Window Layer Thickness Effect on Amorphous Silicon Oxide Solar Cell Performances

Wafa HADJ KOUIDER, Abbas BELFAR, Mohammed BELMEKKI, Hocine AIT-KACI

Laboratory of Physics Plasmas, Cnductive Materials and Their Application (LPPMCA), Sciences and Technology University of Oran - Mohamed Boudiaf (USTO-MB), Oran, Algeria.
* Corresponding Author:wafa.hadjkouider@univ-usto.dz

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ABSTRACT

The recent research and developments of a-Si:H based solar cells have greatly promoted its position as low cost solar cell. Unfortunately, a-Si:H solar cells suffer appreciable light induced degradation for thickness greater than 200nm. It has been reported that boron doped hydrogenated amorphous silicon oxide (p-a-SiOx:H) films have a low temperature coefficient compared to those based on hydrogenated amorphous silicon (p-a-Si:H). Moreover, the solar cells with a p-a-SiOx: H generate more electricity than the solar cells with p-a-Si: H window layer due to the wider band gap (Eg) of these films. We present in this paper a computer simulation on the effects of window layer thickness on the performances of single junction amorphous silicon oxide solar cells. We varied the thickness of the window layer from 5 nm to 25 nm and our simulation results showed that cells parameters are significantly affected window layer thickness. However, the film thickness of the p-a-SiOx:H window layer increased from 5 nm to 25 nm, the power conversion efficiency (PCE) of the solar cells respectively decreased in the ranges of 5.733% to 5.271% .the simulation data are in good agreement with the literature.

I. Introduction

Building Integrated Photovoltaics (BIPV) adoption varies significantly from country to country, depending on government policies, consumption demand, power generation system, the grid-connected PV electricity tariff arrangement , built environment and climate [1]. High operating temperatures degrade the power conversion efficiency of these photovoltaic devices[2]. As a result of the decrease in the open circuit voltage (Voc) [3]. It has been reported that inorganic materials combine low temperature coefficient, stability in outdoor condition and excellent transparency[4]. Doping hydrogenated amorphous Silicon films opened doors in the PV industry. However, solar cells based on this material suffer from light induced degradation (Staebler-Wronski effect) and need to develop their efficiency and stability. Alloying with carbon or oxygen seems to be a good solution to overcome these problems.

Sriprapha et al.[5] have found that wide bandgap a-SiOx: H single-junction solar cells showed a low-temperature coefficient. Furthermore, it has been reported that this material generate more electricity than its conventional counterpart a-Si: H[4].

In p-i-n solar cell, the window layer perform an important role, therefore its band gap define the amount of light achieved the intrinsic layer[6]. This window layer demands high conductivity, high optical transparency and wide optical band gap. The use of wide band gap window material has opened a way for high performance amorphous silicon based a-Si:H solar cells[7]

Wide band gap hydrogenated p-type amorphous silicon oxide p-a-SiOx: H was developed by ichikawa et al.[8] group as a window material, to replace the wide band gap p-type hydrogenated amorphous silicon carbide p-a-SiC: H. to minimize the absorption loss the thickness of window layers needs to be carefully designed to provide sufficient charge because this layer grant the paasage of light to the active layer.

Motivated by the necessity of boosting the performance of wide bandgap a-SiOx: H-based solar cells further, we examined the effect of varying the p-a-SiOx: H window layer thickness on the amorphous silicon oxide-based solar cells using AMPS-1D simulator

II. Simulation model and device structure

II.1. AMPS-1D model for amorphous silicon

Numerical simulation using AMPS-1D (Analysis of Microelectronic and Photonic Structures) supplies a convenient method to estimate the role of the various parameters present in the fabrication processing of BIPV solar cells, such as the amorphous material quality, the amorphous emitter doping, the boron doped a-SiOx: H layer thickness and so on [9].

AMPS-1D solves numerically the three governing semiconductor device equations (the Poisson's equation (see 1), the hole and electron continuity equations (see 2 and 3)[10].

$$\frac{d}{dx}\left(-\varepsilon(x)\frac{d\psi}{dx}\right) = q * [p(x) - n(x) + N_D^+(x) - N_A^-(x) + p_t(x) - n_t(x)] \quad (1)$$

$$\frac{1}{q}\left(\frac{dJp}{dx}\right) = -G_{op}(x) + R(x) \quad (2)$$

$$\frac{1}{q}\left(\frac{dJn}{dx}\right) = -G_{op}(x) + R(x) \quad (3)$$

Where Ψ is the Electrostatic potential , ε is the permittivity, q is the electric charge, ND and NA are the ionized donor-like and acceptor-like dopings, n and p are electron and hole concentration, n_t and p_t are the trapped electrons and holes.

