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Optimization and Comparison between the Efficiency of InGaP and GaAs Single Solar Cells with and without a Window Layer

Fatiha Djaafar [1a], Baghdad Hadri[2], Ghalem Bachir[1b]
[1a] Laboratoire de Développement Durable de l'Energie Electrique, université des sciences et de technologie d'Oran Mohamed BOUDIAF: USTOMB, Oran 31000, Algérie. fatiha.djaafar@univ-usto.dz
[2] Electromagnetism and Guided Optic Laboratory, University of Abdelhamid Ibn Badis, Mostaganem 27000, Algeria, hadriba@yahoo.fr
[1b]ghalem.bachir@yahoo.fr

ABSTRACT

In this paper a numerical optimization and simulation are carried out using a Tcad Silvaco to extract the I-V characteristics of the single solar cells InGaP and GaAs and to predict the effect of the window layer on the performance of the solar cells. First, the InGaP and GaAs solar cells are simulated without a window layer, we have obtained an efficiency (η=15.95) and (η=11.24) respectively. In a second step, both InGaP and GaAs cells are simulated by introducing the window layer ($In_{(0.39)}Al_{(0.61)}As_{(0.16)}P_{(0.84)}$ for InGaP cell) and ($In_{(0.5)}Ga_{(0.5)}P$ for GaAs cell. We noticed an improvement in the characteristics I-V of each cell: fill factor (FF = 91.21%) and (η =21.43%) for InGaP cell and (FF = 88.03%) and (η =25.27%) for GaAs cell. The results were obtained under AM1.5 illumination and 300°K

Key words: Efficiency, GaAs solar cell, InGaP solar cell, Window layer.

1. INTRODUCTION

Solar energy has become one of the most important sources that replace fossil energy because of its abundance. Efforts are made to increase the efficiency of solar cells and reduce the cost of production. The modeling and choice of semiconductor materials constituting solar cells are very important to improve their performance.

The efficiency of a solar cell is also limited by different types of losses: intrinsic losses and or extrinsic losses. So, we try to reduce these losses by modeling, optimizing the different layers of the InGaP and GaAs heterojunction cells in particular the window layer to achieve an optimal efficiency and make a comparison between the performance of InGaP cell and GaAs cell.

The photovoltaic cells use semiconductors to collect the pairs electron-hole created by collision of photons in the material. Electrical energy is generated when photons incite electrons from the valence band into the conduction band in semiconductor materials [1]

Generally, the compounds used in solar cells of high efficiency, are alloys of elements from column III and column V in the periodic table. The main III-V semiconductors as, GaAs and InP can be alloyed with other materials as Al to give ternary compounds such as AlxGa1-xAs and GaxIn1-xP where x is the molar fraction [2].They are formed as thin films to be used in different terrestrial and space applications

The modelling of photovoltaic devices depends on several intrinsic optoelectronic properties of the material, such as surface recombination, lifetime, molar fraction and doping level. Doping level is one of the extrinsic parameters which have an essential role in varying the efficiency.

The main parameter of the solar cell is its efficiency which was quite feeble in single junction solar cells. The InGaP and GaAs single cells will continue to be the focus of many researches in the field of photovoltaic owing to their absorption of the large part of the solar spectrum.

In this paper, we report the design of InGaP and GaAs single junction solar cells with an InAlAsP window layer for InGaP cell and InGaP window layer for GaAs cell.The conversion efficiency and the fill factor are obtained under AM1.5 and 25°C.

The numerical simulation allows modeling the performance of solar cells precisely and evaluates the effect of temperature and window in varying the efficiency of both InGaP and GaAs solar cells. The modeling and optimization of InGap and GaAs cells allow an effective comparison between the two cells and then improving their efficiency. We carried out the simulation under AM1.5 (100 mW/cm^2).

2. OPTIMIZATION OF MATERIALS AND LAYERS

Under a solar spectrum AM1.5, the choice of semiconductor materials has an important role in increasing the efficiency of a solar cell. This choice depends mainly on the gap energy, molar fraction and doping. The optimal gap energy of single-junction solar cells, which give a better efficiency, must not exceed 1.4 eV like GaAs [3] [4].

