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Modelling and Efficiency Analysis of InGaP/GaAs Single Junction PV cells with BSF

Mohammad Asif Iqbal,Arun Dev Dhar Dwivedi

Abstract: ***The purposes of PV cells are to transfer light energy into electrical energy. A compelling BSF is a key basic component for a productive PV cell.. In this paper, two significant materials GaAs and InGaP with top BSF and base BSF cells are researched utilizing the computational numerical modelling TCAD tool based Silvaco ATLAS. Past research observed that on the current coordinating condition with top BSF layer and base BSF layer, the cell show a general upgrade of density in Isc (short circuit current) and Voc (open circuit voltage) subsequently improving the overall efficiency of the cell. In this paper, structure of various thin film PV cells based on III-V materials e.g. GaN, InGaN have been used to design the multi junction PV cells. Extraction of figures of merits (efficiency, open circuit OC voltage, short circuit SC current and fill factor), simulation of electrical and optical characteristics of these devices have been carried out in this work. Our focus is to improve the optical characteristics, refractive index and absorption coefficient of InGaP with BSF and tunnelling features. In this paper complete Simulation and experimental results are shown and compared. The objective of this paper is to examine the productivity of InGaP/GaAs PV cells utilizing the Silvaco Atlas TCAD simulation software.***

Index Terms*: *ATLAS, BSF, PV cells, TCAD, III-V Materials

I. INTRODUCTION

Most essential objectives of PV cell design are to search a optimization point between economy and efficiency. Indium Gallium phosphate is a material that has experienced broad research as a good PV material. With changing in the composition of InGaP/GaAs, the bands-gap of this semiconductor matter can be transformed. The bands-gap scope of InGaP coordinates intently the obvious solar spectrum frequencies. A standout amongst the most significant issues to fathom in PV cell design is efficiency. As efficiency expands, the required number of cells diminishes to satisfy electrical power necessities [1]. Efficiencies of PV cell have improved after expanding the quantity of junctions. Every junction is equipped for removing energy from a section of the solar spectrum. Another way to improving efficiency is to utilize new PV materials, for example, InGaP. It has a band slot that can remove energy from vast section of sun spectrum [2].In order to extend considerably the region of photoactive absorption of solar radiation and decrease the power losses characteristic of sing1e-junction PV cells it is necessary to rising the numbers of $p-n$ junction in series PV cells[3]. Numerical simulation & modelling facilitate to optimize the PV cell structure in perceptive the substantial phenomenon & behaviours, therefore declining the time and cost for progress.

The transition efficiency, Isc and Voc are examined for various BSF structures. Multi junction PV cells would all be able to utilize tunnel junctions to improve execution.

In this paper, structure of various thin film PV cells based on III-V materials e.g. GaAs, InGaP have been used to design the multi junction PV cells. Extractions of figures of merits simulation of electrical and optical characteristics of these devices have been carried out in this work. Our focus is to improve the optical characteristics, refractive index and absorption coefficient of InGaP and GaN.

II. DEVICE FORMATION

(a) Tunnel Junction Model

On adequate band-to-band tunneling (BTBT) with gate bias occur if valence band of the P section align with the conduction band of the intrinsic zone. Valence band Electrons of the p-type zone shifted into the conduction band of the intrinsic area and current can stream over the cell [4]. It assumes that the tunnelling can be modelled as being one-dimensional in character so that it can be planned using a special rectangular mesh superimpose over.

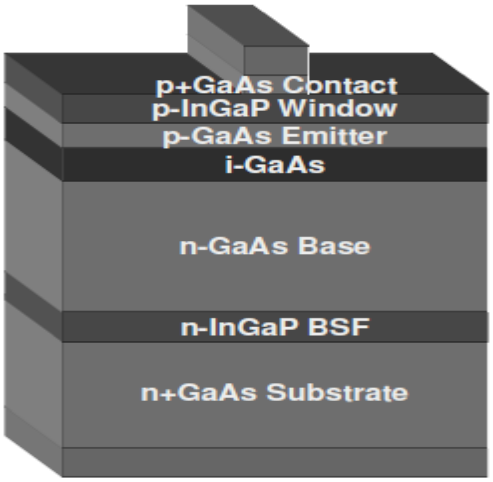

Figure 1: structure of proposed PV cell

(b) Bands-gap

Level of the PV cell responds to light and wavelength of light is depended on bands-gap of the semiconductor material. **Material Bands-gaps (eV) at 300 K for different materials are** Si 1.12, Ge 0.66,

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* Correspondence Author
Mohammad Asif Iqbal*, Research Scholar, SET, Poornima University.
Dr. Arun Dev Dhar Dwivedi, Professor, SET, Poornima University.