Jn and Jp are the electron and hole current Densities, R(x) is the generation Rate, $G_{op}(x)$ is the optical generation rate.

II.2. Solar cell structure and simulation parameters

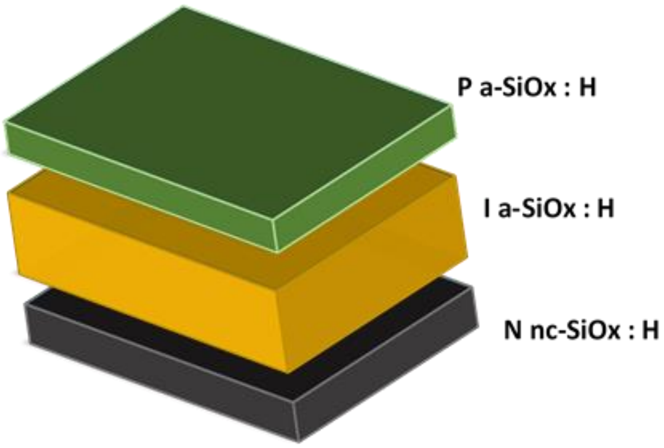

Figure 1. Schematic diagram of the photovoltaic device

In this study, a p-i-n junction structure was employed. The cells were designed in the configuration p-a-SiOx: H/ i-a-SiOx: H/ n-nc-SiOx: H (presented in figure 1).

The i-layer and n-layer inserted into the solar cells themselves were kept the same. On the other hand, we varied the thickness of the p-a-SiOx: H window layer from 05 to 25 nm, while we maintained the other parameters of this layer fixed during calculations.

The layer's physical parameters are summarized in Table 1 This model is a simplification of the real cell and ignores any phenomena related to interface between layers.

Table 1. Material parameters used in AMPS-1D simulator

Layer	p a-SiOx: H	I a-SiOx: H	n nc-SiOx: H
Permittivity EPS (eV)	11.90	11.90	11.90
Electron mobility MUN (cm2/V.s)	5.0000	20.0000	20.0000
Hole mobility MUP (cm2/V.s)	0.5000	4.0000	4.0000
Acceptor doping concentration NA (cm−3)	1.00e+019	0.00e+000	0.00e+000
Donor doping concentration ND (cm−3)	0.00e+000	0.00e+000	1.00e+020
energy band gap EG (eV)	2.02	1.81	2.33
Optical band gap energy EOPT (eV)	1.9	1.79	2.33
Effective DOS in conduction band NC (cm−3)	1.00e+022	2.40e+020	2.00e+020
Effective DOS in valence band NV (cm−3)	1.00e+022	2.30e+020	2.00e+020
Electron affinity CHI (eV)	4.00	4.00	4
BAND TAIL DEFECTS			
Characteristic energy for donorlike/ acceptorlike tails ED/EA (eV)	0.05/0.04	0.06/ 0.05	0.02/0.01
GDO/GAO (cm−3)	1.00e+022	3.00e+022	1.00e+020
TSIG/ND (cm^2)	4.00e-016	1.00e-015	1.00e-015
TSIG/PD (cm^2)	2.00e-017	1.00e-016	1.00e-017
TSIG/NA (cm^2)	2.00e-016	1.00e-016	1.00e-017
TSIG/PA (cm^2)	4.00e-015	1.00e-015	1.00e-015
GAUSSIAN DEFECTS			
Donor gaussian peak energy EDONG (eV)	1.25	1.08	1.15
Acceptor gaussian peak energy EACPG (eV)	1.25	0.98	1.05
Gaussian density for acceptor /donor states NAG/NDG (cm−3)	1.00e+018	2.00e+016	1.00e+018
GSIG/ND (cm^2)	1.00e-014	1.00e-015	1.00e-016
GSIG/PD (cm^2)	1.00e-016	1.00e-016	1.00e-017
GSIG/NA (cm^2)	1.00e-016	1.00e-016	1.00e-017
GSIG/NA (cm^2)	1.00e-014	1.00e-015	1.00e-016

III. Simulation results and discussion

Amorphous silicon alloy single junction solar cells were simulated with varying the thickness of the p-type hydrogenated amorphous silicon oxide p-a-SiOx: H window layer.