2.1The window layer

The window layer is used to minimize the recombination of the surface of the traps of the minority carriers. There are several criteria to consider when choosing the window layer.

The window used for InGaP cell is InAlAsP and that used for GaAs cell is InGaP [5].

- The lattice constant is close to that of the emitter InGaP (5.65A).

-The gap energy of the window must be higher than the gap energy of the emitter (InGaP) (Eg = 2.30eV).

- The window must have a high doping concentration: more than 10^{18} cm^{-3} [6] [7].

2.2Back Surface Field (BSF)

We have used an InAlAsP BSF for the InGaP cell and an AlGaAs BSF for the GaAs cell. This choice must respect the characteristics of the sub layer of the BSF.

For the InGaP cell: the lattice constant of the BSF InAlAsP is close to the lattice constant of the base InGaP (5.65 Å). For the GaAs cell, the lattice constant of the BSF AlGaAs is close to that of the base GaAs (5.64 Å).

The gap energy of the BSF of InGaP cell (InAlAsP) is Eg = 2.30eV, the gap energy of the BSF of GaAs cell (AlGaAs) is Eg = 1.80eV.

The doping concentration is of the order of 10^{20}/ cm^{-3}) [5].

2.3 InGaP material properties

Ga (x) In (1-x) P is a ternary compound. It has a direct gap for a mole fraction less than 0.74 and an indirect gap for a mole fraction greater than 0.74. It is characterized by a low rate of recombination on the surface.

The lattice constant: the epitaxial (heterojunction) of the two different semiconductors can be done only if the semiconductors have very close lattice constants to avoid the mismatch between the substrate and the semiconductor material. The lattice constant of In(1-x)Ga(x)P (a ternary alloy) is calculated according to Vegard's law as follows [4] [6] [8]:

$$\alpha_{In_{(1-x)}Ga_{(x)}P} = x\alpha_{GaP} + (1-x)\alpha_{InP}$$

Where α is the lattice constant and x is the molar fraction.

Whereas the lattice mismatch between the semiconductor materials of the substrate and that of the material of the upper layers is given by [6]:

$$\Delta\alpha = \frac{\alpha(epit)-\alpha(sub)}{\alpha(epit)}$$

The following table shows the material properties Ga(x)In (1-x)P at 300k.

Table 1: Properties of Ga $_{(x)}$ In $_{(1-x)}$ P material at 300k.

Parameter	$Ga_{(x)}In_{(1-x)}P$	$Ga_{0.5}In_{0.5}P$	référence
Gap energy (eV)	$Eg(x)=1.35+0.73x+0.7\,x^2$	1.89	[9]
Dielectric Permitvity ε	12.5-1.4x	11.8	[9]
Affinity ϰ (eV)	$\varkappa(x)=4.38-0.58x$	4.09	[9]
Lattice constante (A°)		5.65	[7]
Auger Coefficient (cm^6/s)	$A(x) = -8.2\times10^{-30}x^2 + 8.3\times10^{-30}x + 9\times10^{-31}$	3×10^{-30}	[6]
Radiative recombination A_0 (cm^3/s)	$A_0(Eg) = (1\pm0.3)10^{-10}$		[6]
Effective mass of electrons and holes $m^*_{e(x)}$ et $m^*_{h(x)}$	$\frac{m_e^*(x)}{m_0} = 0.0254x^2 - 0.114x + 0.08$ $\frac{m_h^*(x)}{m_0} = 0.19x + 0.6$	$\frac{m_e^*(x)}{m_0} = 0.029$ $\frac{m_h^*(x)}{m_0} = 0.695$	[9]

2.4 GaAs material properties

Gallium arsenide is a direct gap compound. It is characterized by a high mobility of electrons and stability at a high temperature. The properties of the GaAs material are shown in the following table [6] [9]:

Table 2: Properties of GaAs Material at 300k.

