Contribution of the Doping of the Lower Window Layer to Improve the Performances of the Tandem Solar Cell

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ABSTRACT

Each layer of the tandem solar cell, its doping or its thickness, plays a primary task in improving the conversion efficiency. The optimization of the doping of the window layer of the lower solar cell of the tandem cell contributes to the reduction of the cost of the manufacture of its cells. The objective of this work is to show the role of doping the lower window layer on the performances of tandem CS in InGaP / GaAs with a tunnel heterojunction. For this a simulation is carried out using the Atlas-Silvaco simulator. It is specially designed for 2D and 3D modeling of components based on the physics of semiconductors, including electrical, optical and thermal properties The adapted structure is essentially composed of an upper cell in InGaP and a lower cell in GaAs. Between the two upper and lower cells, there is a heterojunction tunnel) P^{++} N^{++}. The structure studied is composed of a thin window layer heavily doped with the material$In_{0.629}Al_{0.159}Ga_{0.371}P_{0.841}$ .Our simulation showed that, for an illumination of AM 1.5 and at room temperature, the parameters, such as the short-circuit current and the conversion efficiency, improve with the doping of the upper window layer.The best conversion efficiency is 24.2343% for a doping of 8x1018 cm-3.

I. Introduction

The manufacture of multi-junction solar cells is done almost exclusively with III-V materials, which permits an optimal exploitation of the solar spectrum by the diversity of their band gap energy and by their optoelectronic properties. Multispectral conversion is done by stacking several materials whose gap energies decrease from top to bottom. What gives the probability of using a wide range of solar spectrum is to expect high conversion yields [1]. The first of the tandem cells consisted of a layer of molecules evaporated for the first cell and a polymer layer deposited in the wet region for the second [2]. These cells are based on III-V materials that have been developed since the sixties [3]. The III-V materials are bodies composed from an element of column III and an element of column V of the periodic table of Mandilive. The choice of materials for the solar cell tandem depends on certain parameters such as, the width of the bandgap, the lattice constantand the absorption coefficient. III-V materials have energy as promising for solar cells due to their direct bandgap which covers almost the solar spectrum. [4]

Optimizing the performance of these structures consists of finding optimal technological parameters like the conversion efficiency, short circuit current density and open circuit voltage. The main parameters to optimize in the solar cell tandem, or solar cell multijunction CSMJ, are thickness and its level of doping of each layer. The major problem is the large number of parameters that influence performance. Simulation provides a relation between the experimental world and the theoretical world, it complements theory and the experimental and builds physical reality. Numerical simulation has been an important tool in optimization of tandem solar

cell designs. The simulation of devicessemicomdictor has become more and more used in recent years. Several calculation and simulation software have been developed by the research community in this area. As an example, we can cite: PC-1D, AFORS-HET, ASA, ASPIN, AMPS-1D and SCAPS-1D.
Among the software that effectively simulates the behavior of semiconductor devices is Silvaco (Silicon Valley Societe) [5]. This is achieved by numerically solving the Poisson equation and the equation continuity of charge carriers in two-dimensional n a finite number of points forming the mesh of the structure defined by the user or by the program [6]. The results obtained by the simulation of tandem solar cells, which aim to optimize manufacturing parameters such as thickness, number of layers and doping, can be used to minimize the manufacturing cost of these cells.
The objective of this work is to show the role of doping of the lower solar cell window layer on the performances of the tandem solar cell with a tunnel heterojunction. The solar cell used is a tandem solar cell with an InGaP / GaAs junction. After finding the doping of this layer which will give the best conversion efficiency. To do this, a simulation is realized using the Atlas-Silvaco software

II. Structure of the Solar Cell

The solar cell to be simulated is a tandem solar cell with an InGaP / GaAs junction (heterojunction). The adapted structure is essentially composed of an upper cell ($In_{0.49}$ $Ga_{0.51}P$/ $In_{0.49}$ $Ga_{0.51}P$) and a lower cell (GaAs/GaAs). Between the two upper and lower cells, there is a junction tunnel (homojunction or heterojunction) P^{++} N^{++}(InGaP/GaAs) for the role of the connection between the two cells (Fig 1).

