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STUDY SIMULATION OF TOP-CELL ON THE PERFORMANCE OF $Al_xGa_{1-x}As/Si_{1-x}Ge_x$TANDEM SOLAR CELL

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In this study, numerical optimization and analysis utilizing AMPS-1D software package of a simple model for tunnel junction (AlGaAs) between the top cell (AlGaAs) and bottom cell (SiGe) of cascade solar cells.
The electrical properties and the photovoltaic performance parameters of AlGaAs/SiGe multijunction solar cells .The possible effects of base of the top cell layer thickness and doping level on solar cell performance parameters are addressed. The conversion efficiency of the solar cell has been found to increase significantly with the doping concentration in the range from 10^{15} to 10^{17} cm^{-3} of 19.52% to 31.19% under the AM1.5G spectrum and one sun. These results are very promising for future potential applications in multijunction and high performance AlGaAs/SiGe solar cells technology.

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1. Introduction

The multi-junction cells are composed of different materials deposited in thin layers which allow an optimized use of the solar spectrum. Thus each junction works with its optimum efficiency absorbing the spectral range which is its own. Then during the past few years a great variety of multi-junction solar cells has been developed with the aim of a further increase in efficiency beyond the limits of single junction devices [1]. AlxGa1-xAs/Si1-x Gex is one of a few alloys that can meet this key requirement. While in mechanically stacked multi-junction (MJ) cells the sub cells usually have separate contacts, monolithic MJ cells are epitaxial grown on one substrate and the sub cells are interconnected in series by tunnel diodes leading to a standard two-terminal contact [2].

It is for this purpose, and as part of our research on photovoltaic cells, that we are interested in studying and optimizing the thickness and dopage of the base layer for the top cell.

In this present work, we are using a program of a one-dimensional simulation called an analysis of microelectronics and photonic structures (AMPS-1D) [3]. FIG.1 shows the diagram of the design of solar cells studied in this work.

The objective of this structure simulation is to verify the performance of the solar cell by varying the thickness and dopage concentration of the layer (bass for the top cell) each time. The performance of the solar cell is mainly based on the parameters of the material, the optical parameters, and the electrical parameters of each of the layers used in the structure.

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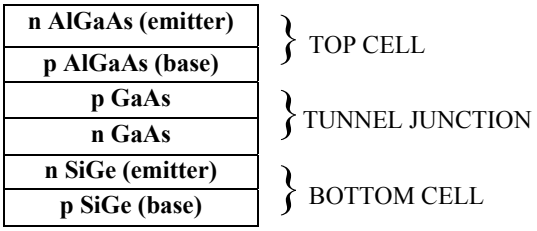

Fig. 1. Tandem solar cell - AlGaAs/ SiGe structure used for the modeling.

2. Optimal device structure

The major objectives of numerical modeling and simulation in solar cell research are testing the validity of proposed physical structures, geometry on cell performance and fitting of modeling output to experimental results. Any numerical program capable of solving the basic semiconductor equations could be used for modeling thin film solar cells. The fundamental equations for such numerical programs are (i) Poisson's equation for the distributions of electric field (φ) inside the device and (ii) the equation of continuity for conservation of electrons and holes currents. [5] [3 - 4].

The AMPS-1D program has been developed for pragmatically simulate the electrical characteristics of multi-junction solar cells. It has been proven to be a very powerful tool in understanding device operation and physics for single crystal, poly-crystal and amorphous structures.

In order to make photovoltaic systems economically viable for large scale terrestrial applications, high efficiency solar cells made inexpensively and with readily available material are required.

This software is a one-dimensional computer program for simulating transport physics in semiconductor devices. It solves numerically the three equations of the device (the equation of Poisson, continuity equation for free holes and that for free electrons) without assuming any assumptions about the transport mechanisms in these devices. For these three state variables, carrier concentrations, current density, voltages, temperature, etc. can then be calculated by: AMPS simulator has been used to stady the effect of multijunctions solar cells based AlxGa1-xAs/Si1-x Gex. [6].

The Poisson equation:

In one-dimensional space, the Poisson equation is given by:

$$\frac{\partial^2 \Psi(x)}{\partial x^2} = -\frac{\rho(x)}{\varepsilon} \tag{1}$$

The continuity equations:

The continuity equations in the delocalized states of the conduction and valence band have the form:

For free electrons

$$-\frac{1}{q}\frac{\partial Jn(x)}{\partial x} = G(x) - R(p(x), n(x)) \tag{2}$$

For free hales:

$$\frac{1}{q}\frac{\partial J_p(x)}{\partial x} = G(x) - R(p(x), n(x)) \tag{3}$$

In this study, a one-dimensional numerical analysis tool, AMPS-1D, is used to create various solar cell models and obtain its results. In AMPS-1D, four different layers are required for the modeling. More layers can be added as long as the grid points do not exceed the limitation, viz. 200-grid points. The six layers that are used in this modeling is the n/AlGaAs(emitter)-p/AlGaAs (base) for the top cell and p/GaAS-n/GaAs for tunnel junction, and n/SiGe (emitter)-p/SiGe (base) for the bottom cell.

