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Modelling and simulation of AlGaAs/GaAs solar cell

Devendra KC[1*], Raju Wagle[2], Raid Gaib[3], Anik Shrivastava[4], Lekha Nath Mishra[5]

[1]Lebesby Oppvekstsenter School, Lebessby, Norway
[2,3] UiT The Arctic University of Norway, Narvik, Norway
[4]Naval Material Research Laboratory, Maharastra, India
[5] Tribhuvan University, Patan Multiple Campus, Nepal
Corresponding Author: Devendra KC

ABSTRACT: *Enhancing the efficiency and finding optimal combination of thickness and concentration of multi- junction solar cell is most prominent problem in photovoltaic. In this paper AlGaAs/GaAs solar cell with four layer comprising of N-AlGaAs as window layer , N-GaAs as a emitter layer, P-GaAs as a base layer and P-AlGaAs as a back surface field(BFS) layer. is modeled in PC1D simulation software. The effect with varying thickness and doping concentration of base layer is analyzed. The optimum conversion efficiency of 31.1% is achieved at the doping levels concentration of* $10^{16}cm^{-3}$ *and base layer thickness of 2.2 µm.*

KEYWORDS: *Solar cell,AlGaAs/GaAs, PC1D, efficiency, thickness.*

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I. INTRODUCTION

The world is moving toward renewable energy in order to avoid the use of fossil fuel and nonrenewable energy [1]. Fossil fuels not only create environmental problems but also have limited lifespan so for better future planning of energy resources, people are looking for different option of renewable sources of energy [2]. One of the most popular source of renewable energy is Photovoltaic (PV) energy. However, PV also suffers from numerous problem like low efficiency [2], dependency on solar irradiance[3], complex active and reactive power controller [4], high use of power electronics devices. Therefore, people around the world are focusing on enhancing the efficiency of the solar cell either by optimizing the output power from PV or by producing an optimal combination and thickness of solar cell material. Solar energy is transformed to electrical energy by the use of Solar Cell [5]. Some commonly available basic solar cells are Si based SCs, thin film SCs, Perovoskite SCs, organic SCs and III-V material based SCs [6]. As Multi-junction solar cells have higher conversion efficiency compared to single junction SC, it is gaining higher popularity in the research industry [7]–[9]. Most popular multi-junction SC having high band gap are InGaP, AlGaAs, InGaAs, and InGaN [6]–[10].

GaAs based solar cells has been extensively used over Si based semiconductor for following reasons like direct bandgap, higher carrier mobility than silicon, ability to operate in higher temperature range than silicon and higher the absorption coefficient compared to Si [11]. However, higher recombination rate of GaAs solar cell is still a major problem [12]. In [13] AlxGa1-xAs thin film material with large band gap energy, acting as a Back Surface Field (BFS) and a window layer is used to improve the performance of cell significantly. Crystalline parameters of AlxGa1-xAs and GaAs is studied in [14] which shows that the properties are similar despite of few defects and recombination centers.

The performance of solar cell depends upon short circuit current (I_{sc}), open circuit voltage(V_{oc}), fill factor (FF) and efficiency. $I_{sc}$is the maximum current from solar cell when the voltage across the cell is zero and is produced in a cell due to generation and recombination of carriers when light fall on solar cell. It depends on area of structure, number of photons from solar spectrum, incident light spectrum, optical properties and probability of collection of light on the cell. V_{oc} is the maximum voltage produced by the solar cell when no current is flowing in the cell. Fill factor gives the measure of quality of solar cell and is given as the ratio of maximum power produced by solar cell to the product of V_{oc} and I_{sc}.

$$FF = \frac{P_{max}}{V_{oc} * I_{sc}} \quad (1)$$

Where,
P_{max} is the maximum power output from solar cell
I_{sc} is the short circuit current
$V_{oc}$is the open circuit voltage

Photovoltaic conversion efficiency (η) is the ratio of output power from solar cell to the input power from the sun light. The input power (P_{in}) for efficiency calculation used here is 0.1Wcm^{-2}
Hence,

$$\text{photovoltaic conversion efficiency} = \frac{P_{max}}{P_{in}} \quad (2)$$

from equation 1 and 2, the efficiency is given equation (3)

$$\eta = \frac{V_{oc} * I_{sc} * FF}{P_{in}} \quad (3)$$

Many simulation tools are used to model the solar cell to check the performance and analyze the effect of different properties of the solar cell [6]–[10], [13]. In this work PC1D [15], an open source modeling software is used to model AlGaAs/GaAs solar cell. The basic properties like fill factor, efficiency, short circuit current and open circuit voltage are calculated and with the help of these parameters, the performance of AlGaAs/GaAs solar cell is analyzed. Analysis with various thickness and doping level of base layer and its effect on performance is also presented.