GaAs 1.42, InP 1.34. The transition formula among bands-gap and wavelength is[5]:

$$\lambda\,(\mu m) = \frac{hc}{Eg(eV)}$$

$$\lambda\,(\mu m) = \frac{1.24}{Eg(eV)}$$

Where λ: wavelength (micrometers)
h: P1anck's constant
c: speed of 1ight in vacuum
Eg: bands-gap energy (eV)

An eV is roughly equivalent to 1.6x10-19 J of energy. On account of Galium Arseenide, the wavelength that compares to 1.42 eV is 0.873 µm. At the point when light has energy more prominent than 1.1 eV, the silicon PV cell creates power. Also, light with energy more prominent than 1.43 eV energizes the external shell electrons of the galium arseenide sunlight based cell. Lastly, light with energy more noteworthy than 1.7 eV is valuable for aluminium galium arseenide PV material.

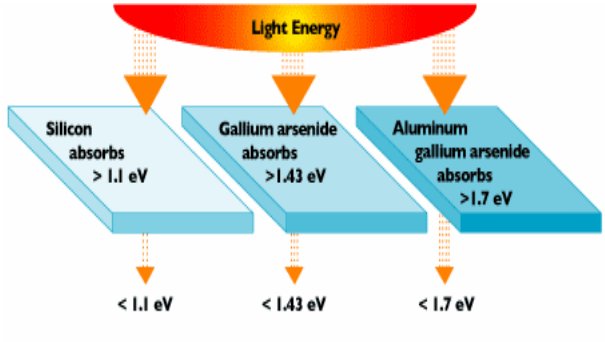

Figure 2: Light energy Effects with different bands-gaps

1. **Transitionefficiency of the PV cell**

$$n(\%) = \frac{\mathrm{I_{sc}}.\mathrm{V_{oc}}.\mathrm{FF}}{P_{in}}$$

2. **bands-gap energy:**

$$Eg(In_xGa_{1-x}P) = x.E_g^{InP} + (1-x).E_g^{GaP} - b.x.(1-x)$$

$$E_g(T_L) = E_{G300}(In_xGa_{1-x}P) + E_{g\alpha}\left[\frac{300^2}{300+E_{g\beta}} - \frac{T_L^2}{T_L+E_{g\beta}}\right]$$

$$EG(x) = 3.42x + 0.77(1-x) - 1.43x\,(1-x)$$

3. **Electron or hole mobility**

$$U_o(N,T) = U_{min,i}\left(\frac{T}{300}\right)^{B1} + \frac{(U_{max,i}-U_{min,i})(\frac{T}{300})^{B2}}{1+(\frac{N}{Nref\left(\frac{T}{300}\right)^{B3}})^{\gamma(\frac{T}{300})^{B4}}}$$

4. **Open circuit voltage**

$$\mathrm{V_{oc}} = \frac{K_BT}{q}\ln\left(\frac{J_{sc}}{J_O}+1\right)$$

(c) PV cell Junctions

In order to increase PV cell's efficiencies, different junctions can be made. For instance the top intersection would be comprised of Aluminium Gallium Arsenide. This intersection would absorb light energy more noteworthy than 1.7 eV. The gallium arsenide intersection would then absorb the photons with energy more prominent than 1.4 eV. The rest of the photons would be absorbed by the silicon intersection.

(d) Lattice Combination or Matching

Semiconductors are 3D structure in their cell. The generic cubic structure serves to outline the idea of cross lattice.