For proper bottom solar cell based SiGe, first one have to analyze the equation of material main parameters such as band gap, electron affinity, optical property, carrier mobility, density of states, permittivity, absorption coefficient, electric field distribution and stability at higher operating temperature etc. At room temperature, band gap (eV) of the Si1-xGex material is given by the relation [7]:

$$Eg(x)= (1.155 – 0.43x + 0.0206x^2)\ eV \quad for \quad x < 0.85 \tag{4}$$

The electron affinity of SiGe is expressed by the relation given below [8]:

$$\chi(x) = 4.05\ 1 - x\ + 4.0x \tag{5}$$

The effective density of states in the conduction band:

$$Nc = 5.3\cdot\ 10^{15}x\ T^{3/2} \tag{6}$$

The effective density of states in the valence band:

$$Nv = 2.\ 10^{15}x\ T^{3/2} \tag{7}$$

The relative permittivity:

$$\varepsilon_r\ = 11.8 + 4.2x \tag{8}$$

Mobility of electrons:

$$\mu n(x) = 1500(1 – x)+ 3900x \tag{9}$$

Mobility of hole:

$$\mu p(x) = 450\ (1 - x) + 1900x \tag{10}$$

The absorption coefficient α (λ) is related to the particular wavelength and band gap of the Si1-xGex material:

$$\alpha = A.\ [\frac{(h\gamma - E_g\ - E_{phonon}\ )^2}{1-\exp\left(-\frac{E_{phonon}}{KT}\right)} + \frac{(h\gamma - E_g\ + E_{phonon}\ )}{\exp\left(-\frac{E_{phonon}}{KT}\right)-1}] \tag{11}$$

With

$$A(x)=3200(1-1.161x+9.581x^2) \tag{12}$$

$$Ephonon=0.050(1+0.026x-1.066x^2) \tag{13}$$

In this simulation, emitter's dopage layer from 10^{17} to 10^{18} cm^{-3} and surface recombination velocity from 10^3 to 10^7in window and Bsf layers for front and back contacts.

Table 1. Shows all the required parameters for the simulation:

Table 1. AMPS-1D algaas/sige tandem solar cell parameters.

Layers / Parameters	N/Al0.3Ga0.7As	N/Al0.3Ga0.7As	N/SiGe	N/SiGe
Thickness (µm)	**0**.1	0.1-6	7	7
Dielectric constant ε	5.6	5.6	12.93	12.93
Electron mobility μ_n (cm²/Vs)	2956	2956	2110	2110
Hole mobility μ_p (cm²/Vs)	67.77	67.77	812	812
Carrier density, n or p (cm^{-3})	Nd:5E16	Na:1E16 to 5E18	n:3E18	1E18
Optical band gap, E_g(eV)	1.75	1.75	0.96	0.96
Effective density, N_c (cm^{-3})	4.82E+18	4.82E+18	2.5E20	2.5E20
Effective density,N_v (cm^{-3})	1.73E+19	1.73E+19	2.5E20	2.5E20
Electron affinity , χ(eV)	4.42	4.42	3.92	3.92
Front Contact Windows PHIBO	1.73	-	-	-
Back Contact BSF PHIBL	-	-	-	0.020
surface recombination velocity	103-107	-	-	-103-107

3. Results and discussion

3.1. Influence of thickness (P/AlGaAS) on performances of tandem solar cell study

The first part of this work is dedicated to the effect of layer base (P/AlGaAS) of top cell thickness on output parameters of MJSC (AlGaAs/SiGe). To study this effect, the thickness is varied from 0.1 to 6µm with the concentration doping Na=$10^{16}$$cm^{-3}$.

Fig. 2 shows the effect of the thickness of the base layer forthe top cell on the short-circuit current and open circuit voltage.

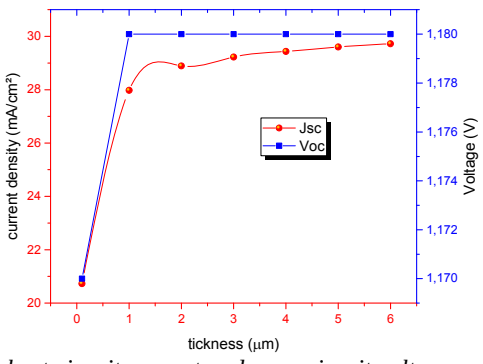

Fig. 2. Variation of short circuit current and open circuit voltage according to thickness.

Depending to Fig. 2 we notice that when the layer thickness base increases, there is a growth rate in the short current but the open circuit voltage is constant.

Fig. 3shows the effect of the thickness of the base layer for the top cell on efficiency and fill factor of the device study.