Parameter	**GaAs**
Gap energy (eV)	1.42
Dielectric Permittivity ε	13.2
Affinity ϰ (eV)	4.07
Lattice constant (À)	5.65
Auger coefficient (cm^6/s)	Doped (n) :1.9×10^{-31} Doped (p) : 12×10^{-31}
Radiative recombination A_0 (cm^3/s)	10^{-10}
Effective mass of electrons and holes $m^*_{e(x)}$ et $m^*_{h(x)}$	$\frac{m_e^*(x)}{m_0} = 0.067$ $\frac{m_h^*(x)}{m_0} = 0.642$

3. THE SOLAR SPECTRUM

The optimized InGaP and GaAs cells are illuminated by an AM1.5 solar spectrum whose energy is 1000W / cm2 because this spectrum allows the extraction of the I-V characteristic (current / voltage) and consequently the calculation of the efficiency of the cell.

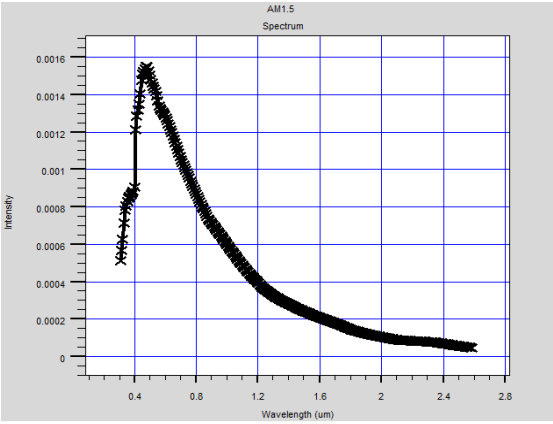

Figure 1: AM1.5 solar spectrum illuminating the solar cell.

The wavelengths of the absorbed photons range from 539 nm to 0.873 nm. The following Table V-5 shows the wavelengths of the materials used.
For indium gallium (InGaP), the band gap energy Eg is equal to 1.42 eV. The wavelength of the photon energy is calculated as follow: $\lambda(\mu m) = \frac{1.24}{1.42} = 0.873$

Table 3: Wavelengths of the used materials.

Matériaux	InGaP	GaAs
Longueurs d'ondes (nm)	873	652

4. SIMULATION RESULTS AND DISCUSSION

4.1 Mathematical approach

The power conversion efficiency (η) is the most important parameter for a solar cell. It is defined by the following equation [6] [10]:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{FFV_{OC}I_{SC}}{P_{in}} \quad (1)$$

Where P_{in} is the incident power of AM1.5 spectrum (P_{in} = 1000w / m2).

I_{SC} :is the short-circuit current and is calculated as follow:

$$J_{SC} = I_{SCN} + I_{SCD} + I_{SCP} \quad (2)$$

The sum of the three currents (I_{SCN} ,I_{SCD} , and I_{SCP} is the contribution of n-type region, the depletion region, and the p-type region (I_{SCP}) respectively.

The open-circuit voltage can be determined as

$$V_{OC} = \frac{KT}{q} ln \frac{I_{SC}}{I_{01}} \quad (3)$$

K: Boltzman constant, T: temperature in Kelvin, q: is the electrical charge, I_{01}: the dark saturation current.

The Fill factor (FF) gives how the squareness I-V characteristic is. It is defined as

$$FF = \frac{P_{MP}}{V_{OC}I_{SC}} = \frac{V_{MP}I_{MP}}{V_{OC}I_{SC}} \quad (4)$$

Where: P_{MP}: is the maximum power point.