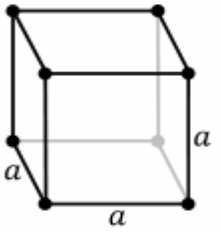

Figure 3: Simple cubic lattice structure

(e) AM0 Spectrum

The area of the PV cell influences the information solar radiation range. The energy got outside Earth's climate is around 1365 W/m2. Range known as AMO (Air Mass Zero). This sunlight based range is called AM1.5[6].from the figure 4 we can see the AM0 spectrum between Wavelength & Irradiance, but Figure 5: AM0-spectrum between Energy & Irradiance

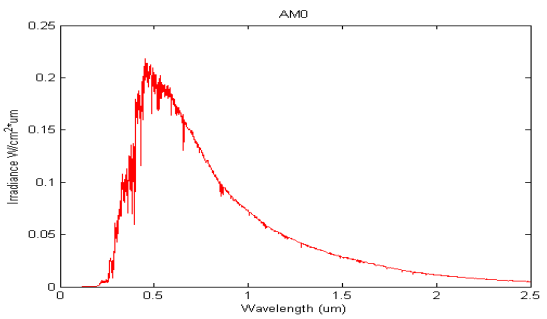

Figure 4: AMO-spectrum between Wavelength & Irradiance

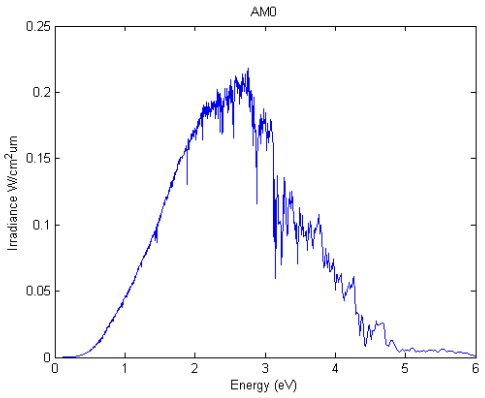

Figure 5: AMO-spectrum between Energy & Irradiance

(f) Current (I)-Voltage (V) Curves

When the voltage is zero then I_{sc} starts initiating. it is the highest absolute value current. Power (P) is find through product of current, voltage, the maximum power point track at (V_{mppt}, I_{mppt}).

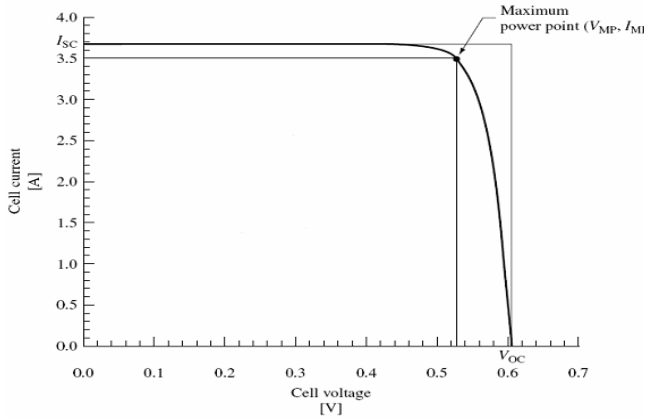

Figure 6: Sample IV curve used in efficiency calculations

PV cell's efficiency calculations:

$$P_{max} = I_{mp}V_{mp}$$

$$FF = \frac{P_{max}}{I_{sc}V_{oc}} = \frac{I_{mp}V_{mp}}{I_{sc}V_{oc}}$$

$$\eta = \frac{P_{max}}{P_{in}}$$

Where

- P max = maximum power point
- η = efficiency
- FF = fill factor

(g) Electrical Output

In order to determine IV characteristics the dark current should subtracted from light current.

$$I = IL - ID$$

When bias is applied in the dark the current passes through the cell is known as dark current.

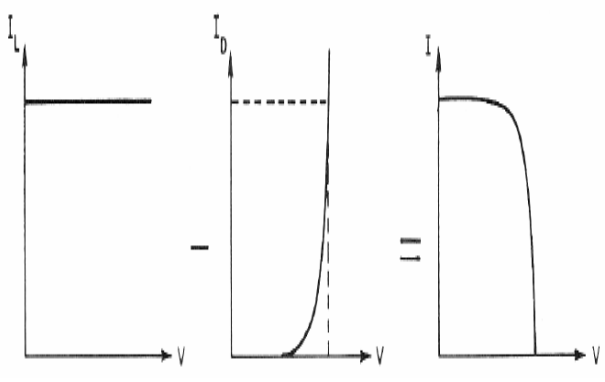

Figure 7: PV cell IV characteristic

(h) Coefficient of Absorption

Absorption coefficients determine distance of travelling light into materials of a fastidious wavelength can enter earlier than it is absorbed. When a material having low absorption coefficient it means capability to absorb light is also very poor. The absorption coefficient depends on the material & wavelength of light to be absorbed. In semiconductor materials, the absorption coefficient of light energy is calculated when the minimum energy is required to boost the electron so that it reaches from valence band to conduction band. Absorption coefficient α of InGaP is given by

