STUDY OF A SOLAR CELL WITH A MULTILAYERED WINDOW BASED ON $Si_{1-x}Ge_x$ USING AMPS-1D

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The Silicon-Germanium (SiGe) technology, whose preliminary developments date from the mid-1980s and whose arrival on the market is recent, meets this joint need for economy and performance. In our days solar cells to thin films are increasingly used primarily because of their low cost. In recent decades the performance of these cells were significantly improved. In this work, we simulate solar cell base Si (1-x) Ge (X) multilayer window using software (AMPS-1D) to analyze some parameters. In particular, the properties of the window layer (thickness, doping, etc.) play a key role in the performance of the cell, and in order to optimize them, their influence on the photovoltaic quantities of the solar cell is studied. In order to highlight the importance of the deposition of a Si (1-x) Ge (X) type window layer on the Si (1-x) Ge (X) solar cells, a comparison between three cells , one with a window layer, the other with two layers windows and the third with three layers windows was made under 300 K and one sun (AM1.5) . The optimal solar cell was founding for the first window layer (100 nm ; x = 0.3) ,second window layer (80 nm ; x = 0.2) and the third window layer (60 nm ; x = 0.1) for 15.56 % optimal efficiency. This comparison led to the following conclusion: the multiplication of the cascade windows leads to a cell equivalent to a gradual window.

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Keywords: Solar cell, Window layer, AMPS-1D, Performance, Si (1-x) Ge (X)

1. Introduction

Photovoltaic is accepted as a promising technology that directly takes advantage of our planet's ultimate source of power, the sun. When exposed to light, solar cells are capable of producing electricity without any harmful effect to the environment or devices. Therefore, they can generate power for many years (at least 20 years) while requiring only minimal maintenance and operational costs. Currently the widespread use of photovoltaic over other energy sources is impeded by the relatively high cost and low efficiency of solar cells [1-2].

The silicon-germanium technology (SiGe) (IV.IV), whose preliminary developments date from the middle of 1980s. The silicon-germanium (SiGe) alloy, which is compatible with silicon semiconductor technology and has a smaller band gap and a lower thermal conductivity than silicon, has been used to fabricate electronic devices such as transistors, photo detectors, solar cells, and thermoelectric devices [3].

In the present work, we have modeled and simulated solar cell based with SiGe material using AMPS 1D we have stadied the effect of multilayer widows based on Si1-xGex for differences values of molar fraction.

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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.

AMPS simulator has been used to stady the effect of multilayer windows based Si1-xGex. The structure of SiGe solar cell is shown in Fig .1.

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3. Results and discussion

For each layer, we study the effect of the thickness on the output parameters of the solar cell.

3.1. Effect of thickness layers on solar cell $Si_{1-x}Ge_x$ with windows

3.1.1. Effect of one layer window n^+ $Si_{0.7}Ge_{0.3}$

In this simulation, we have studied the effect of one layer thickness window on performance of solar cell structure. The window layer (n+ Si0.7Ge0.3 ; Nd = 5e1018 cm-3) varied from 20 nm to 120 nm.

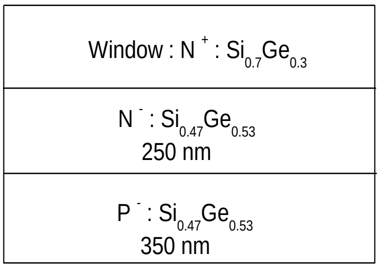

Fig. 1.Solar cell structure with one Window n+ $Si_{0.7}Ge_{0.3}$.

Table 1.The parameters of solar cell.