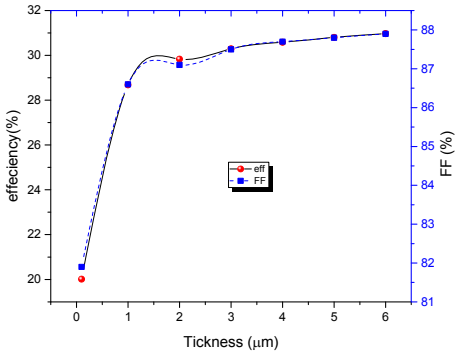

Fig. 3. Variation of efficiency and fill factor according to thickness.

The curve shows that the increase in the thickness of the emitter allows a remarkable increase in the efficiency of the cell, it has a direct effect on the increase of the photons absorbed by the top cell. The cell conversion efficiency which growth between 20.009% to 30.971% justified by the current increase.

2. Influence of concentration doping of (P/AlGaAS) on performances of tandem solar cell study

In this part to study the influence of the with the doping of the base layer top cell on the photovoltaic parameters of the solar cell, we look the previous structure (Fig. 1) of the thickness base layer (6 µm) and we have varied the doping (Na) $10^{16}$to 5.10^{18} cm^{-3}.

The short circuit current and open circuit voltage as a function of the concentration of base layer top cell is represented in Fig.4.

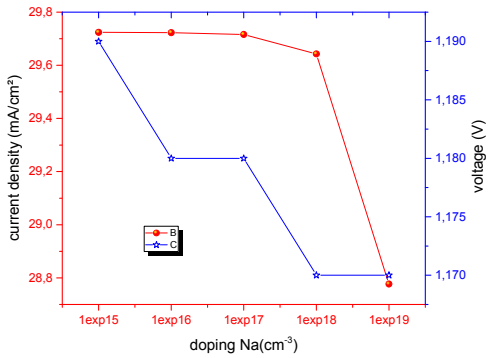

Fig. 4. Variation of short circuit current and open circuit voltage according to doping.

We can see that the sort current circuit decreases slowly (about 1%) when the doping of base layer increases from 10^{15} to 10^{19} cm-3.

The Fig. 5 represents the fill factor and efficiency as a function of base for the top cell layer doping.

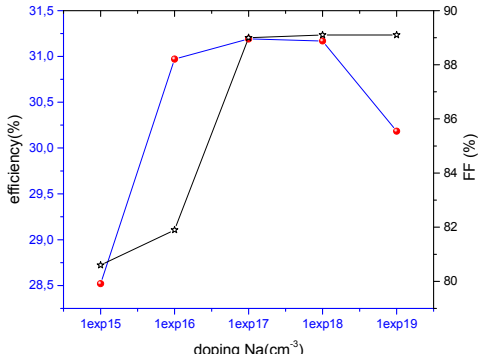

Fig. 5. Variation of efficiency and fill factor according to doping.

The efficiency of this device increases with base layer the top cell doping concentration up to the doping value 10^{17} cm-3 reaches a maximum efficiency of 31.19 %. After we notice decrease to 30.189.

From the above results are obtain software we can determine the tandem solar cell which has the best performance while giving the doping and thickness of base layer the top cell.

Table2.The doping and thickness of layer base of solar cell optimized

Thickness (µm)	6
Doping(cm^{-3})	10^{17}

The current-voltage and power-voltage characteristics for the device multijunction solar cell AlGaAs/Si0.25Ge0.75 layers with the optimal concentrations doping and thickness for the base layer for the top cell are shown in Fig.6, and the corresponding parameters PV (V_{CO}, J_{SC}, FF and efficiency) are summarized in Table 3.

Table 3. Optimal parameters PV for tandem solar cell .

Vco (v)	jsc(mA/cm²)	ff (%)	η (%)
1.18	29.716	89	31.19

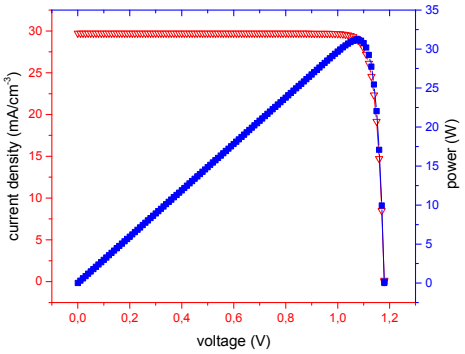

Fig.6. I(V) and P(V) characteristic of the tandem solar cell with the optimum performance.

4. Conclusions

Whatever the structure of a solar cell, an optimization of its parameters is necessary to have a good performance. Usually, among the parameters to be optimized are the thickness and concentration, of the cell and the optical confinement.

The calculation of the photovoltaic parameters of the AlGaAs/SiGe tandem solar cell with tow junctions was designed and optimized with different thickness and concentration doping of the base layer for the top cell. It is shown that the electrical parameters such as, the density current, fill factor and efficiency has strong dependence on the thickness of intrinsic layer ,has allowed to achieve the best solar cell structure with optimum performances.

The optimum efficiency, found under normalized conditions is 31.19 % using 6000 nm as thickness and concentration doping 10^{17} cm^{-3} of the base layer.

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