COMPARATIVE STUDY OF A PIN HOMOJUNCTION A-Si:H SOLAR CELL

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Hydrogenated amorphous silicon (a-Si:H) has been widely investigated as a viable material for inexpensive and efficient solar cells. The paper presents a numerical simulation of the output parameters of a PIN a-Si:H solar cell under AM1.5 spectrum. These parameters are the short circuit current (J_{sc}), the open circuit voltage (V_{oc}), the fill factor (FF), the conversion efficiency (η) and the spectral response (SR). The simulation was performed with SCAPS-1D software version 3.2 developed at ELIS in Belgium by Marc Burgelman et al. The obtained results are in agreement with experiment. In addition, the effect of the intrinsic layer thickness (I) on the output parameters of the cell is also presented. It was found that a intrinsic layer thickness of 0.3 µm consists the optimum value for the cell efficiency.

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1. Introduction

Hydrogenated amorphous silicon (a-Si:H will be abbreviated as a-Si) thin films are currently used in solar cells and numerous electronic devices. In particular, amorphous silicon (a-Si) has been favored for its better characteristics compared to crystalline silicon and polysilicon, such as higher absorption coefficient, better response in low light environment. Conventional Amorphous-silicon alloys have great promise as low cost solar cell materials. Nevertheless, the Staebler–Wronski effect (S–W effect) of amorphous silicon reduces the conversion efficiency [1].

The application of a-Si:H based solar cells offer four advantages: first, the simple fabrication of a-Si:H (and their alloys) films by the decomposition of silane (SiH4/ using PECVD system; second, the high absorption coefficient α of the a-Si:H material resulting in low material consumption; third, the amorphous material can be deposited on different substrates that can withstand the process temperature of 250–300 °C; fourth, the a-Si:H solar cells can be fabricated in a continuous process as integrated solar modules.

The thickness of the intrinsic layer in a solar cell, play a crucial role in its performances. In order to optimize them, we discuss the influence of thickness in the intrinsic layer on external parameters of PIN a-Si:H solar cell. In this context, we use the software called SCAPS-1D (Solar Cell Capacitance Simulator in one dimension)[2]. SCAPS is a windows application program, made available to university researchers in the photovoltaic community after the second PV World Conference in Wien, 1998[2]. It solves structures with up to seven different layers, plus two contacts [3-5]

The obtained results agreed well with the reported experimental findings [6].

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2. Theoretical model

The basic solar cell performance parameters are the short circuit current density J_{sc}, the open circuit voltage V_{oc}, the fill factor *FF* and the efficiency η. These parameters are briefly discussed below.

2.1. Short circuit current density J_{sc}

The flow of carriers into the external circuit constitutes a reverse electrical current density which under short circuit conditions (V = 0) is known as the short circuit current density J_{sc}. By convention, we take J_{sc} as a positive quantity, and describe the actual current density at short circuit as either $+J_{sc}$ or $-J_{sc}$, depending on the current reference adopted.

2. 2. Open circuit voltage V_{oc}

The separation of charges sets up a forward potential difference between the two contacts of the solar cell, which under open circuit conditions (J = 0) is known as the open circuit voltage V_{oc}.

2.3. Fill Factor FF

The fill factor is a measure of the "squareness" of the *JV* curve under illumination and is defined as the ratio:

$$FF = \frac{J_m V_m}{J_{SC} V_{OC}} \tag{6}$$

where J_m and V_m are respectively the values of current density and voltage at the maximum power condition. Again, J_m is treated as a positive quantity; the actual current at maximum power then is $\pm J_m$ depending on the current *reference.*

2.4. Efficiency η

The efficiency of the cell is the power density delivered at the maximum power point as a fraction of the incident light power density P_{inc}

$$\eta = \frac{J_m V_m}{P_{inc}} = \frac{J_{SC} V_{OC} FF}{P_{inc}} \tag{7}$$

2.5. JV characteristics

The overall current voltage response of the solar cell, its current voltage characteristic, is the sum of the short circuit current and the dark current. The dark current can usually be approximated quite well by a slight adaptation of the ideal Shockley equation. The *JV* characteristic is then described by:

$$J = J_0 \left[\exp\left(\frac{qV}{nkT} \right) - 1 \right] - J_{SC} \tag{8}$$

J_0: is the saturation current density, q the elementary charge, k Boltzmann's constant and T the absolute temperature. Thus, the expected current density at reverse bias in the dark is $-J_0$. In Eq. (4), n is called the diode quality factor, or the diode ideality factor. J = 0 yields

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{J_{SC}}{J_0} + 1 \right) \tag{9}$$

In real cells, the *J-V* curve deviates from the ideal Eq. (4) by parasitic effects, which can be described by two resistances, one in series (R_s) and onein parallel (R_{sh}) with the cell. Series resistance is due to the resistance of the cell material to current flow, especially through the front surface to the contacts. The parallel resistance can be due to a leakage current trough the cell (e.g. around the edges of the device).

