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Design, Modelling and Analysis of a Double Junction Gaas Solar Cell using Silvaco Software

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Abstract:

This paper inspects the potential use of Gallium Indium Phosphide material used as a photovoltaic cell.A double-junction GaAS solar cell was simulated using Silvaco Atlas. Gallium Indium Phosphide material was uesd as the top junction and Gallium Arsenide was used as the bottom junction. The composition percentage of Indium phosphide and Gallium Arsenide within the Gallium Indium phosphide provides the band gap of the junctions used in the device. The results of this investigation reflects that Indium Gallium Phosphide and Gallium Arsenide are promising semiconductor for solar cell use.
***Keywords:** Photovoltaic material, double-junction solar cell, band gap, Gallium indium phosphide.*

I.Introduction

The main objective of designing a solar cell is to improve the conversion efficiency while keeping the total cost competitive. A key element in increasing the viability of photovoltaics is to increase its efficiency. A higher efficiency technology can improve the cost of electricity by reducing several cost components of a photovoltaic system. In a higher efficiency system, solar cell material costs are reduced since a higher efficiency technology produces more power per gram of material; area related material costs become lower since fewer of these materials are needed for the same amount of power; and are related balance of system costs are substantially reduced as a smaller system area is needed for the same power. The reduction of these costs has a dramatic impact of PV costs.

During the years 1970s and 1980s, Research Triangle Institute and by Varian Research centre introduced multijunction solar cells which was a double junction cell. The device was formed by growing an AlGaAs junction on the top of a GaAs junction.Both the junctions were interconnected through a semiconductor tunnel junction. A tandem device which was formed by growing a GaInP junction on the top of a GaAS junction grown on an active Ge substrate by the Solar Energy Research Institute(National Renewable Energy Laboratory: NREL) during the same decade. The introduced device was a 2-junction device. The designed device provides better efficiency for a double and tripple junction solar cells with changing the thickness of the top cell. If it concerns about the efficiency of a soalr cell then multijunction solar cell will be highly attractive for cost-effective terrestrial concentrator systems. When ever it deals with the efficiency, then the multijunction solar cells with group III-V materials growing most rapidly. A record efficiency of 32.3% was achieved for terrestrial concentrator cell grown at Spectrolab and processes at NREL. Inverted metamorphic 3-junction cells proovides a 40.8% efficiency under the standard concentrator terrestrial spectrum.

In this paper, Indium Gallium Phosphide layer of the solar cell is simulated to predict the efficiency. After obtaining the efficiencies of devices , a comparison is done. Silvaco Atlas TCAD simulation software is used to investigate these efficien-

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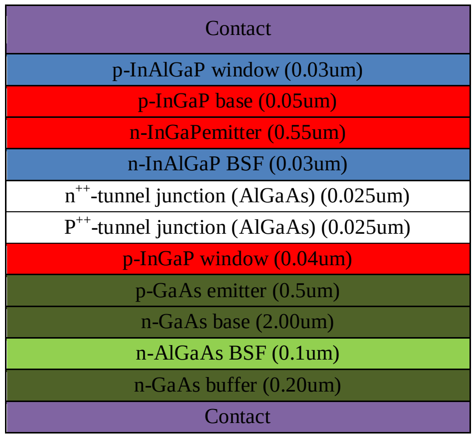
cies. The major contribution is the use of Gallium Arsenide (GaAs) and Indium Gallium Phosphide (InGaP) photovoltaic material to design double-junction solar cells, which provide more efficiency to that of conventional Si-solar cell. To calculate the efficiency with respect to the different intensity, with the changes in the thickness of the different layers used in the cell to analyse the variation in the V_{oc} and I_{sc}.

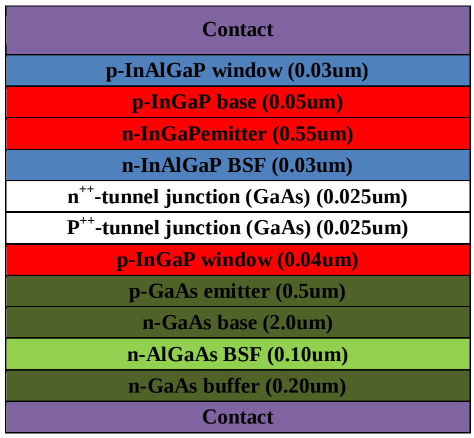
Organization of the paper is as follows: Section II gives detail of the modelling of the device. Section III contains the simulation results, discussion of the results. Section IV tells about the conclusion.