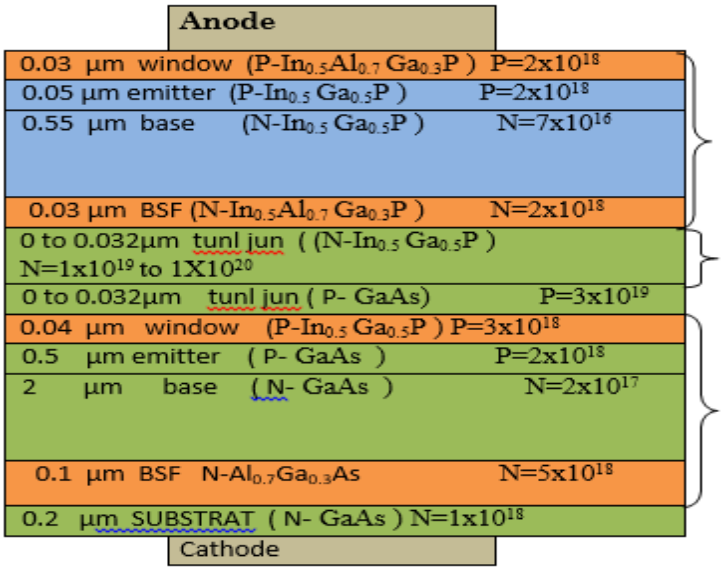


Figure 1 : Tandem solar cell structerused[7]

Usually, these tandem solar cells use GaAs / GaAs tunnel junction, i.e. a homojunction. But in this work we used a tunnel junction in InGaP / GaAs, that is to say a herojunction tunnel. [8]

II.1. Window Layer

The window layer is a conductrive layer. It allows electrons to flow to the electrical contacts without increasing the series resistance of solar cell. The material used must meet the following requirements:

- It must have a mesh parameter close to the emitter's mesh parameter. [8]
- It gap must be greater thane the gap of emitter. [9]
- It must have a wide valence band offset from the emitter, to create a strong potential barrier for minority holes.
- Its concentration must be greater than $10^{18} cm^{-3}$.
- Material must be of high quality to minimize surface recombination.

In this work, we use the material $In_{0.629}Al_{0.159}Ga_{0.371}P_{0.841}$ in the upper window and $In_{0.49}$ $Ga_{0.51}P$for the inder window of the tandem solar cell

II.2. Properties of the Material used in theUpperWindow

Knowledge of the electronic and optical properties of all III-V alloys composing atandem solar cell is also a major challenge for the development of the photovoltaic device. For our material $In_{0.629}Al_{0.159}Ga_{0.371}P_{0.841}$,which is used in the construction of the upper window, the main parameters are given below:

1) Band Diagram

Figure 2 illustrates the energy band structure of a front window layer coupled to a pnhomojunction (Figure 1(a), then of a pnhomojunction coupled to a rear window layer (Figure2(b).

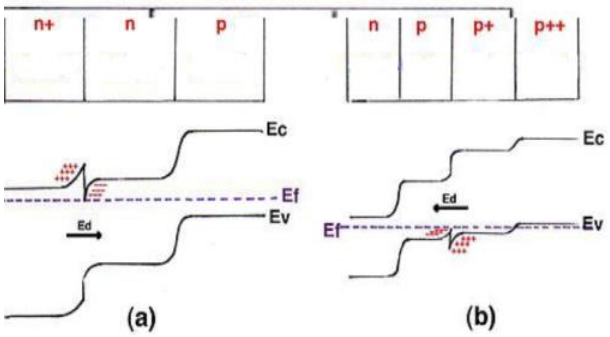


Figure 2: Window layer (a) front et (b) back [10]

In the figure 2: theE_f is a spatially independent reference energy known as the Fermi. The conduction and valence bands, whose energy minimum is located at energies E_c and E_v respectively.