Layer	n+ Si $_{0.9}$ Ge $_{0.1}$	n+ Si $_{0.8}$ Ge $_{0.2}$	n+ Si $_{0.7}$ Ge $_{0.3}$	n Si $_{0.47}$ Ge $_{0.53}$	p Si $_{0.47}$ Ge $_{0.53}$
Molar fraction	0.1	0.2	0.3	0.53	0.53
Eg (eV)	1.11	1.06	1.02	0.93	0.93
Nc (cm^{-3})	2.75e18	5.50e18	8.26e18	1.45e19	1.45e19
Nv cm^{-3}	1.03e18	2.07e18	3.11e18	5.50e18	5.50e18
Affinity (eV)	4.04	4.04	4.03	4.02	4.02
Dielectric constant	12.22	12.64	13.06	14.02	14.02
Electron mobility (cm^2/Vs)	1740	1980	2220	2772	2772
Hole mobility (cm^2/Vs)	595	740	885	1218.5	1218.5
Thickness (nm)	80	100	100	250	350

Depending to the simulation results, we notice that when the layer thickness window increases, there is a growth rate in the short current and efficiency slow increase in circuit voltage. This result, layer thickness 100 nm is the best for the thickness of window, it will be use in the second simulation.

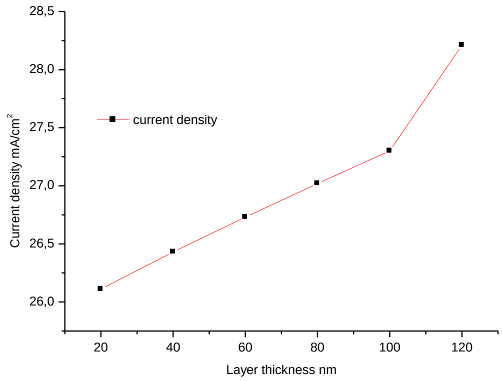

Fig. 2. Current dansity vs layer thickness with one window layer n+ $Si_{0.7}Ge_{0.3}$.

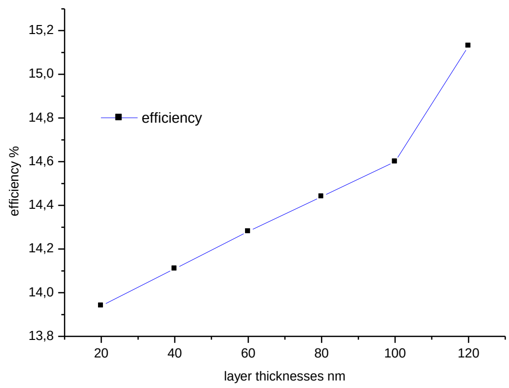

Fig. 3. Efficiency vs layer thickness with one window layer n+ $Si_{0.7}Ge_{0.3}$.

3.1.2. Effect of two layers windows n^+ $Si_{0.7}Ge_{0.3}$ / n^+ $Si_{0.8}Ge_{0.2}$

In that part, the device have two layers windows the first N+ Si0.7Ge0.3 with 100 nm length and the second N+ Si0.8Ge0.2 varied from 20 nm to 100 nm. Table 2 show the effect of second layer of window on performance of solar cell.

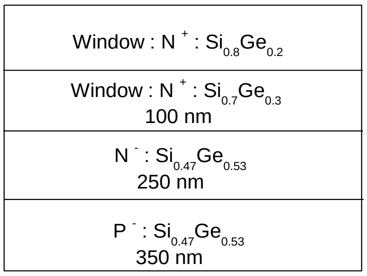

Fig.4. Solar cell structure with two windows layers.

Table 2. Parameters of solar cell with second window layer n+ $Si_{0.8}Ge_{0.2}$.

Thickness of 2nd window layer (nm)	Jsc (mA/cm^2)	η (%)	FF	Voc (V)
20	27.57	14.72	0.83	0.64
40	27.83	14.92	0.83	0.64
60	28.08	15.05	0.83	0.64
80	28.32	15.18	0.83	0.64
100	28.54	15.29	0.83	0.64

The second window layer played good role; we notice that when the layer thickness window increases, there is a growth rate in the short current and efficiency slow increase in circuit voltage. This result, layer thickness 100 nm is the best for the thickness of window, it will be use in the second simulation.

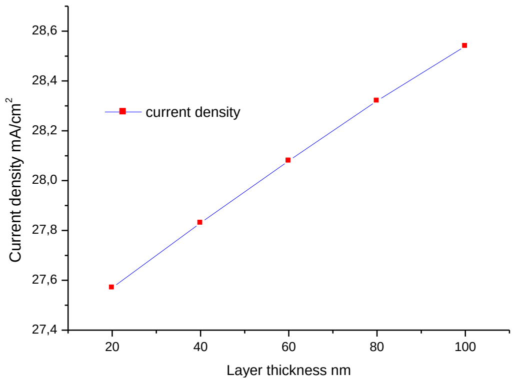

Fig. 5. Current dansity vs layer thickness with second.