$$\alpha\ (In_xGa_{1-x}P) = \sqrt[10^5]{(E_{ph} - E_g) + D(E_{ph} - E_g)^2}$$

Table 1: Properties of InGaP

S.no.	Specifications	Rating	Properties
1	Chemical Formula	InGaP	Chemical Properties
2	CAS No.	7440746	
3	Group	III-V	
4	Crystal Structure	Zinc Blende	
5	Bands-gap Type	Direct	
6	Bands-gap	4.1 eV	Electrical Properties
7	Dielectric Constant	11.8	
8	Lattice Constant	5.653 Å	
9	Intrinsic Carrier Concentration	1018 cm-3	
10	Specific Heat (SHC)Capacity	0.31+0.12x J g-1°C-1	
11	Symmetry Group	Td2-F43m	
12	Density	4.81-0.67x g/cm3	Mechanical Properties
13	Melting (MP)Point	220°C	
14	Bulk (BM)Modulus	(7.11+1.71x)•1011 dyn/cm 2	
15	Surface Microhardness (x=0)	460 kg/mm2	
16	Modulus of Young	(6.11+4.19x) x 1011 dyn/cm2	
17	Poisson Ratio	0.36-0.05x	
18	Refractive Index (589 nm @ 293 K)	3.32	Optical Properties

III. SINGLE-JUNCTION PV CELL

Figure 8 represent a basic view of sing1e junction PV cell. Width of the emitter is 0.01 μ*m* and the doping: 1x1016/cm3. Width of the base is 3 μ*m* and the doping: 1x1016/cm3.

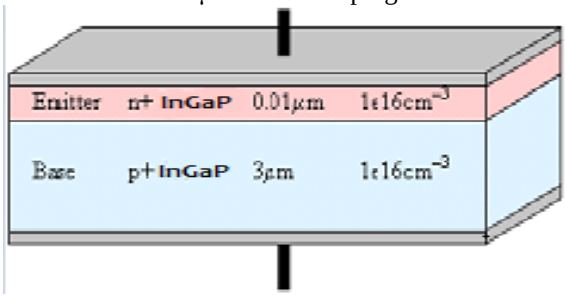

Figure 8: Simple sing1e-junction InGaN PV cell.

