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Simulation study of an all p-i-n amorphous silicon oxide solar cell

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ABSTRACT

For thin film solar cells, it has been reported that using hydrogenated amorphous silicon oxide in absorber layer (with low oxygen concentration) could generate more electricity than hydrogenated amorphous silicon layers in short wavelengths due to wide band gap (E_g). This work is concerned about the analysis of all p-i-n amorphous silicon oxide based solar cell by numerical simulation. The calculation was carried out by using Analysis of Microelectronic and Photonic Structures (AMPS-1D) simulator. We optimized hydrogenated amorphous silicon oxide (a-SiO_x: H) as an active layer in the hydrogenated amorphous silicon oxide (a-SiO_x: H) p-i-n single junction solar cell. We have achieved a power conversion efficiency of 5.716 %. Also, a good agreement between our simulated results and experimental results was obtained.

Introduction

Global population will be 8.1 billion. Consequently, total primary energy supply will reach 17208 Mtoe in 2020 according to a report of the World Energy Resources [1]. Unfortunately, energy production often rely on fossil fuels, which include petroleum, coal and natural gas.

They supply more than 80 percent of all the energy consumed by the industrially developed countries. The combustion of fossil fuels is the principal contributor to liberation of greenhouse gases in particular CO_2, to the atmosphere [2]. These gases contribute to the global warming. To suppress this environmental issue one must look for new clean and renewable sources of energy. Because of its prosperity, solar energy becomes the most used renewable energy. Its fortitude is that photo-voltaic conversion can be realized with different materials and device designs. Crystalline silicon (c-Si) solar cell has been known since the outset, as the only long-term sustainable, environment-friendly, inexpensive renewable energy source to replace fossil fuels [3].

Thin film silicon solar cells have been developed widely due to their low cost and temperature fabrication and large-scale deposition [4,5]. Hydrogenated amorphous silicon (a-Si:H) has been used for decades — doped and as intrinsic absorbing layers — in thin-film silicon solar cells. Whereas it continues to interest material scientists and physicists [6,7]. But exposing it to light for long periods, creates about 1017 cm^{-3} of meta-stable defects which degrade the optical properties of this material (Staebler-Wronski effect)[8]. To overcome this effect, Amorphous silicon alloy solar cells are favorable as low cost[9] and good absorbing material for solar cells. Carbon, Nitrogen and Oxygen are commonly used impurities in hydrogenated amorphous silicon [10] due to their wide band gap. Amorphous hydrogenated sub-oxides (a-SiOx: H) deposited by plasma enhanced chemical vapor have a band gap which can be tuned from 1.9 to 3.0 eV [11]. With this wide band gap it becomes a good alternative for the passivating layer due to its suppression of low light absorption [12].

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Device structure and simulation model

We used analysis of microelectronic and photonic structures (AMPS-1D) program to investigate the effect of fabricating all p-i-n hydrogenated silicon-oxygen alloy based solar cell. AMPS-1D solves standard semiconductor equations using finite differences and Newton-Raphson methods [13, 14].

Poisson's equation:

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

where :
Ψ: the electrostatic potential
n and p: the free electrons density and the free holes densities
n_t and p_t: the trapped electrons and holes.
N_D^+ and N_A^- : ionized concentrations of donors and acceptors.
ε : dielectric permittivity of the material .
q : free charge of electron.

and the two carrier continuity equations,
Electrons:

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

J_n represents the electron's current density.
Holes:

$$\frac{1}{q}\left(\frac{dJ_p}{dx}\right) = G_{op}(x) - R(x)$$

J_p represents the hole's current density.
$G_{op}(x)$ describes the creation process of free electron-hole pairs.
R(x) is the recombination rate [15].
The benefit of calculating with AMPS-1D is that it allows going until 30 layers and that it has a good user interface. A schematic structure of the a-SiOx: H solar cell in this work is shown in Fig.1. Wherein the cell is composed of : a front contact /P-a-SiO_x: H / I-a-SiO_x: H / N-nc-SiO_x: H / back contact. Device materials properties used for the simulations are listed in Table I.