The second section of this paper describes aboutAlGaAs/GaAs solar cellstructure. The third section discusses performance analysis, and finally the conclusion and future prospective is made in the fourth section.

II. ALGAAS/GAASSOLAR CELL STRUCTURE

Figure 1 shows the device structure considered in this work. The different layers are window layer, Emitter layer, Base layer and BFS layer. N-AlGaAs acts as window layer , N-GaAs as a emitter layer, P-GaAs as abase layerand P-AlGaAs as aback surface field(BFS). The parameters of solar cell [16]–[18] are as mentioned on table1.

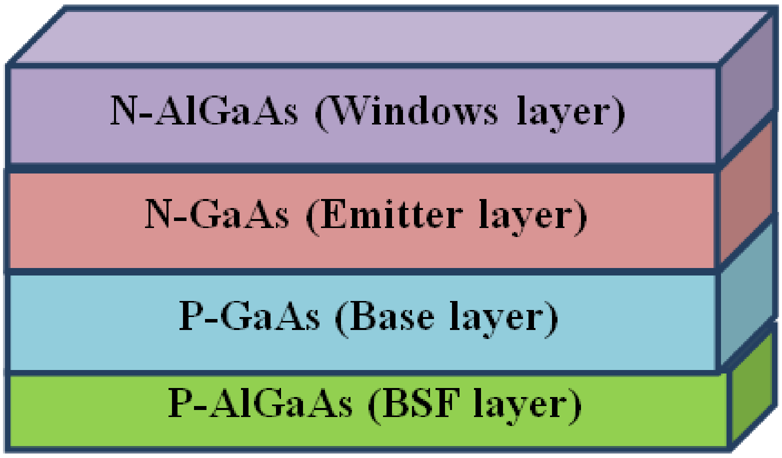

Figure 1: Device structure of Solar cell

Table 1: solar cell parameters

Parameters	Value
Device area	100 cm2
n-AlGaAs	300 nm
n-GaAs	300 nm
P-GaAs	2.2 micrometer
p-AlGaAs	300nm
Background doping P- AlGaAs	1.00E+16 cm-3
Background doping p- GaAs	1.00E+16 cm-3
Background layer n-GaAs	1.00E+18 cm-3
Background doping n-AlGaAs	1.00E+18 cm-3
Excitation mode	Transient

Temperature	25°C
Other parameters	Internal model of PC1D
Primary light source	AM 1.5D spectrum
Bulk recombination	1000 ms

III. PERFORMANCE ANALYSIS

III.I I-V CHARACTERISTICS

After simulation of solar cell using the parameters shown above in table 1 in PC1D, I-V curve as shown in **Figure 2** has been obtained by optimizing thickness and doping concentration. From the I-V characteristics, Short- circuit current (I_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and efficiency (η) has been calculated using equations mentioned below. The value of I_{sc} ,V_{oc},FF and η has been observed as 3.091A, 1.046 V, 88.5% and 28.64% respectively.