II. Proposed Work

In this work, the active layers modeled is of a p-material and n-material(GaAs) as cell1 and a p-material and n-material(InGaP) as cell2, a tunnel junction of AlGaAs is sandwiched between the two cells. The device has been characterised under the light and dark condition. We have obtained the I-V characteristics along with the measurement of the transparency of the active layer.To model an inorganic bulk-heterojunction is very difficult as it is having a complicated geometry with themicroscopic scale of the internal mechanics. The device was simulated using a standard solar cell device simulator i.e Silvaco ATLAS. The critcal issues of the device for its performance were identified, and the influence these issues were quantified (based on the actual parameters for InGaP-GaAs cells). (1) Performance of the device becomes weak due to poor absorption and solar illumination. (2) Mobility of the charge carriers i.e electrons and holes in the material also affects the performance of the cells. With increasing mobility, the efficiency increases monotonously. The measured sensitivity is approaximately 25% relative to efficiency gain for an increase of the carrier mobilities. In this solar cell structure, for cell(1) the donor material is n-GaAs and the acceptor material is p-GaAs and for cell(2) the donor material is n-InGaP and the acceptor material is p-InGaP. The active material is placed in between two electrodes. The hole transport layer PEDOT-PSS is given



(a)



(b)

Figure 1. (a) & (b): Schematic of double-junction InGaP/GaAs solar cell structure

between active layer and anode. Here, conductors are used for cathode and anode. When an electron-hole pair generated, the electrons moved from n-GaAs to p-GaAs. Where as the holes move towards the p-GaAs to n-GaAs. The energy gap for GaAs will be approximately 1.42 eV, whereas the energy gap for InGaP is 1.78eV. Here, using Silvaco ATLAS performance of a 2-dimensional device was analyzed and it was modelled.The modeling was done with an assumption of abrupt p-n junction, normal incidence of light,Lambert-Beer absorption(no reflection losses),room

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temperature(300K) and AM1.5 direct I-sun and concentrated illumination. The second device is having a tunnel junction of GaAs sandwitched between two cells, in which the bottom cell is of a p-material and n-material(GaAs) and top cell is of a p-material and n-material(InGaP).

