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Analysis of a-Si:H/SiGe heterostructure solar cell

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In this paper we present the results of the numerical simulation using wx-AMPS1D software of a solar cell based on hydrogenated amorphous silicon (a-Si: H / c-SiGe), the top layer has the largest band gap, while the bottom layer has the smallest bandgap. This design allows less energetic photons to pass through the upper layer(s) and be absorbed by the layer below, which increases the overall efficiency of the solar cell to obtain an efficiency high conversion rate. As the results, remarkable improvements on Voc, Jsc and FF have been achieved with the incorporation of n-c-SiGe layer, we achieved an efficiency of 11.93%.

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Keywords: Hydrogenated amorphous silicon, Silicon germanium, Hetero-structures solar cells

1. Introduction

Scientific research in the photovoltaic's field has been directed towards the study of heterojunction solar cells based on hydrogenated amorphous silicon.

This form of semiconductor was discovered in the early sixties; at first it was not usable because it had too many defects, but towards the end of the sixties, Chittick observed that by depositing the amorphous silicon by a silane plasma (SiH4), more than 99.9% of the defects were saturated with hydrogen which made this material usable as a semiconductor.[1]

Intrinsic and p-doped layers have been widely studied and their influence on the HJ solar cell performances. By contrast, little research has been done on n-doped layer and its impact on the overall device performance, and therefore it is difficult to quantify. Nevertheless, this n-doped layer is a key part of the solar cell and plays a valuable role to obtain high efficiencies. Our simulation work consists in introducing a C-SiGe layer in the reference hydrogenated amorphous silicon P-I-N cell [2] to find its effect on the output parameters.

Silicon-germanium, is a general term for the alloy $Si_{1-x}Ge_x$ which consists of any molar ratio of silicon and germanium. It is commonly used as a semiconductor material in integrated circuits (ICs) for heterojunction bipolar transistors or as a strain-inducing layer for CMOS transistors.

Solar applications typically have low-energy conversion rates (typically 15% to 20%). But with SiGe solar cells, that number can potentially rise to 30%-40% in energy conversion efficiency. Using single-crystal SiGe can also improve the operational life of a solar panel system from 25 to 30 years to approximately 80 years. It's worthwhile noting, too, that most materials used for solar applications are more expensive and less abundant than SiGe. [3-5]

2. Description of simulation parameters

Amorphous silicon solar cells are normally prepared by glow discharge, sputtering or by evaporation, and because of the methods of preparation, this is a particularly promising solar cell for large scale fabrication. Because only very thin layers are required, deposited by glow discharge on substrates of glass or stainless steel, only small amounts of material will be required to make

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these cells. The efficiency of amorphous silicon solar cells has a theoretical limit of about 15% and realized efficiencies are now up around 6 or 7%. If efficiencies of 10% can be reached on large area thin film amorphous silicon cells on inexpensive substrates, then this would be the best approach to produce low cost electricity.[6]

The simulated structure is a solar cell (Figure. 1) composed of two layers of hydrogenated amorphous silicon a-Si: H (P) / a-Si: H (I) of the reference cell [3]and one layers of silicon germanium SiGe (N).

The cell was deposited on a metal substrate which acts as a rear contact. For the front contact, a TCO (Transparent Conducting Oxide) layer has been deposited, on the p side.

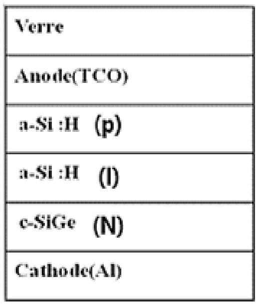


Fig. 1. Structure of the simulated solar cell.

Hetereojunction solar cells combine two different technologies into one cell: a crystalline silicon cell sandwiched between two layers of amorphous “thin film” silicon. Used together, these technologies allow more energy to be harvested compared to using either technology alone[7].