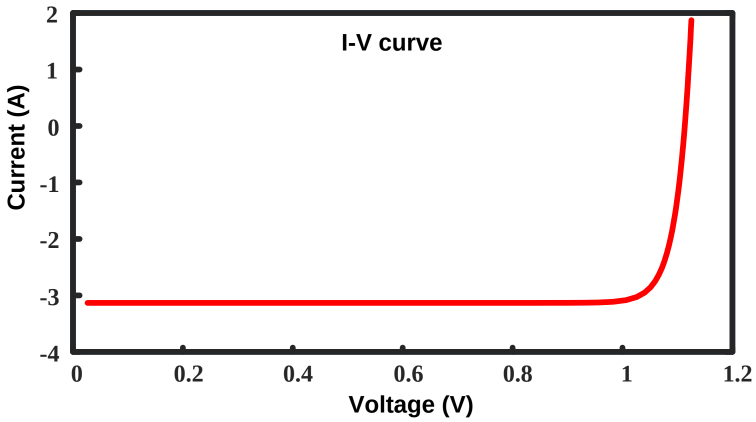

Figure 2: I-V characteristics of solar cell

III.II Effect of Base layer thickness

Efficiency of solar cell as a function of base layer thickness in this sub section and **Figure 3** shows the relationship of base layer thickness and efficiency. The thickness of the base layer is increased from 0.3 µm to 2.2 µm. As we increased the thickness of the base layer the efficiency of the solar cell is also increased. The increase in the efficiency was observed till 2.2 µm. Further increase in thickness has reduced the efficiency. Therefore, thickness of 2.2 µm and conversion efficiency 28.66% is taken as optimum .

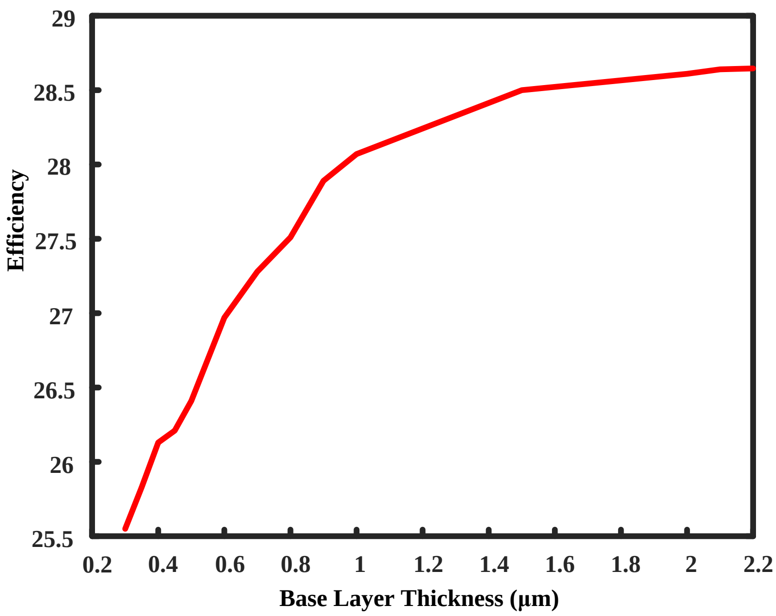

Figure 3: Thickness Vs efficiency of base layer

Figure 4 and **Figure 5** shows the effect of thickness of base layer on open circuit voltage and short circuit current. As the thickness of base layer of AlGaAs/GaAs was increased from 0.3 µm to 2.2 µm open circuit voltage decreased from 1.087 V to 1.046 V and short circuit current increased from 2.647 A to 3.091 A.

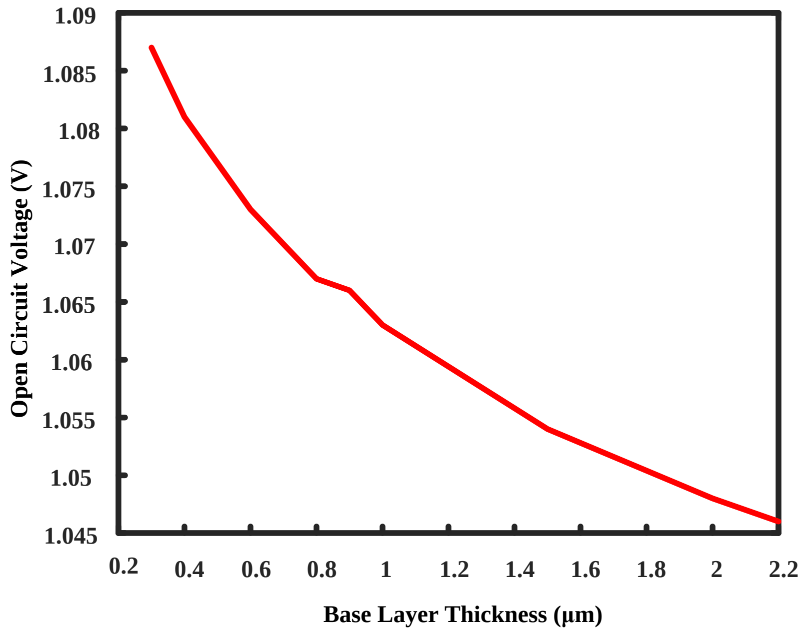

Figure 4: Effect of base layer on open circuit voltage.