Figure 2 illustrates the generated carrier's density in the active layer for different window layer thicknesses of the simulated devices.

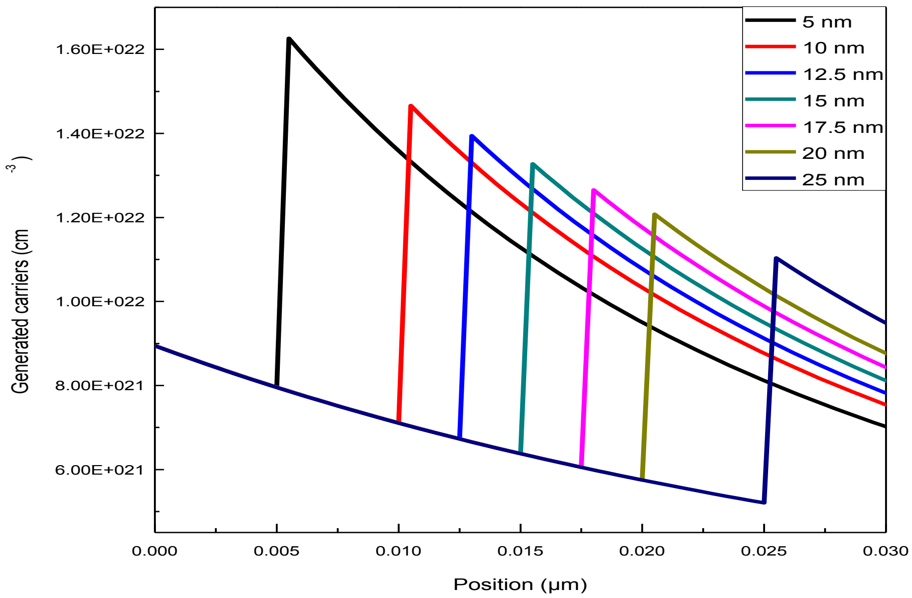

Figure 2. Generation rate versus position for different p-layer thicknesses.

The results presented above are the consequence of the enhancement in light trapping for small thicknesses of the p-layer, which leads to an improvement of the generation rate of electron-hole pairs in the structures.

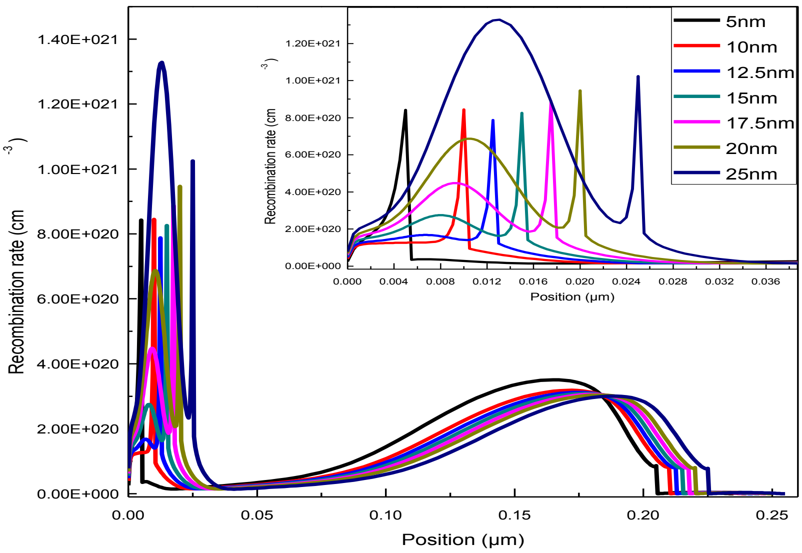

Figure 3. Recombination rate versus position

The recombination rate profiles as a function of the position for different window layer thicknesses are given in figure 3. Figure 3 shows that the recombination rate increases with decreasing the p-layer thickness, which results in a lower Voc (see table 2). To sum things up, increasing the window layer thickness promotes the recombination and leads to a drop in carrier collection.