When the two semiconductors come into contact, the carriers are diffused from one region to the other of the junction, in the same way as a homo-junction. At thermodynamic equilibrium, the fermi level is single along the entire cell. The photon having an energy lower than Eg_1 and higher than Eg_2 cross the first semiconductor and its absorbed by the second. Heterojunction have better performance than homojunction:

- Better spectral response and exploitation of the maximum of the solar spectrum
- Low series resistance, if the first semiconductor is heavily doped (without affecting the light transmission characteristics)
- Improved absorption of photons if the first semiconductor is thick (absorption in both semiconductors)
- Fairly high-open circuit voltage. [8]

Our simulation work consists in introducing a C-SiGe layer in the reference hydrogenated amorphous silicon P-I-N cell [2] to find its effect on the output parameters.

For simulation, we used the simulation tool wxAMPS (Analysis of Microelectronic and Photonic Structures) that is a well-known solar cell simulation tool developed by Fonash et al. at the Pennsylvania State University. wxAMPS is a powerful program for analyzing and designing thin film solar cell, particularly well adapted to simulating amorphous silicon solar cells with large densities of point defects in the energy gap [9, 10].

AMPS-1D solves three coupled differential equations each subject to boundary conditions and then calculates the electrostatic potential and the quasi-Fermi level for holes and electrons at all point in the solar cell. Once these values are known as a function of depth, it is straightforward to calculate the carrier concentrations, electric fields and currents, and device parameters like the open-circuit voltage (*Voc*), shortcircuit current density (*Jsc*), fill-factor (FF), and the efficiency (η). These parameters define the performance of a solar cell. [11]

The physical parameters of the materials defined in the interface of the AMPS-1D software are presented in Table (1)

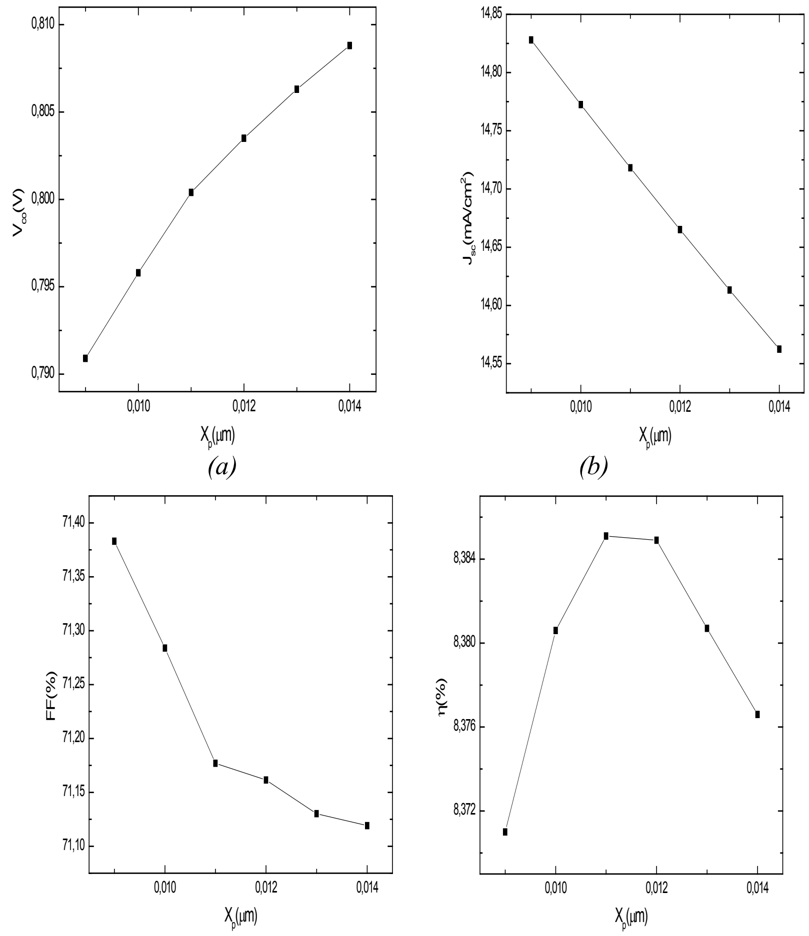
Table 1. The parameters extracted from the simulation of three layers