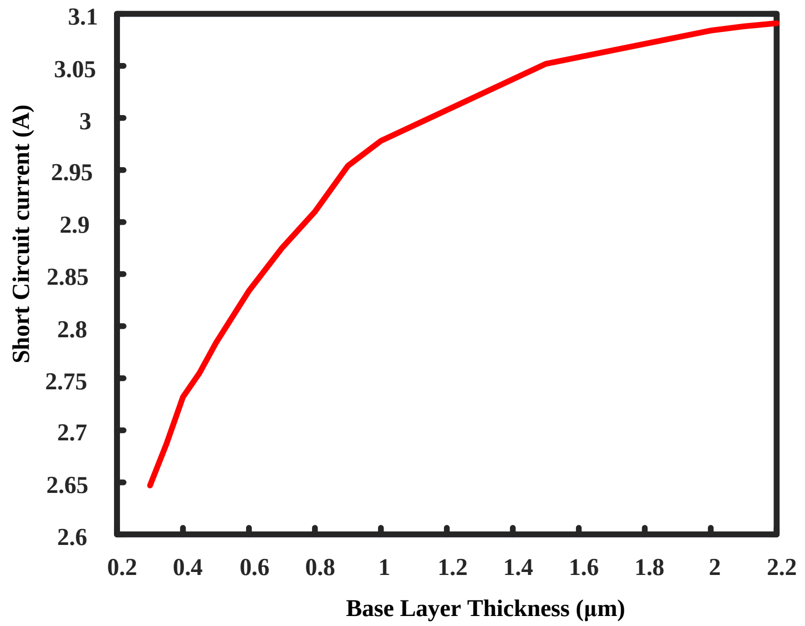

Figure 5: Effect of base layer thickness on short circuit current.

The impact of different base layer thickness of AlGaAs/GaAs solar cell is observed. **Figure 6** shows I-V characteristics with different thickness 0.5 µm, 1 µm, 1.5 µm and 2.2 µm. FromF**igure 6**it is observed that the current also changes with base layer thickness however the notch point for all thickness remains almost same at around 1.046 V.