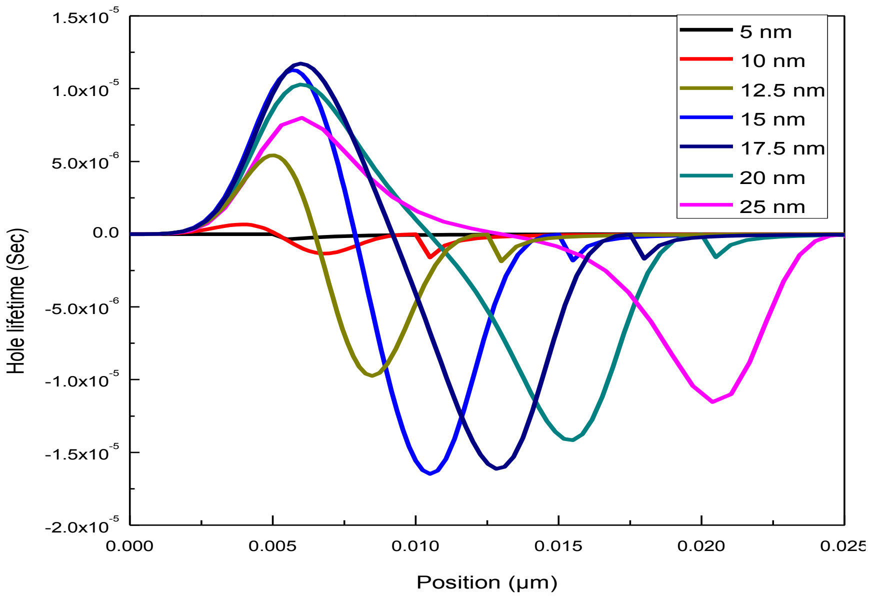

Figure 4. Hole lifetime versus position for different p-layer thicknesses

Figure 5 illustrates the hole lifetime courbes with variable window layer thickness. The hole lifetime τh increases in the interval [5 nm – 17 nm], then it drops rapidly with increasing window layer thickness.

Table 2. Photovoltaic parameters for a-SiOx: H solar cells with variable thickness.

Thickness	Jsc (mA/cm²)	Voc (Volts)	Eff (%)	FF (%)
5 nm	10.877	0.853	5.733	63.1
10 nm	10.687	0.853	5.768	63.3
12.5 nm	10.545	0.853	5.697	63.4
15 nm	10.400	0.852	5.618	63.4
17.5 nm	10.254	0.852	5.537	63.4
20 nm	10.105	0.851	5.452	63.4
25 nm	9.791	0.850	5.271	63.4

The extracted photovoltaic external output, such as Voc, Jsc, FF and power conversion efficiency (Eff), are listed in Table 2 As can be seen from Table 2, it is obvious that with the increase of p+-layer thickness, VOC decreased slightly from 0.853 V to 0.850 V while the fill factor increased slightly from 63.1 % to 63.4 %. The short circuit current density Jsc decreased significantely from 10.877 mA/cm² to 9.791 mA/cm² when increasing the window layer thickness from 05 nm to 25 nm. The power conversion efficiency was found to rise from 5.733 % to 5.768 % with the increase of the thickness. However, beyond 10 nm its value decreased significantly from 5.768 % to 5.271 %.

The light J–V characteristics of the studied devices are represented in figure 6. The short circuit current Jsc shows a continuously decrease when we enlarge the p-layer thickness. Whilst, the open circuit voltage Voc shows a slight decrease.

The modest decrease in the open circuit voltage is mainly due to the increase in the recombination rate of photocarriers.

One can interpret this reduction of the sohrt circuit current density Jsc: with the increase of the parasitic absorption (the light absorbed in this layer does not contribute to current) in the window layer caused by the change of the thickness. Or, with the decrease of the photo-generated current in the active layer caused by the low amount of light passing through it because the p-layer is thick [11].