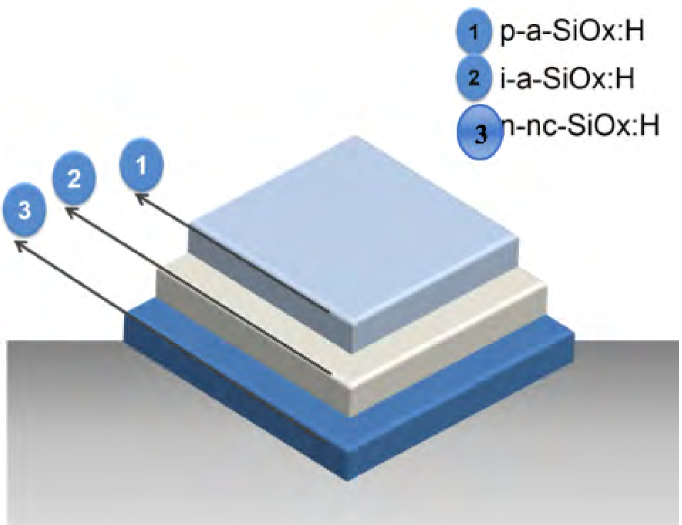

Fig. 1. Schematic structure of a-SiOx: H solar cell.

Results and discussions

The purpose of this simulation study is to identify the impact of fabricating an all p-i-n amorphous silicon oxide solar cell. The p-i-n a-SiOx: H single junction characterized by the parameters given in Table I, was simulated and its solar cell output parameters are given in Table 2.
As can be seen from the table above, our result agreed well with the experimental results.
The band diagram of the calculated amorphous silicon oxide based solar cell, is presented in Fig. 2.

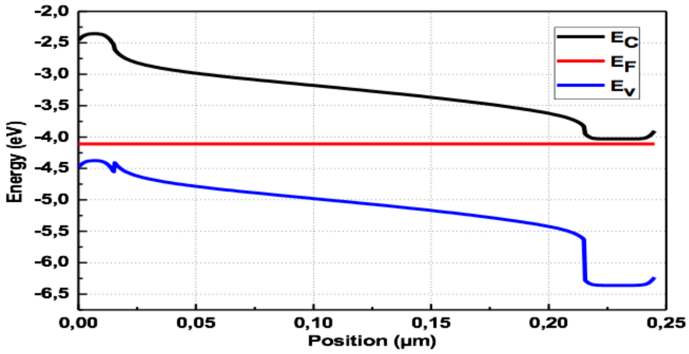

Fig. 2. Energy band diagram of the simulated a-SiOx: H solar cell.

Previous study of [16] evaluating a-SiO_x: H performances in order to realize efficient BIPV (building integrated PV) window system observed that the efficiency of semitransparent solar cells increased at a CO_2/SiH_4 ratio in the intrinsic amorphous silicon oxide layer of 0.2.

The Fig. 3 illustrates a comparison of J-V reverse voltage characteristics under dark condition for the a- SiOx:H solar cells.

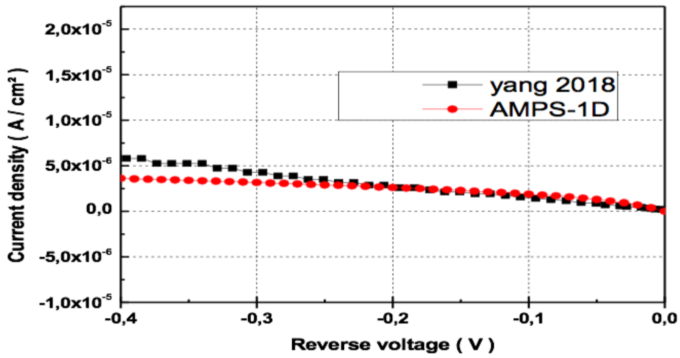

Fig. 3. Illuminated current density versus voltage curves of the a-SiOx: H simulated and fabricated solar cells [16].

Fig. 4 compares the experimental and the simulated current density-voltage characteristics. We have obtained a good fit. The JSC of a-SiOx: H solar cell (10.667 mA/cm²) was higher than the a-Si:H solar cell short circuit current density (9.95 mA/cm²) [16].