parameters	a-Si :H(p) [2]	a-Si :H(I))[2]	SiGe(N) [12]
ε_r	7.2	11.9	12.93
Eg (ev)	1.79	1.66	0.96
x (ev)	3.9	3.7	4.03
Nc ($\mathbf{cm^{-3}}$)	2.5 e20	2.5 e20	7.3 e18
Nv ($\mathbf{cm^{-3}}$)	2.5 e20	2.5 e20	9.3 e18
$\mathbf{\mu_n(cm^2/V_S)}$	10	20	2100
$\mathbf{\mu_p(cm^2/V_S)}$	1	2	812
$\mathbf{N_d(cm^{-3})}$	0	0	2. e19
$\mathbf{N_a(cm^{-3})}$	2 e18	0	0
$\mathbf{G_{DO}/G_{AO}}$	10^{21}	10^{21}	
$\mathbf{\sigma_{nD}/\sigma_{nA}}$	$10^{-15}/10^{-16}$	$10^{-15}/10^{-16}$	
$\mathbf{\sigma_{pD}/\sigma_{pA}}$	$10^{-16}/10^{-15}$	$10^{-16}/10^{-15}$	
$\mathbf{N_{DG}/N_{AG}}$	$10^{18}/10^{16}$	$7.10^{15}/7.10^{15}$	

3. Simulation results

3.1. Influence of P layer thickness

In this part and at T = 300 ° K, the thickness of the a-Si:H (P) layer is varied, while all the other parameters are set to the values indicated in Table 1.



(a) *(b)*

(c) *(d)*

Fig. 2. Influences of the thickness of the a-Si: H (p) layer on the performance of the cell: (a) the open circuit voltage, (b) the short circuit current, (c) form factor, (d) efficiency.

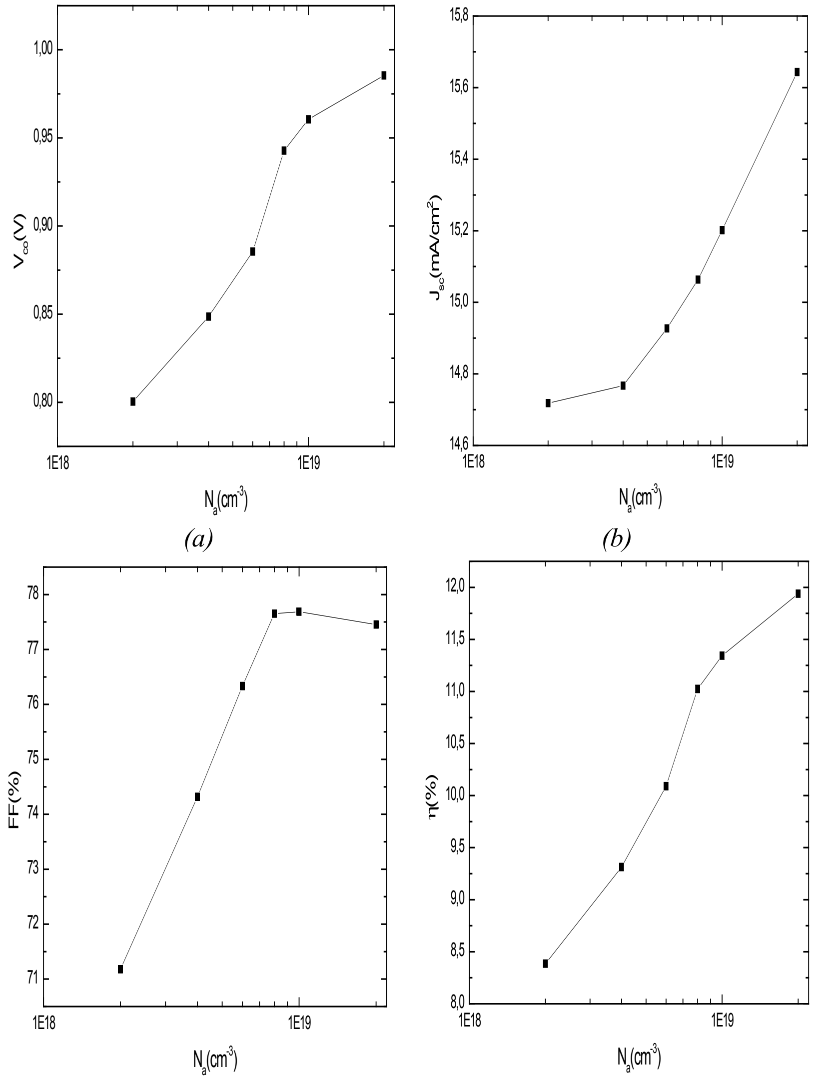
In the simulation, AM 1.5 radiation was used as the illumination source with a power density of 100 mW/cm^3