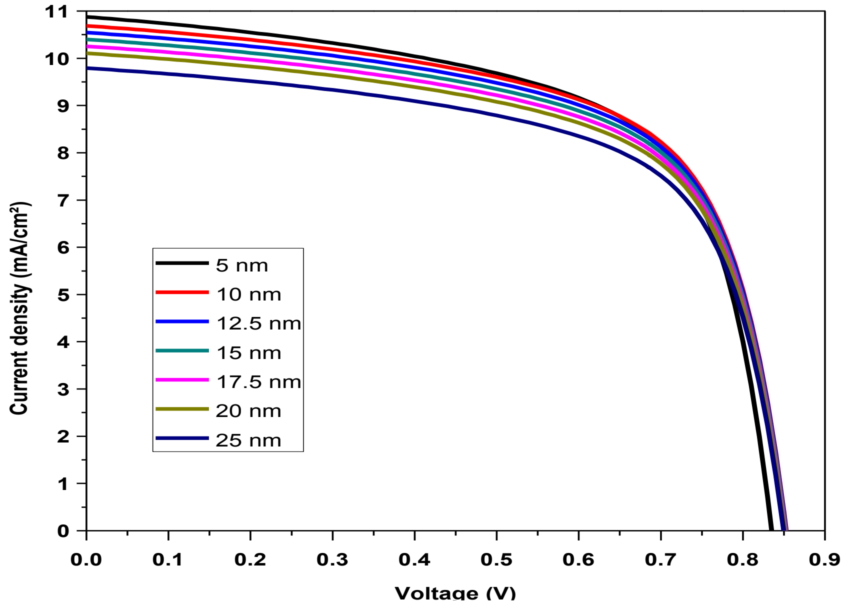

Figure 5. Light J–V characteristics of different devices under AM1.5 illumination

The decrease of Voc is not important while the decrease of Jsc is significant. As a result, this last plays an essential role in the decrease of the power conversion efficiency Eff.

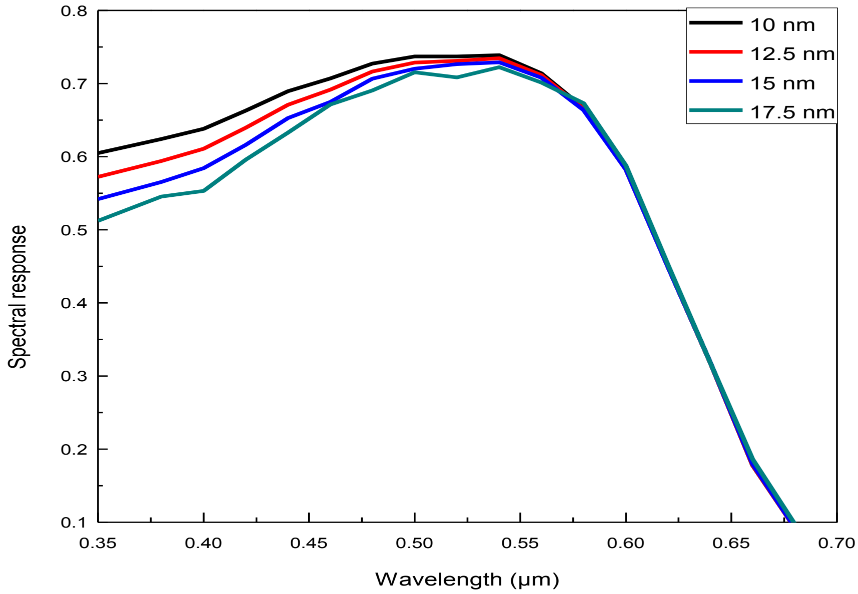

Figure 6. Simulated spectral response spectra in 350–700 nm for amorphous silicon oxide single junction solar cells with different p-layer thicknesses.

Figure 7 shows the soectral response variation when increasing the window layer thickness. Here we notice a decrease of the spectral response at short wavelengths with the decrease of the p-layer thickness.The drop in the spectral response is caused by the increase in carrier recombination in the excessively thick window layer[11].

IV. Conclusion

In this study, the dependence of the wide band gap hydrogenated amorphous silicon oxide based solar cells performances on p-a-SiOx: H window-layer thickness in p-i-n single junction was investigated by using AMPS-1D simulator.

From our calculations, we have found that increasing the p-a-SiOx: H film thickness from 05 to 25 nm led to decreases in both electrical and optical performances. The spectral response exhibits a drop in the absorption in short wavelengths and the power conversion efficiency exhibits a significant decrease. The enlargement of the born doped amorphous silicon oxide p-a-SiOx: H window layer thickness lead to create a thick p-layer that absorbs more light, which is not favorable for the enhancement of the solar cell performance. Moreover, this massive window layer does not allow sufficient photons to pass to the active layer and that worsen the generation of photocurrent. In brief, the thickness of the window layer was studied to be optimised at 10 nm for the sake of reducing the parasitic absorption.

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