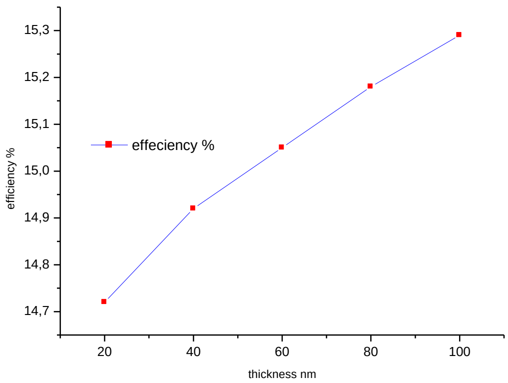

Fig. 6. Efficiency vs layer thickness with second window layer n+ $Si_{0.8}Ge_{0.2}$.

3.1.3. Effect of three layers windows n+ Si 0.7 Ge0.3 / n+ Si 0.8 Ge0.2 / n+ Si 0.9 Ge0.1

In that part, the device have three layers windows the first n+ Si0.7Ge0.3 with 100 nm length ; the second n+ Si0.8Ge0.2 with 80 nm length and the third varied from 20 nm to 80 nm . Table 3 show the effect of third layer of window on performance of solar cell.

Table 3. Parameters of solar cell with third window layer n+ $Si_{0.9}Ge_{0.1}$.

Thickness of 3nd window layer (nm)	Jsc (mA/cm^2)	η (%)	FF	Voc (V)
20	29.10	15.61	0.83	0.64
40	29.25	15.68	0.83	0.64
60	29.46	15.75	0.83	0.64
80	29.62	15.56	0.81	0.64

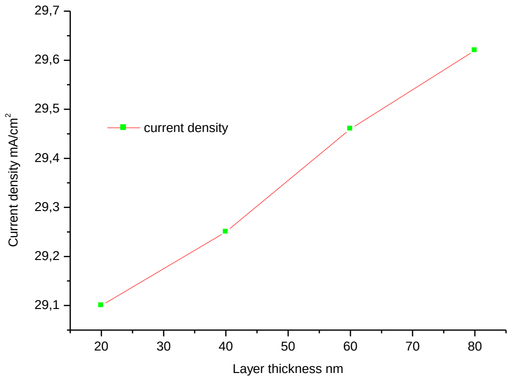

Fig.7. Currentdensity vs. layerthicknesswiththirdWindow layer n+ $Si_{0.9}Ge_{0.1}$.

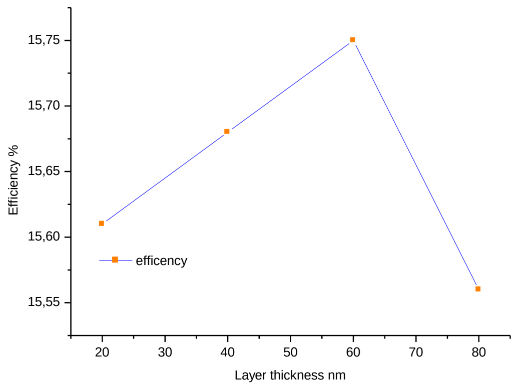

Fig. 8.Efficiency vs layer thickness with third window layer n+ $Si_{0.9}Ge_{0.1}$.

We observed that the current density increase from 29.10mA/cm^2 to 29.62 mA/cm2 When the thickness change from 20 nm to 60 nm. For efficiency we see amelioration (15.61% to 15.75%) from 20 nm to 60 nm but for 80 nm thickness layer the efficiency decrease to 15.56%,therefore the best thickness was 60 nm (15.75% and 29.46mA/cm^2).