The basic solar cell performance parameters the short circuit current density Jsc, the open circuit voltage Voc, the fill factor and the efficiency η are represented in figure 2.

For a layer thickness of a-Si: H (p) varies between 0.009 to 0.014µm, we observe a decrease in cell performance with increasing thickness, because a large number of photons are absorbed in the layer P before having arrived at the intrinsic layer. So, we prefer that the thickness of the layer P is the smallest therefore, the optimal value is X_p = 0.011 µm which gives us a good efficiency of 8.38%.

3.2. Influence of P layer dopant concentration on the performances of solar cell

The results of the variation of performance of the solar cell as a function P layer dopant concentration are shown in figure 3. As result, we obtain the conversion efficiency of the cell presents an optimum value of 11.93% for a doping of 2. 2.10^{19} cm^{-3}.



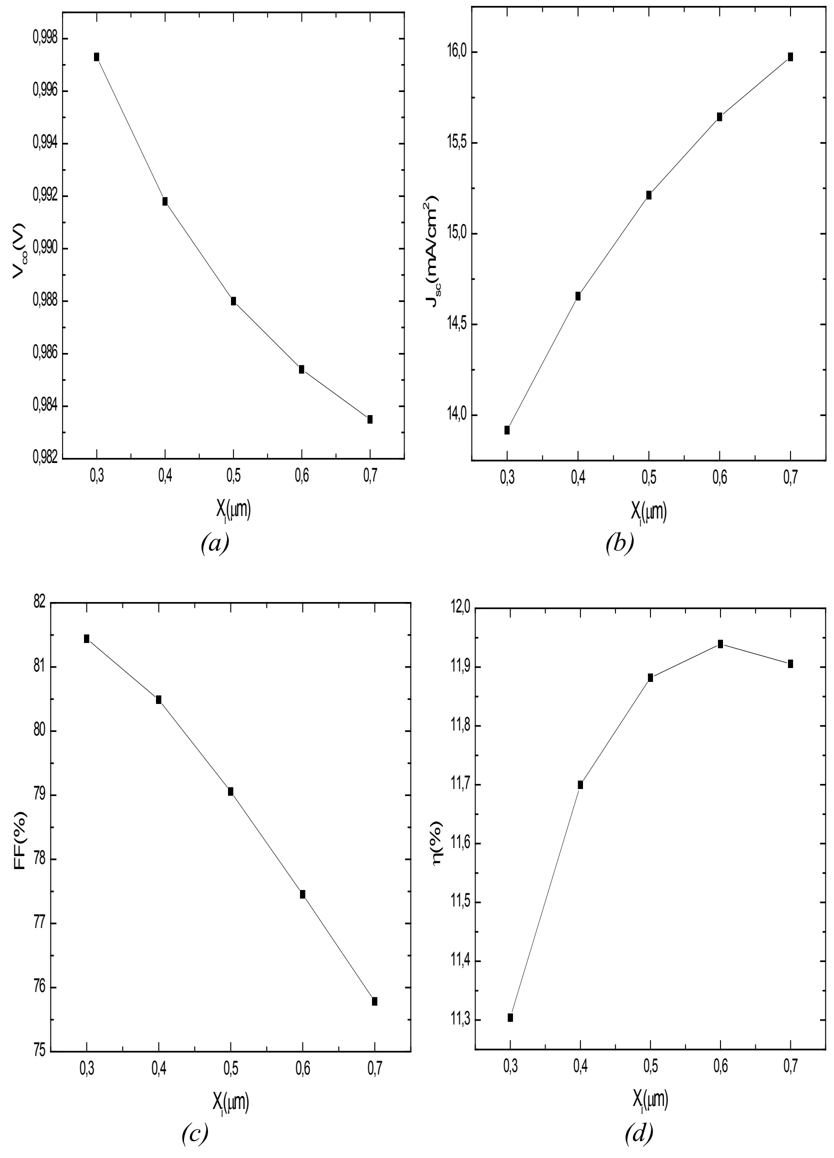
(a) *(b)*

(c) *(d)*

Fig. 3. Influence of doping of the a-SI: H (P) layer on the performance of cell : (a) the open circuit voltage, (b) the short circuit current, (c) form factor, (d) efficiency.

3.3. Influence of the intrinsic layer thickness

In order to understand the effect of the intrinsic layer thickness I (a-Si) on the photovoltaic performances, we simulated the a-Si: H / c-SiGe solar cell output characteristics, the open circuit voltage, the short circuit current, form factor, efficiency (Figure. 4). The intrinsic layer thickness is simultaneously varied from 0.3 µm to 0.7 µm.



(a) *(b)*

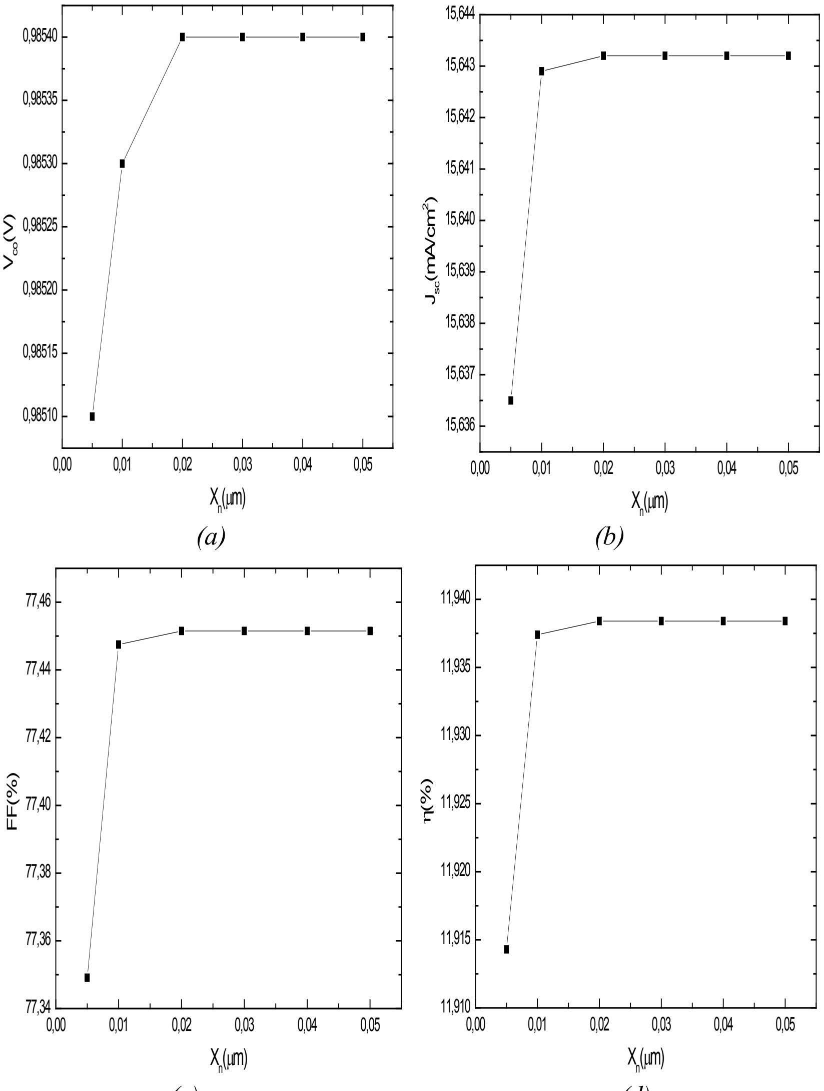
(c) *(d)*

Fig. 4. the influence of the thickness of the intrinsic layer (a-Si) on the photovoltaic performance: (a) the open circuit voltage, (b) the short circuit current, (c) form factor, (d) efficiency.