2)Main Parameters

The main parameters which characterize the material$In_{0.629}Al_{0.159}Ga_{0.371}P_{0.841}$such as E_g, a, *X*and $\boldsymbol{\varepsilon_r}$, are given in table 1

Table 1: The mains parameters of$In_{0.629}Al_{0.159}Ga_{0.371}P_{0.841}$

Parameters	Valeus
E_g(eV)	2.23
a(A)	5.68
X (eV)	4.01
$\boldsymbol{\varepsilon_r}$	11.3

Where *X* is the electron affinity of the semiconductor material, Eg is the bandgap, a is the lattice constant and$\boldsymbol{\varepsilon_r}$is relative permittivity.

III. Atlas-SilvacoSoftware

SILVACO is a company that specializes in the development of simulation software targeting almost all aspects of modern electronic design. The diagram of the inputs and outputs are given in Figure 3.

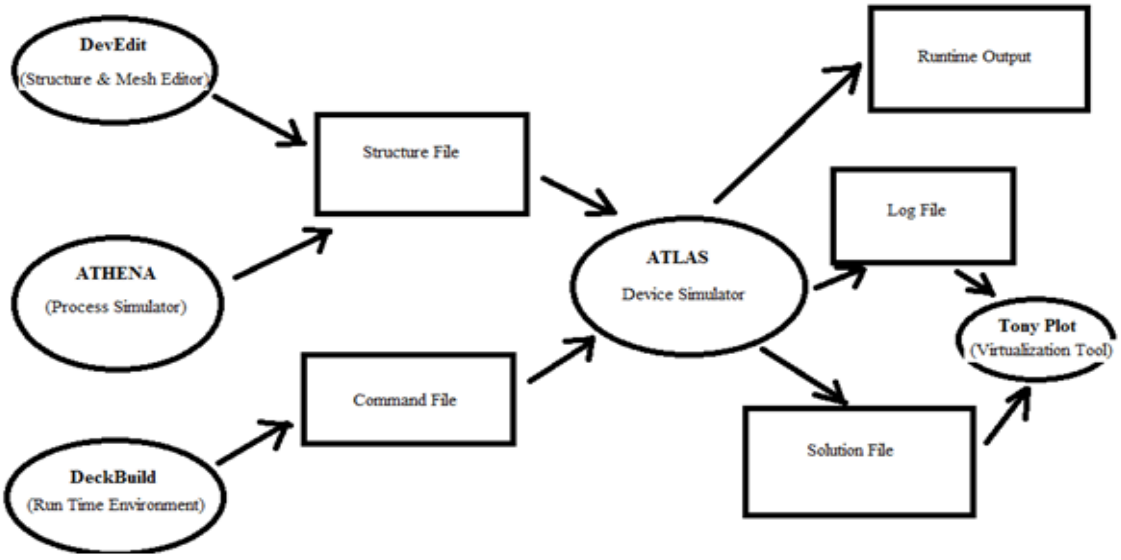


Figure 3: ATLAS inputs and outputs [11]

There are five groups of commands, these groups must be organized correctly (Fig 4).

Group		Statements
1. Structure specification	____	MESH REGION ELECTRODE DOPING
2. Material models specification	____	MATERIAL MODELS CONTACT INTERFACE
3. Numerical method selection	____	METHOD
4. Solution specification	____	LOG SOLVE LOAD SAVE
5. Results analysis	____	EXTRACT TONYPLOT

Figure 4: Atlas control groups and primary declarations

The simulation is based on inputs and outputs. The inputs are made, first of all, the specification of the structure which is based on a very precise mesh, the determination of each region and the location of the electrodes. The type and level of doping are also defined.TheAtlas-Silvaco tool is used to define the dimensions of the simulated structure, the parameters of the doped zones (location, type, level and doping profile), to place the electrical contacts on the structure and to define the mesh [11].