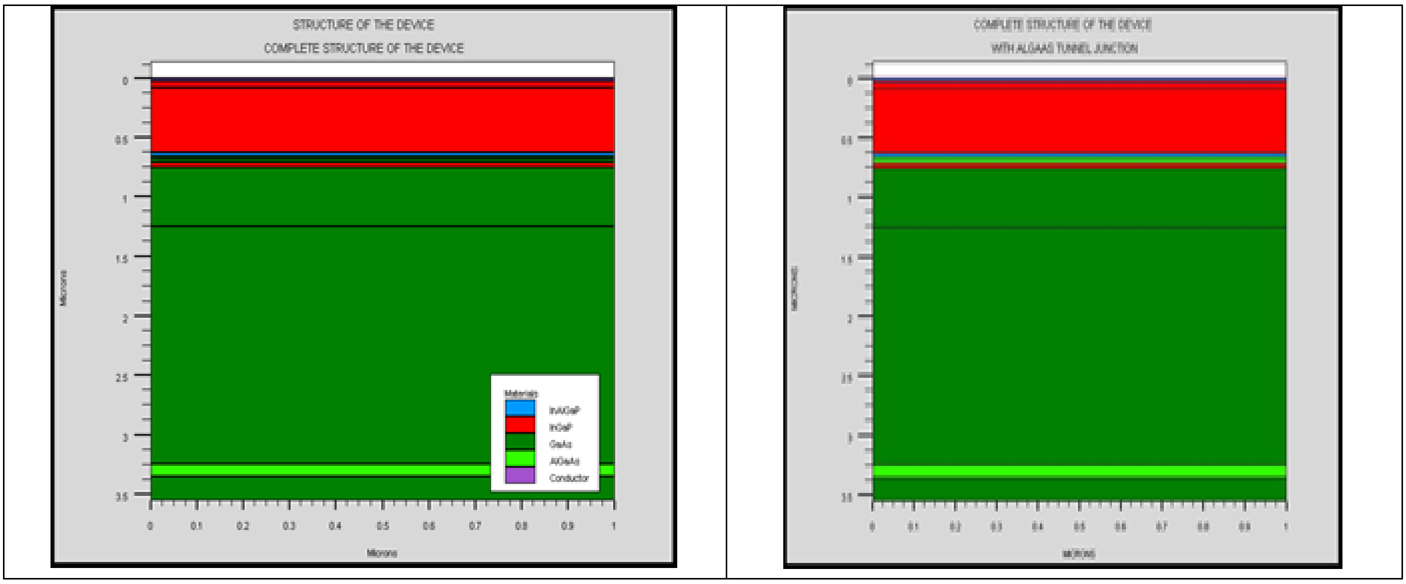

Figure 2. (a) and (b) Simulated structure of the device

III Result and Discussion

The second part of the deck includes the most important aspect of this work i.e. the characteristics of the used materials were enumerated. ORGANIC materials were used as the base material of the active layers. Electron affinity, mobility of the charge carriers, band gap of the materials, doping concentrations, conduction band and valence band densities, thickness, material composition, thermal velocity of the charge carriers, the alloy density, Auger recombination for carriers and band-to-band recombination were considered during the modelling of the device. Table1 shows the optimized material parameters used for simulation using optimizer

Table 1: Material parameters used for simulation

Parameter Name	Minimum value	Maximum value
Electron Affinity	3.54	4.08
N_c (300)	7.0×10^{16}	2.0×10^{19}
N_v (300)	2.5×10^{18}	2.5×10^{20}
I_{ds}.exciton	0.0	0.0

Here we have used solar spectra of AM1.5 as the source of light. For the calculation of frequency aspects of life Silvaco uses SOPRA refractive index files. Current-Voltage(J-V) characteristic measurements with bias voltage varying between 0.1 V and 2.7 V is carried out. Positive bias means positive voltage to the cathode. The J-V characteristic curves are taken both in the dark and light condition under simulated solar illumination (AM 1.5-spectrum, 100 mW/cm²). Table 2 shows the optimized material parameters used for simulation using optimizer.

Table 2: Material parameters used for simulation

Parameter Name	Minimum value	Maximum value
Electron Affinity	3.54	4.08
N_c (300)	7.0×10^{16}	2.0×10^{19}
N_v (300)	2.5×10^{18}	2.5×10^{20}

I_{ds}.exciton	0.0	0.0

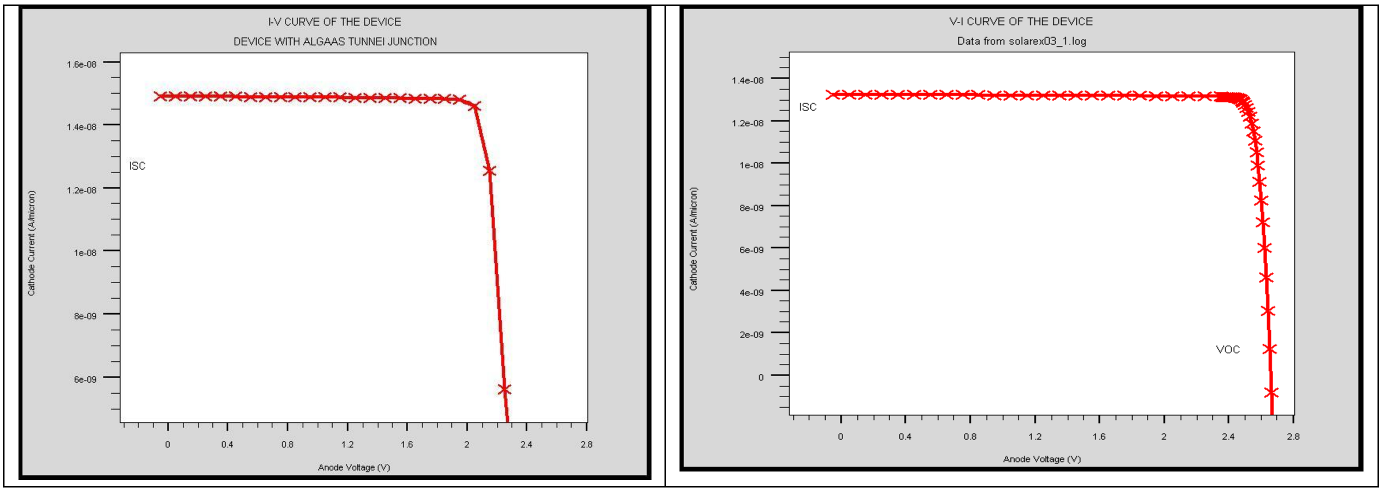

Figure 3. (a) and (b) I-V Curve of the device

The effect of illumination concentration on the performance of the active layers InGaP/GaAs were analyzed by focusing the direct light on concentrator photovoltaic system. Figure 3. (a) and (b) shows the illuminated I-V characteristics of the device with different illumination concentration. Table 3 and 4 indicates figure of merit of both the devices. Auger recombination becomes dominant when the injection level is high. Which provides a lower enhancement in V_{oc}, an increase in dark current, change in fill factor and power efficiency. At low injection, the short circuit current increases linearly by by increasing the incident flux of light on the device. The enhancement in the carrier generation is because of increase in the open circuit voltage of each sub cell. Thus, at 10-suns illumination, the Voc of the device improves for each subcell. The V_{oc} (open circuit voltage) of the device depends up on the band gap of the material. Boosting in the V_{oc} is greater for low-bandgap subcells. The simulation results indicate, at 100-suns illumination, the Voc increases by 12%. A maximum efficiency of 28.60% was found for a concentration of 100-suns with a tunnel junction of GaAs. An efficiency of 30.69% was found for a concentration of 100-suns with a tunnel junction of AlGaAs which is maximum one.