Table 1: Attributes of Cleveland dataset

4.2 Simulation of the InGaP cell

The InGaP solar cell is simulated with the characteristics mentioned in figure (3). The obtained simulation results are shown in figures 2, 3 and 4:

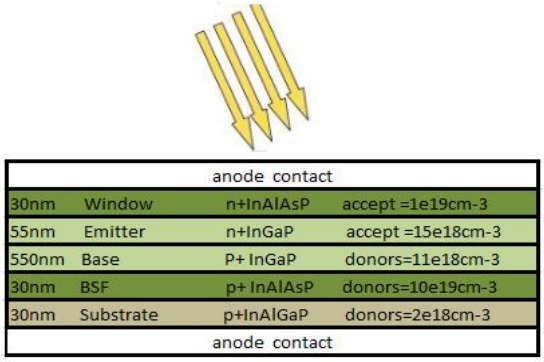

Figure 2: Optimized InGaP Cell Design.

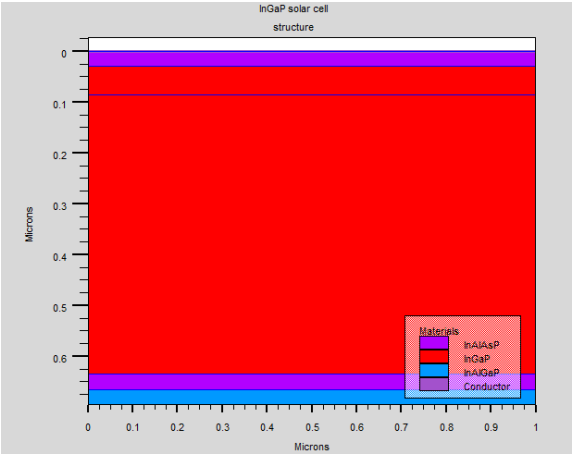

Figure 3: Design structure of the optimized InGaP Cell with an InAlAsP window.

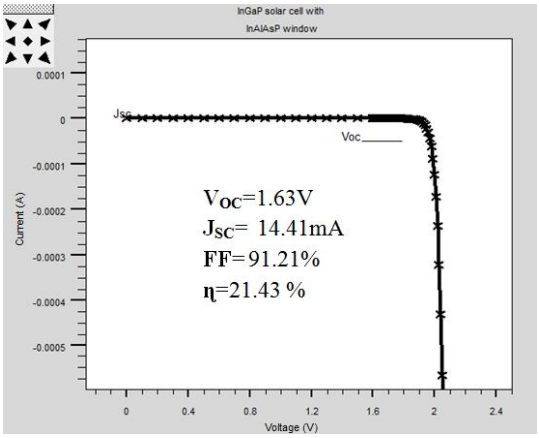

Figure 4: I-V characteristics with InAlAsP layer window.

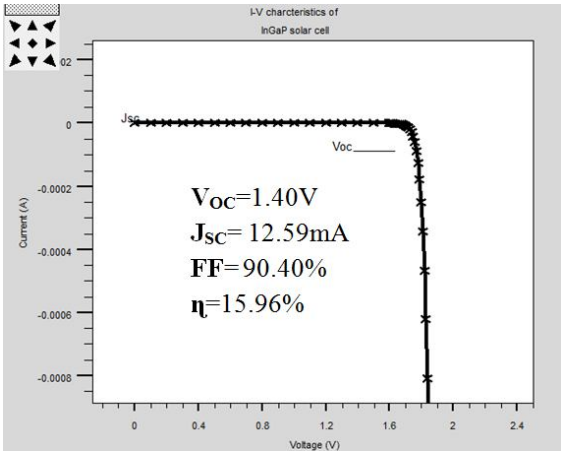

Figure 5: I-V characteristics of InGaP cell without an InAlAsP window.

4.3 Simulation of GaAs Solar Cell

Anode contact			
40nm	Window	n+ InGaP	accept=5e20cm-3
550nm	Emitter	n+ GaAs	accept=1e18cm-3
3µm	Base	p+GaAs	donors=1e17cm-3
10nm	BSF	p+ AlGaAs	donors=10e19cm-3
150nm	Substrate	p+ GaAs	donors=1e18cm-3
cathode contact			

Figure 6: Optimized GaAs Cell Design..