III.1. Model

The introduction of the adopted physical models leads to a good simulation of the structure. It is therefore essential to introduce the appropriate parameters in physical models. The choice of models depends on the materials chosen for the simulation and their environment and dimensions.

The Atlas-Silvacocould be used to simulate our structure. The template declaration syntax is as follows:

MODELS <model flag><general parameter><model dependent parameters>

In this work, the models concerned are optical generation, mobility and recombination model.

1).Optical Generation Model

The incident illumination corresponds to the 1M1.5 spectrum. The wavelengths of the absorbed photons range from 0.305 to 3.455 µm. It is introduced into the Atlas-Silvaco program by the instruction:

BEAM x.o=0.5 y.o=0.5 angle = 90 wavel.star=0.305 wavel.end=3.455 wavel.num=0.305

2)Recombination Models

The latter often consists of three types: SRH recombination (Shockley-Read-Hall)(equition(1) [12-13] radiative recombination and Auger recombinationequition(2) [14] ,. Total recombination is the sum of these three types.

$$R_{SRH} = \frac{pn - n_i^2}{\tau_{P0}\left(n + n_{ie}\exp\frac{E_{tr}}{KT_L}\right) + \tau_{P0}\left(p + p_{ie}\exp -\frac{E_{tr}}{KT_L}\right)} \quad (1)$$

Where E_{tr} is the difference between the trap energy level and the intrinsic Fermi level, T_L is the lattice temperature in degrees Kelvin and T_{N0} and T_{P0} are the electron and hole lifetimes

$$R_{AUGER} = AUG_N(pn^2 - nn_i^2) + AUG_P(np^2 - pn_i^2) \quad (2)$$

Where the model parameters AUG_N and AUG_P are user-definable in the MATERIAL. You can activate this model with the AUGER parameter from the MODELSstatement. . n and p areconcentaration of electron and hole(cm^{-3}) respectively, $n_i$is the interseque concentration(cm^{-3}).

The rest of the constants are given in the table 2[5]:

Table 2: Constants used in recombination model

Parameters	Values
$\tau_{n0}(s)$	1×10^{-7}
$\tau_{P0}(s)$	1×10^{-7}
$E_{tr}(eV)$	0
$AUG_N\left(cm^6/s\right)$	8.3×10^{-3}
$AUG_P\left(cm^6/s\right)$	8.3×10^{-3}

3) Mobility Model

With this model, the mobilities of the electrons µ_n and of the holes µ_p are calculated using the following formulasequition (3) and (4):

$$\mu_{n0} = MUN\left(\frac{T_L}{300}\right)^{-TMUN} \quad (3)$$

$$\mu_{p0} = MUP\left(\frac{T_L}{300}\right)^{-TMUP} \quad (4)$$

The low field mobility parameters: MUN, MUP, TMUN and TMUP can be specified in the MOBILITY statement. The constants are given in table 3

Table 3: Constants use in mobility model

Parameters	Values
MUN(Cm^2/Vs)	1000
MUP(Cm^2/Vs)	500
TMUN	1.5
TMUP	1.5

4) Tunnel model

Three types of tunnel effect were used in the simulation:

- Inter-band tunnel**.**

- Intra-band tunnel

IV. Results

To study the influence of the doping of the window layer of the lower cell d on the photovoltaic characteristics of the cascade solar cells studies we fixed the optimal thickness and we chose a range of electron doping concentration between $2x10^{19}$and $8X10^{19}$ cm^{-3} for the window layer

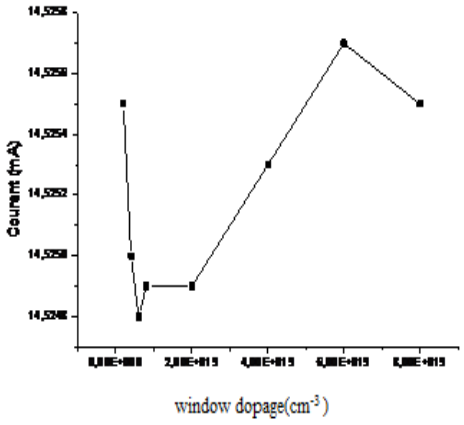
The first solar cell is simulated without the window layer of the upper cell. The values of the parameters are given in the table 4.