Open circuit voltage and fill factor decrease with increasing intrinsic layer thickness, the main limitation of V_{co} is volume. The fill factor takes into account the percentage of pairs collected compared to the pairs created we can say that a-Si has a lot of defects, so many pairs trap and less pairs collected. The short circuit current density increases with the intrinsic layer thickness. The widening of the intrinsic layer leads to the widening of the region of the photo carriers generation, hence the number of photo carriers generated by the light increases and the density of the short circuit current also increases.The efficiency has a maximum value of around 11.93% corresponding to an optimum thickness of the intrinsic layer of around 0.6 µm. This makes it possible to consider the use of thinner amorphous layers for photovoltaic applications and this is because of the absorption coefficient of a-Si: H is higher than that of c-Si [12].

4.4. Influence of the N layer of C-SiGe thickness

In this part, the thickness is varied between 0.02 and 0.05 µm, while the other parameters are constant, to study the change in the output parameters of the cell (Figure (III. 15)). We notice an improvement in the four parameters from 0.005µm to 0.01µm then it remains stable from 0.02 to 0.05µm.



(a) *(b)*

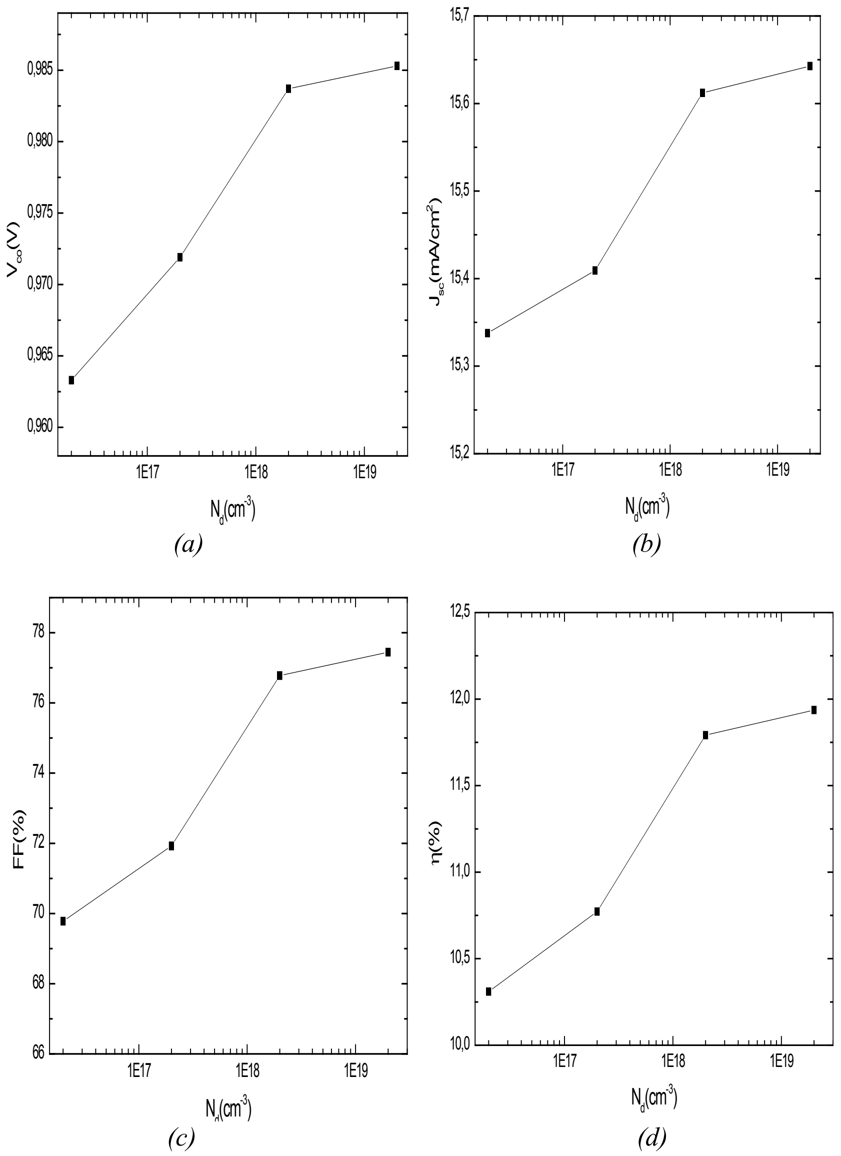
(c) *(d)*

Fig. 5. Influence of the thickness of the C-SiGe layer on the performance of solar cell: (a) the open circuit voltage, (b) the short circuit current, (c) the factor of form, (d) the yield.

3.5. Doping influence of the N layer of C-SiGe

In order to study the influence of N_d doping on the solar cell performance, we varied the doping concentration of the C-SiGe N layer. Figure. 6 present the variation of performance of the solar cell as a function N layer dopant concentration.

We note that the increase in the N-layer doping concentration of the leads to a small improvement in the output electrical parameters of the simulated cell (B), an optimal N_d doping value of 2. 2.10^{19} cm^{-3}.giving an efficiency of 11.9369%.