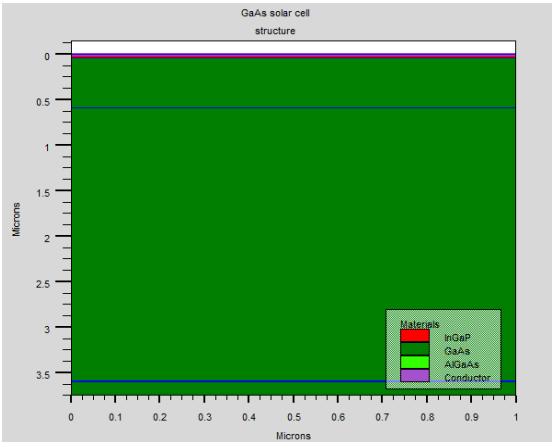

Figure 7: Design structure of the optimized GaAs Cell with an InGaP window.

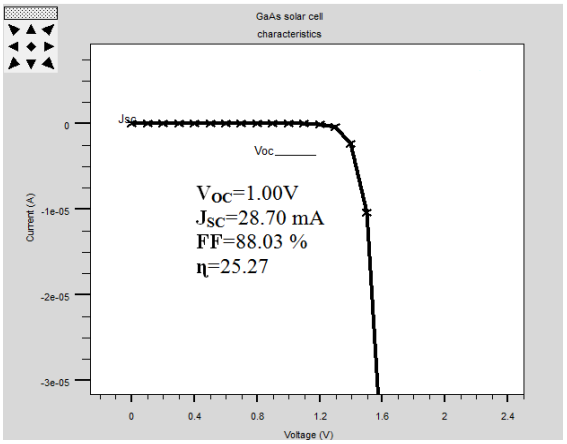

Figure 8: I-V characteristics of the optimized GaAs cell with InGaP layer window.

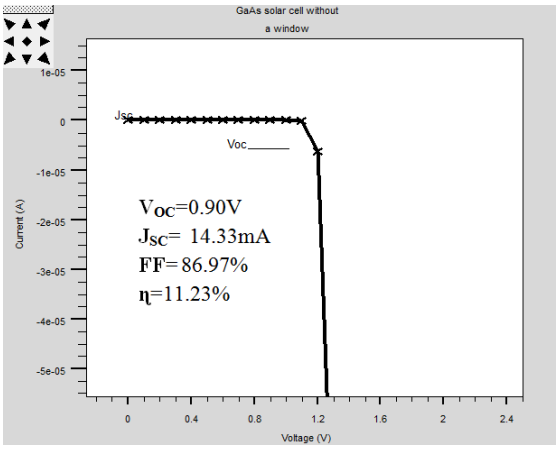

Figure 9: I-V characteristics of GaAs cell without an InGaP window.

5. COMPARISON RESULTS AND DISCUSSION

The choice of the thin and highly doped (10^{19}cm-3) "InAlAsP" window layer for InGaP cell and "InGaP" for GaAs cell is done by taking into consideration certain criteria such as the gap energy which must be greater than that of the cell emitter.

Firstly, the InGaP and GaAs solar cells are simulated without the window layer, the I-V characteristics, the values of short circuit current (J_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and efficiency (η) before and after introducing a window layer are illustrated in following table:

Table 4: Comparison between the optimized InGaP and GaAs cells efficiency.

	J_{SC} (mA)		V_{OC} (V)		η (%)		FF (%)	
Solar cell	Before	After	Before	After	Before	After	Before	After
InGaP cell	12.59	14.40	1.40	1.63	15.96	21.43	90.40	91.21
GaAs Cell	14.33	28.70	0.90	1.00	11.24	25.27	86.97	88.03

We notice that the GaAs cell exhibits the highest efficiency and short-circuit current density after the introduction of the window layer (η=25.27% and J_{SC}=28.70mA) while the InGaP cell allows for a smaller efficiency and current density (η =21.43% and Jsc=14.40mA). The use the window layer has an important role in improving the performance of the solar cells. Thus, the window layer is a conductive layer. It allows the electrons to flow to the electrical contacts without increasing the resistance of the cells in series, to avoid surface recombination and solve the problem of mesh mismatch and consequently to increase the efficiency of the cell. In order for the light rays to penetrate into the layers of the photovoltaic solar cell, it is necessary to use a window layer with semiconductor materials whose gap energy is important to be transparent to light [11]. The base thickness of the GaAs cell (3µm) which is greater than the base thickness of the InGaP cell (0.55µm) affect on the short current density and the conversion of each cell due to the fact that deep levels are more effective in GaAs which has smaller energy gap than InGaP. As the thickness increased (decreased), Jsc and η increased (decreased) [12].