Window : N $^{+}$: $Si_{0.9}Ge_{0.1}$
Window : N $^{+}$: $Si_{0.8}Ge_{0.2}$ 80 nm
Window : N $^{+}$: $Si_{0.7}Ge_{0.3}$ 100 nm
N $^{-}$: $Si_{0.47}Ge_{0.53}$ 250 nm
P $^{-}$: $Si_{0.47}Ge_{0.53}$ 350 nm

Fig. 9. Solar cell structure with three windows layers.

3.1.4. Solar cell optimal multilayered windows based $Si_{1-x}Ge_x$

Fig.10 present the solar cell optimal multilayered window based $Si_{1-x}Ge_x$in our study.

Window : N $^{+}$: $Si_{0.9}Ge_{0.1}$ 60 nm
Window : N $^{+}$: $Si_{0.8}Ge_{0.2}$ 80 nm
Window : N $^{+}$: $Si_{0.7}Ge_{0.3}$ 100 nm
N $^{-}$: $Si_{0.47}Ge_{0.53}$ 250 nm
P $^{-}$: $Si_{0.47}Ge_{0.53}$ 350 nm

Fig. 10. The optimal Solar cell structure.

Table 3.Splicing of each layer of the solar cell $Si_{1-x}Ge_x$ optimize.

Layer	P-$Si_{0.47}Ge_{0.53}$	N-Si $_{0.47}Ge_{0.53}$	N+Si $_{0.7}$Ge $_{0.3}$	N+$Si_{0.8}Ge_{0.2}$	N+ $Si_{0.9}Ge_{0.1}$
length nm	350	250	100	80	60

The corresponding PV parameters (open-circuit voltage Voc, short-circuit current Isc, fill factor FF and efficiency (η) are all summarized in Table 5.

Table 5. Parameters PV of the optimized Si $_{1-x}Ge_x$ device.

J_{sc} mA/cm^2	**η %**	**FF**	**V_{oc} (V)**
29.62	15.56	0.816	0.64

The following figure shows the results of the simulation of the I (V) characteristic on the solar cell with $Si_{1-x}Ge_x$-based multilayer window.

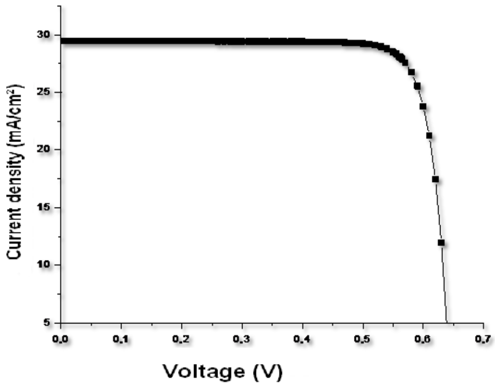

Fig.12.Currentdensity-voltage characteristics SiGe device optimal.

4. Conclusions

In this work we presented the results of simulations of solar cells based on (Si(1-x)Ge(x)) alloys with multiple windows by AMPS-1D and different thicknesses of the layers to avoid recombination on the surface were very favorable to increasing efficiency.

The optimum efficiency (eff=15.56%) found, under normalized Photovoltaic parameters conditions (AM1.5G, 0.1 W/cm^2, 300 K and 1sun). The results obtained show that the cell multilayer window gives the best efficiency and the thickness of the solar cell is an important parameter for the absorption of photons.

References

[1] Atouani, Toufik et al. *Journal of Nanoelectronics and Optoelectronics* 13 (2018): 1145-1152.
[2] Further mention of cost competitiveness: Solar PowerLightens Up with Thin-Film Technology, Scientific.
[3] D. Maamar, D. Benmoussa, F. Mustafa, Digest Journal of Nanomaterials and Biostructures 13(3), 759 (2018).
[4] S.J. Fonash, A manual for One-Dimensional Device Simulation Program for the Analysis of Microelectronic and Photonic Structures (AMPS-1D) (The Center for Nanotechnology Education and Utilization, The Pennsylvania State University, University Park, PA 16802).H. Gould, J. Tobochnik, Computer Simulation Methods. Applications to Physical Systems (New York: Addison-Wesley Publishiong: 1988).
[5] S.M. Sze, Physics of semiconductor devices, New York: John Wiley & Sons Press, 1981.
[6] R. Braunstein, A. R. Moore, Frank Herman, Physical Review**109**(3), 695(1958).