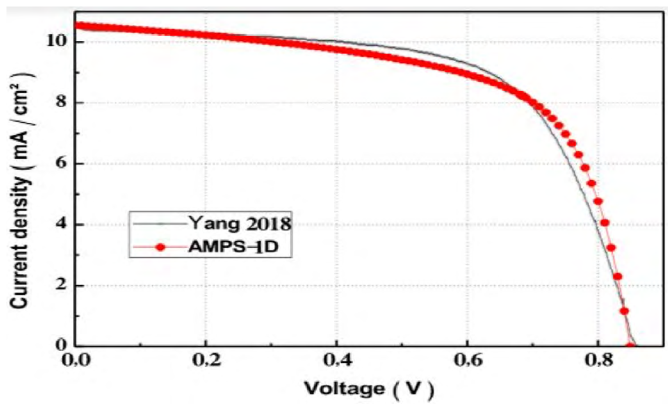

Fig. 4. Illuminated current density versus voltage curves of the a-SiOx: H simulated and fabricated solar cells [16].

Table 1. Physical parameters used to simulate a-SiO_x: H solar cell.

Parameters	p-a-SiO_x:H	i-a-SiO_x:H	n- nc-SiO_x:H
L (nm)	15	200	30
ε_r	11,9	11,9	11,9
χ (eV)	3,76	3.8	3.9
E_g (eV)	2,02	1,80	2,33
Nc (cm^{-3})	10^{22}	2. 10^{20}	2. 10^{20}
Nv (cm^{-3})	10^{23}	2. 10^{20}	2. 10^{20}
N_A (cm^{-3})	10^{19}	0	0
N_D (cm^{-3})	0	0	10^{19}
μ_{e-} ($cm^2V^{-1}s^{-1}$)	5	20	20
μ_{h-} ($cm^2V^{-1}s^{-1}$)	0,5	4	4
G_{DO}/G_{AO} ($cm^{-3}eV^{-1}$)	10^{22}/10^{22}	3.10^{22}/3.10^{22}	10^{14}/10^{14}
E_D/E_A (eV)	0.05/0.03	0.06/0.05	0.01/0.01
N_{DG} (cm^{-3})	10^{18}	2.10^{16}	10^{18}
N_{AG} (cm^{-3})	10^{18}	2.10^{16}	10^{18}
E_{DG} / E_{AG} (eV)	1.25/1.25	1.08/0.98	1.15/1.05
σ_{de} (cm^2)(tails)	4.10^{-16}	10^{-15}	10^{-15}
σ_{dh} (cm^2)(tails)	2.10^{-17}	10^{-16}	10^{-17}
σ_{ae} (cm^2)(tails)	2.10^{-16}	10^{-16}	10^{-17}
σ_{ah} (cm^2)(tails)	4.10^{-15}	10^{-15}	10^{-15}
σ_{de} (cm^2)(gauss)	10^{-14}	10^{-15}	10^{-16}
σ_{dh} (cm^2)(gauss)	10^{-16}	10^{-16}	10^{-17}
σ_{ae} (cm^2)(gauss)	10^{-16}	10^{-16}	10^{-17}
σ_{ah} (cm^2)(gauss)	10^{-14}	10^{-15}	10^{-16}

Table 2. Comparison of calculated and experimentally obtained photovoltaic characteristics of a-SiO_x: H solar cells.

Solar cell	Voc (V)	FF	E_{ff} (%)	Jsc (mA/cm^2)
AMPS-1D	0.850	63.1	5.71	10.667
YANG 2018	0.852	64.4	5.71	10.4

Conclusion

The main purpose of the current study was to analyze the impact of using hydrogenated amorphous silicon oxide as a fabrication material of p-i-n single junction solar cells. A numerical simulation was performed using AMPS-1D program. As a result, we have achieved a short circuit current density of 10.667 mA/cm^2, an open circuit voltage of 0.850 V, an FF of 63.1% and a power conversion efficiency of 5.71%. The results obtained from simulation gave a good agreement with experimental results.

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Conflicts of interest

Authors declare no conflict of interests.

Notes

The authors declare no competing financial interest.

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