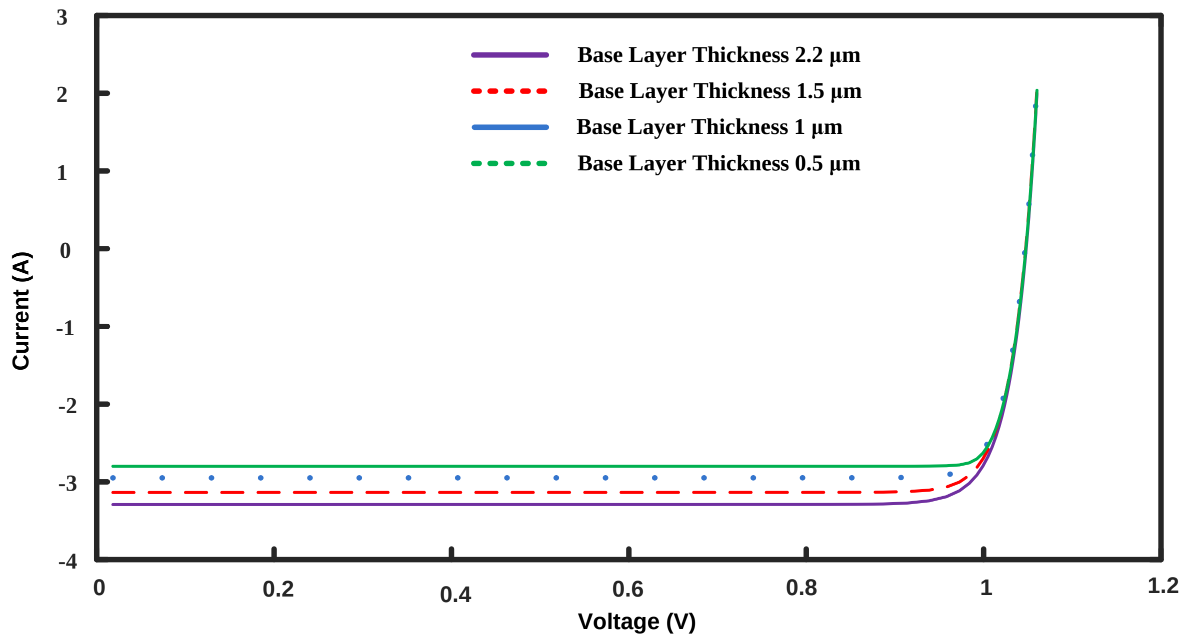

Figure 6: I-V characteristics of the solar cell with varying base layer thickness.

III.III Effect of doping level in base layer of AlGaAs/GaAs solar cell:
The role of doping on the efficiency of the solar cell is very important. By varying the doping levels of the base layer, the efficiency of the solar cell and be changed. Figure 7 shows the effect of doping concentration on efficiency. The doping level is varied from 10^{15} to 10^{20} cm^{-3}. The maximum efficiency achieved in base layer doping is 10^{16} cm^{-3}. The higher level of doping causes the damage the crystal structure of the solar cell, resulting in drop in efficiency of the solar cell. The optimum conversion efficiency of 31.1% is achieved at the doping levels $10^{16}cm^{-3}$.

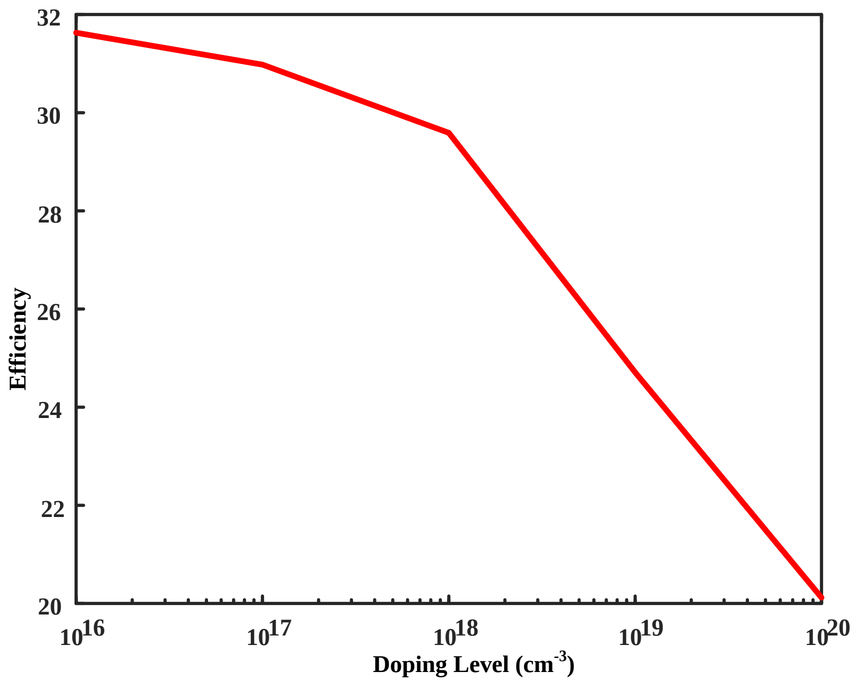

Figure 7: Doping level vs efficiency of solar cell.

IV. Conclusion

In this study four layer, AlGaAs/GaAs is theoretically designed and simulated by PC1D software. Among window layer, emitter layer, base layer and BSF layer, only base layer thickness and doping concentration is varied and the performance of the solar cell with mentioned variation is observed. The simulation result has shown that, for doping concentration $10^{16} cm^{-3}$ and base layer thickness 2.2 µm. Fill factor is 85.15% and the conversion efficiency of proposed solar cell is 31.10%. Future work will analyze the effect of variation in thickness and doping concentration on other layers.

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