aspect

V. CONCLUSION

This paper is an analysis on the improvement of a Germanium based p-i-n solar cell device in terms of fill factor and efficiency. In this case the development is dependent on the one and only doping concentrations of semiconductor i.e. the acceptor doping concentration. There are other parameters such as permittivity, affinity, radiated recombination rate, electron and hole density of states and lattice constants which are used to evaluate the performance of a solar cell. Our future plan is to analyze the performance of Germanium based solar cell by changing these parameters and design a solar cell having an efficiency of more than 26.04%. By comparing the efficiency and fill factor of two devices, the degree of advancement can be calculated. Processing and analyzing the performance of solar cells involve significant research and challenges. There are a lot of available areas for the improvement of solar cells in the remaining future. We hope to develop and design a solar cell which will serve the mankind with its maximum output.

REFERENCES

[1] Baldomero Garcia, Jr.; “Indium Gallium Nitride Multijunction Solar Cell Simulation Using Silvaco Atlas”; Naval Postgraduate School, Monterey, California.

[2] Tsutagawa & Michel; Triple Junction InGaP/GaAs/Germanium solar cell optimization- The design parameters for a 36.2% space cell using Silvaco ATLAS modelling and Simulation Department of Electrical & Computer Engineering, Naval Postgraduate School, Monterey, CA 93943, 2009.

[3] Donald A. Neaman; Semiconductor Devices and Physics; 3rd Edition.

[4] S. O. Kasap; Optoelectronics And Photonics; Professor of Electrical Engineering, University of Saskatchewan, Canada.

[5] Robert Germaniumlinas; “A Novel Approach to Modeling Tunnel Junction Diodes Using Silvaco ATLAS Software”; Naval Postgraduate School, Monterey, California.

[6] E. Yablonovitch, T. Gmitter, R. M. Swanson, and Y. H. Kwark, Applied Physics Letters 47 (1985) 1211.

[7] P. Würfel, Physics of Solar Cells - From principles to new concepts, Wiley-Vch Verlag GmbH & Co KgaA, Weinheim, 2005.