6. CONCLUSION

In this paper, we have accurately optimized, simulated and compared between single heterojunction solar cells InGaP and GaAs. We have extracted the characteristics (J_{SC}, V_{OC}, FF and η) for each cell with interpretation. Then, we conclude that the introduction of a window layer has an important role in improving the performance of InGaP and GaAs cells. We aim for further work on improving the single cells performance and using different semi conductor materials for window layers that can exhibit higher cell efficiencies.

REFERENCES

1. F.Kürker. September 2010. **Microfabrication based Design and Simulation of Heterojunction Solar Cel**l. Master's Thesis, Çukurova University Institute of Natural and Applied Sciences, Adana.
2. Meftah , N. Sengouga , A.M. Meftah , S. Khelifi, "**Numerical simulation of the effect of the Al molar fraction and thickness of an AlxGa1_xAs window on the sensitivity of p+-n-n+ GaAs solar cell to1 MeV electron irradiation"**, Renewable Energy, no. 34, pp. 2426–2431, 2009. [Online]. Available: http://dx.doi.org/10.1016/j.renene.2009.03.
3. M.Green, **"Solar Cells: Operating Principles, Technology, and System Application"**, Prentice- Hall, Englewood Cliffs, NJ, 1-12, 1982
4. G. Writing, **"Global Energy Assessment, toward a sustainable future"**, 2012, Cambridge University Press. ISBN 9780521182935.
5. F.Djaafar, B.Hadri et B.Ghalem, **"Comparison between the Efficiency of Heterojunction Thin Film InGaP\GaAs\Ge and InGaP\GaAs Solar Cell"**, International Science Index, Energy and Power Engineering Vol: 11, No: 3, 2017,waset.org/Publication/10006842, Singapore.
6. A. Mahfoud, **« Modélisation des cellules solaires tandem à couches minces et à haut rendement »,** thèse de doctorat, université de Sétif 1, 2015.
7. F.Djaafar, B.Hadri, G.Bachir, **"The Effect of a Back Surface Field (BSF) on the Efficiency of Dual Junction InGaP/GaAs Cell",** Proceedings of the International Conference on Recent Advances in Electrical Systems, Tunisia, 2017.
8. A. Bali, **"Etude Comparative entre les Cellules Solaires de Type P+-AlGaAs/ P-GaAs/N-Gaas Et Une Autre De Type N+-AlGaAs/N-GaAs/P-GaAs"**, Mémoire de magister, 2013.

9. ATLAS User's Manual: Device Simulation Software. Santa Clara, CA: SILVACO International, 2012.
10. Antonio Luque and Steven Hegedus, **"Handbook of photovoltaic science and engineering**. ISBN 0-471-49196-9 (alk. paper) 1. (Antonio) II. Hegedus, Steven Photovoltaic cells. 2. **Photovoltaic power generation**.TK8322 .H33 2003 621.31_244 – dc212002191033, 2003
11. Khelifi et A. Belghachi, **« Le Rôle de la Couche Fenêtre dans les Performances d'une Cellule Solaire GaAs »** , Rev. Energ. Ren. Vol.7 (2004)13-21
12. AF. Meftah a,*, AM. Meftah a, N. Sengouga a, S. Khelifin, **"The AlxGa1_xAs window composition effect on the hardness improvement of a p+–n–n+GaAs solar cell exposed to the electron irradiation",** Energy Conversion and Management 51 (2010) 1676–1678. https://doi.org/10.1016/j.enconman.2009.11.025