Table 4 :Parameters of the tandem cell without window of the lower cell

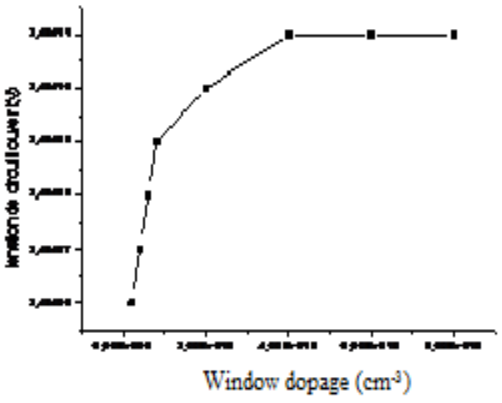
$I_{sc}\,(mA)$	$V_{CO}(V)$	$FF(\%)$	$\eta(\%)$
13,9503	2.40198	91.3877	22.1823

The second solar cell is simulated with a window layer of the upper cell. The variations of the parameters Icc, Vco, FF and n depending on the doping are given in the following graphs:

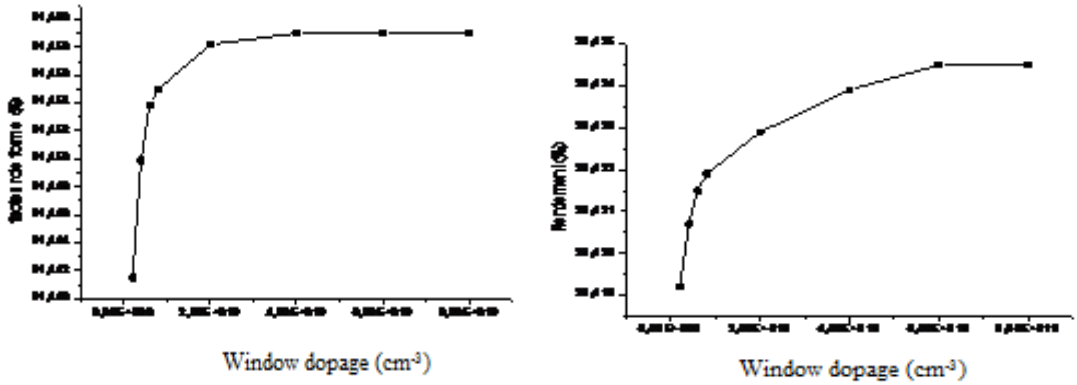
The effect of doping the window of the lower cell is presented in figures 5 (a) (b) (c) (d)



(a)



(b)



(c) (d)

Figure 5: The effect of window layer doping,
(a) short circuit current (b) open circuit voltage (c) form factor (d) conversion efficiency

In the first zone (I): there is a significant increase in efficiency with doping, this phenomenon is due to the increase in electron-hole pairs.In the second zone (II): there is a proportional increase in the yield as a function of the variation in doping compared to the increase in the first zone.It is noted that the increase in the doping level of the window allows a remarkable improvement in the conversion efficiency of the structure.So according to the figure also, the current receives an unexplainable change between $1x10^{19}$and$2X10^{19}$ cm^{-3}. For the three other parameters, such as the open circuit voltage ,the form factor and conversion efficiency, their increase is due to the reduction of the resistance and the diminution of the potential barrier.
For the tandem second solar, with a window layer to the upper solar cell, the optimal values are given in the table 5.These values are obtained for a doping level of$8x10^{18}$ cm^{-3}