Table 3: Extracted electrical parameter of device1 as a function of illumination

# of Suns	**V_{oc}(v)**	**J_{sc}(A/cm^2)**	**FF (%)**	**Efficiency(%)**
1	2.24	0.14	81.39	26.02
10	2.34	1.49	82.16	27.46
50	2.38	7.45	83.00	28.39
75	2.39	11.19	83.39	28.54
100	2.40	14.92	83.43	28.60

Table 4: Extracted electrical parameter of device2 as a function of illumination

# of Suns	**V_{oc}(v)**	**J_{sc}(A/cm^2)**	**FF (%)**	**Efficiency (%)**
1	2.38	1.324*10-10	81.39	26.95
10	2.526	1.324*10-9	82.16	29.16
50	2.566	2.648*10-9	83.00	29.67
75	2.617	6.622*10-9	83.39	30.29
100	2.656	1.324*10-8	83.43	30.69

Detail investigation of the active layers thickness which depends on photovoltaic (PV) properties of solar cells is done. Maximum Jsc and η values are found for devices with the designed ac-

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tive layer. The variation in the thickness of the active layer of the photovoltaic cell also affects the open circuit voltage (Voc) and fill factor (FF) to some extent. The characteristics show that the short circuit current increases with increase in thickness of the active layer. It is well known that, if the active layer thickness increases the absorption efficiency increases. As more photons are absorbed, it raised the number of excitons generated causing increase in the short circuit current. The extracted electrical parameters are shown in Table 5. show the variations in FF, Voc, Jsc and η with different active layer thicknesses (nm).

Table 5: Extracted electrical parameter with different active layer thicknesses

Parameters	InGaP (0.04um, 0.5um)	GaAs (3.0um, 0.60um)	GaAs (3.0um, 0.70um)	GaAs (1.00um)	GaAs (0.60um)	GaAs (1.00um, 0.4um)
J_{sc}	1.338 $*10^{-8}$	1.338 $*10^{-8}$	1.338 $*10^{-8}$	1.244 $*10^{-8}$	1.327 $*10^{-8}$	1.228 $*10^{-8}$
V_{oc}	1.527	2.651	2.648	2.658	2.653	2.662
P_m	1.641 $*10^{-8}$	3.235 $*10^{-8}$	1.314 $*10^{-8}$	3.042 $*10^{-8}$	3.218 $*10^{-8}$	3.009 $*10^{-8}$
V_m	1.25	2.470	2.46	2.48	2.47	2.49
I_m	1.313 $*10^{-8}$	1.309 $*10^{-8}$	1.314 $*10^{-8}$	1.226 $*10^{-8}$	1.302 $*10^{-8}$	1.208 $*10^{-8}$
FF	80.264	91.163	91.250	91.98	91.394	91.997
Efficiency	15.688	30.91	30.90	29.071	30.74	28.75

In summary, the device was characterized by simulation procedure with the help of SILVACO software. The discussion in the paper based on the nature of the models, and their relationship to the polymer solar cell. Maximum efficiency obtained at concentration of 100 no of cells i.e. 30.69%. With increasing the thickness of the bottom cell to 3.0um, 0,60um, the efficiency increases to 30.91%. Also, by increasing the thickness of the acceptor region of the Gallium Arsenide layer to 0.6um, the efficiency increases to 30.7%.

IV.Conclusion

The device provides the maximum efficiency of 30.69 % (at 100 suns). With further increase in no of suns the efficiency does not increases. The overall efficiency depends on no of suns, open circuit voltage (V_{oc}), short circuit current (J_{sc}), thickness of the layers of the sub cells, different losses, lattice mismatch, less doping, absorption coefficient and fill factor. Using Gallium Arsenide as tunnel junction, an efficiency of 30.69% has been obtained, to improve the lattice matching Aluminum Gallium Arsenide as tunnel junction has been used. With Aluminum Gallium Arsenide, 28.60% of efficiency is obtained, which has to be improved.

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