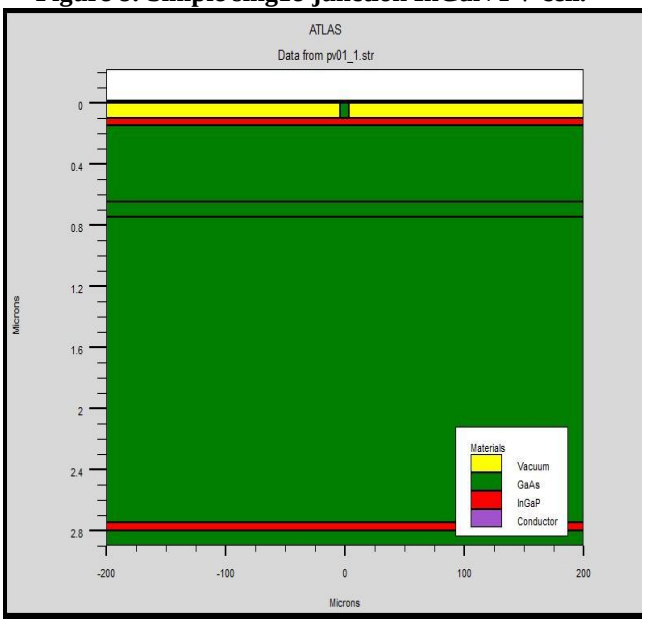

Figure 9: Device structure from TCAD

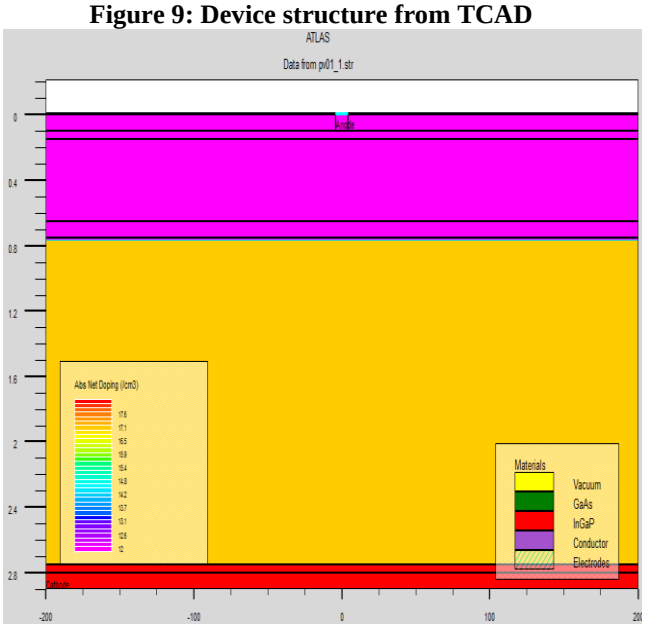

Figure 10: Device structure with Doping concentration

from TCAD

The initial step is to create sing1e junction PV cells. This relates to a determined bands-gap of 2.66 eV. Extra The dielectric constants were then changed over to list of refraction (n) and annihilation coefficient (k) utilizing a Matlab content. The bandgap and the optical information were gone into the information deck. The reproduction kept running in Silvaco Atlas. From the log record, the current and voltage information was extricated.

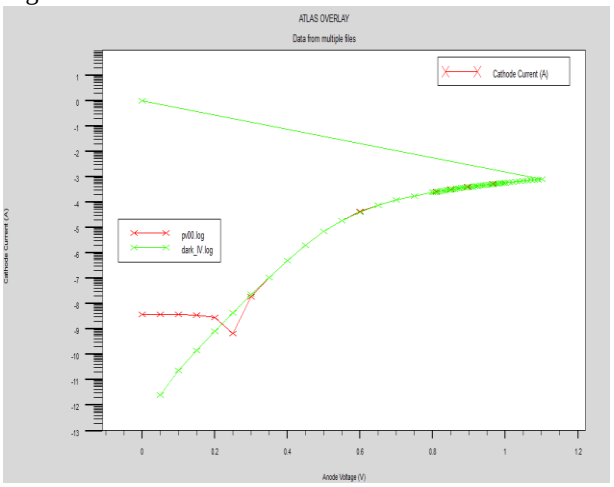

Figure 11: I-V characteristics of device

Figure 11 demonstrates the IV curve of sing1e-junction PV cells. The l-V curve example relates to experiential discoveries of other multi junction PV cells. Naturally, the cells with the highest voltage have the least current. The cells with the most minimal voltage have the high current. Table 2 demonstrates figure of merits of Solar cells based on InGaP of the sing1e-junction PV cells displayed in Fig. 3.

Materials	J_{sc}	$J_{scm}A_{cm2}$	v_{oc}	P_m	v_m	I_m	FF	O_{pt_int}	Efficiency
InGaP	1.4225357 02e^{-10}	14.2254	2.4207574 0735099	3.1519922 8326e^{-10}	2.2600006 46973968	1.3946796 6955898e^{-10}	91.531084 76599978	0.1380488 586	27.3988

Table 2: figure of merits of Solar cells based on InGaP

IV. CONCLUSION

From the tabular analysis we can observed that high efficiency can be achieved by implementing BSF layer and tunnelling feature of the device. When we compare our device with convention sing1e junction PV cell now the efficiency became 27.39%. Tunnelling effect have major role to improve the efficiency from conventional PV cells. The InGaP PV cell simulation can be more appropriate by varying the width of the junction and varying the doping concentration. This improvement can be the matter of futuristic study. The findings shows that InGaP is a promising semiconductor for PV cell due to its high transmittance in in between the layers as well as high chemical, thermal and mechanical stability

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AUTHOR PROFILE

Mohammad Asif Iqbal received the M.Tech Degree in Power system with First class from Rajasthan Technical University, Kota India in 2014. He is a research scholar in Department of Electrical Engineering at Poornima University. His research interests include Photo detectors Materials and Power system.

Dr. Arun Dev Dhar Dwivedi received his M. Sc. Degree in Electronics with First class from IIT BHU, India in 2003. He received the PhD Degree in Electronics from IIT BHU, India in 2010 His research interests include Photo detectors Materials and Microelectronics.