(a) *(b)*

(c) *(d)*

Fig. 6. Influence of doping of the N layer of C-SiGe on the performance of solar cell: (a) the open circuit voltage, (b) the short circuit current, (c) the form factor, (d) the yield.

3.6. JV characteristic of solar cell

We resemble the optimal parameters obtained by the simulation, we will have optimal performance of the cell based on hydrogenated amorphous silicon (a-Si: H / c-SiGe) studie. The JV characteristic and the parameters photovoltaic cells obtained by the simulation of the solar cell are presented in figure. 7.

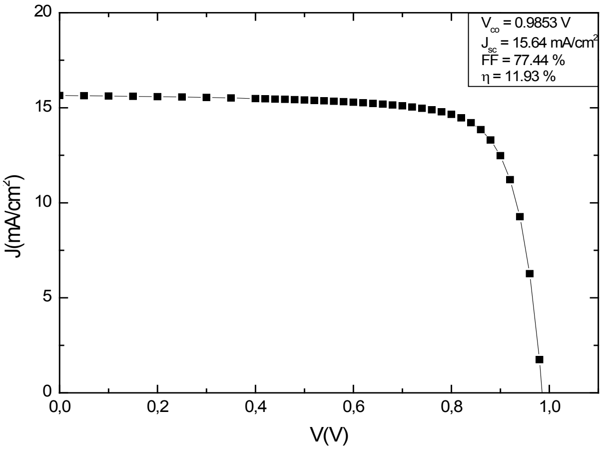


Fig. 7. J_V characteristics.

Table 2 summarize a comparison of the values of the output parameters of the cell based on hydrogenated amorphous silicon (a-Si: H / c-SiGe) studied obtained by the simulation and the results obtained for a PIN cell in hydrogenated amorphous silicon [2] and those obtained by the simulation of a heterojunction cell (a-Si: H / c-Si) [12]

We notice an improvement in the four parameters of a-Si: H / c-SiGe solar cell.

Table 2. Comparison between the results obtained and that found by the works of references [2, 12].

	V_{co}	J_{sc}	FF	η
Pa-Si :H/Ia-Si :H/Na-Si :H [3]	0.7735	14.7028	62.52	7.11
P(a-Si :H/I(a-Si :H/N(C-Si) [9]	0.7492	14.92	57.23	6.40
Simulation structure	0.9853	15.6427	77.4456	11.93

4. Conclusions

The influence of n-doped c-SiGe layer on HJ solar cell performance was investigated using wxAMPS-1D simulation program. In order to have an optimum result, a various parameters have been simulated. We find an improvement in the four parameters of a-Si: H / c-SiGe solar cell compared by a-Si: H / c-Si solar cell [13]. The highest efficiency of 11.93% was reached. This structure offers a very interesting approach for a simple and less expensive solar cell technology.

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