Table 5 :Parameters of the tandem cell with a window layer of the lower cell

$I_{sc}\ (mA)$	$V_{CO}(V)$	$FF(\%)$	$\eta(\%)$
15.1436	2.42117	91.2450	24.2343

III. Conclusion

The window layer is used to minimize reflection losses.The conversion efficiency obtained for the tandem slar sell without the window layer of the lower cell is around 22.1823%. And for the same cell and with a window layer the yield amounts to 24.2343%.The conversion efficiency reaches its maximum value stabilizes from the value of $8x10^{18}$ cm^{-3}, then this is the optimal doping of the window layer of the lower cell. In conclusion, we have shown that the window layer of the upper cell has a considerable advantage over the energy efficiency of the tandem solar cell.

References

[1] Shur M, « Physics of semi-conductors devices », New York ,printice Hall first Edition.1990

[2] G.Domler et al . Applied physics letters 2006 -29-073502

[3] M. Wolf, Limitations and possibilities for improvement of photovoltaic solar energy converters, Proc. Inst. Radio Engineers, vol. 48, 1960.

[4] Badoud, A. Bond Graph Model for Fault Detection of Partial Shaded PV Array Considering Different Module Connection Schemes and Effects of Bypass Diodes. Algerian Journal of Renewable Energy and Sustainable Development, 2019, 1(1),41-59. https://doi.org/10.46657/ajresd.2019.1.1.5

[5] Atlas user's manual, Silvaco international, 2013.

[6] M. Izzeddine, 'Simulation des cellules solaires hétérojonction Si-SiGe par silvaco ' Thèse (2014) Université de Mohamed Khider, Biskra.

[7] Tahiri, F. Bekraoui, F. Boussaid I, Ouledali, O. Harrouz A. Direct Torque Control (DTC) SVM Predictive of a PMSM Powered by a photovoltaic source. Algerian Journal of Renewable Energy and Sustainable Development, 2019, 1(1),1-7. https://doi.org/10.46657/ajresd.2019.1.1.1

[8] M. FILLALI, B. DENNAI 'Impact of tunnel heterojunction (InGaP/GaAs) doping concentrtion on the performance of InGaP/GaAstondem solar cell using Silvaco-Atlas software', Journal of Ovonic Research -Vol. 15, No. 5, September – October 2019, p. 279 – 285.

[9] D.J. Friedman, J.M. Olson, S. Kurtz, High-efficiency III–V multijunction solar cells, in:A. Luque, S. Hegedus (Eds.), Handbook of Photovoltaic Science and Engineering, John Wiley & Sons, Ltd., Chichester, West Sussex, UK, 2011, pp. 314–364.

[10] Oudrane A, Hamouda M, Aour B. The Thermal Transfers of a Habitable Envelope in an Extremely Dry Area and These Effects on Thermal Comfort. Algerian Journal of Renewable Energy and Sustainable Development, 2019, 1(1),79-91. https://doi.org/10.46657/ajresd.2019.1.1.8

[11] Andrew D. Bates, "Novel optimization techniques for multijunctionsolarcell design using Silvaco ATLAS," M.S. thesis, Naval PostgraduateSchool, Monterey, CA, 2004

[12] ATLAS User's Manuel,"Device simulation software ", SILVACO International, California, 2004.

[13] W. Shockley and W. Read, "Statistics of the Recombinations of Holes and Electrons," Phys. Rev., vol. 87, pp. 835–842, sep 1952.

[14] R. N. Hall, "Electron-hole recombination in germanium," Phys. Rev., vol. 87, pp. 387–387,Jul 1952.

[15] P. Aguer, "Sur les rayons β secondaires produits dans un gaz par des rayons X," C.R.A.S.,vol. 177, pp. 169–171, 1923.

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