Thus when parasitic resistances are included the diode equation (4) becomes:

$$J = J_0\left[\exp\left(\frac{q(V - JR_S A)}{nkT}\right)\right] + \frac{(V - JR_S A)}{R_{sh}A} - J_{SC} \quad (10)$$

3. Simulation results and discussion

The four quantities *Jsc, Voc, FF* and η are the key performance characteristics of a solar cell. All of them should be defined for particular illumination conditions. The standard test conditions (STC) or standard reporting conditions (SRC) for solar cells are the Air Mass 1.5 Global spectrum ('AM1.5G'), an incident power density of 1000 W/m^2 and a cell or module temperature of 300°K.

3.1. Solar cell structure details

Fig. 1 shows the structure of the cell used in the simulation. The structure is composed of a glass window, a transparent conductor oxide (TCO) anode, a P-I-N junction and a Al cathode. The input set used in our simulation is reported in Table 1.

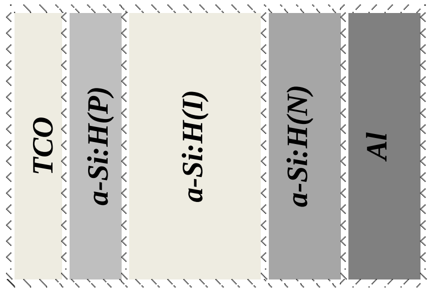

Fig. 1. a-Si:H solar cell.

Table 1. Parameters used to simulate the a-Si:H solar cell.

Parameter	**p-layer**	**i-layer**	n-layer
Layer thickness (nm)	9	500	**20**
Relative permittivity	7.2	11.9	**11.9**
Electron affinity (eV)	3.90	4.00	**3.99**
Mobility gap (eV)	1.95	1.78	**1.80**
Electron mobility (10^{-4} m^2/Vs)	20	20	**20**
Hole mobility (10^{-4} m^2/Vs)	5	5	**5**
Effective DOS in CB (m^{-3})	1x10^{26}	1x10^{26}	**1x10^{26}**
Effective DOS in VB (m^{-3})	1x10^{26}	1x10^{26}	**1x10^{26}**

3. 2. Comparison between simulation and experimental

A comparison between the experimental [6], modeling [7] and the simulated *JV* characteristic of the solar cell is presented in Fig. 2 under AM1.5 spectrum. It can be concluded that there is an acceptable agreement between experimental values and the simulated one.

Table 2. Experimental and simulated values of pin hydrogenated amorphous silicon solar cell performance at T=300K

Parameters	Experimental [6]	Simulation
V_{co} (volt)	0.82	0.965
J_{ph} (mA/cm^2)	18.3	17.36
FF (%)	0.683	0.691
η (%)	10.3	11.59

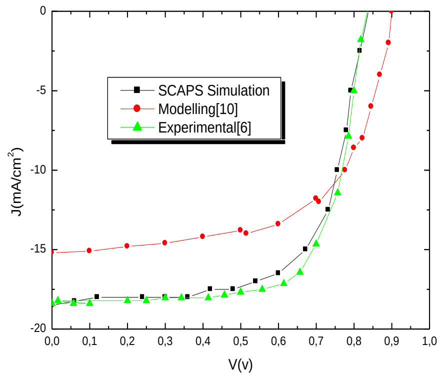

Fig. 2. Experimental [6], modeling [10] and simulated J-V characteristic of the a-Si:H solar cell.

3. 3. The intrinsic layer thickness effect

In this paper we use intrinsic gap layer on the middle of the a-Si:H cell and we study the effect of its thickness on the output parameters of the cell exposed to 1000 W/m^2. The external cell parameters are: the short circuit current (J_{sc}), the open circuit voltage (V_{oc}), the fill factor (FF) and the conversion efficiency (η).

The obtained results are summarized in Figure. 3. It was found that V_{oc} and FF show a decrease while J_{sc} increases when the i-layer thickness increases from 0.05µm to 0.4µm. The conversion efficiency η of the cell presents an optimum value for the i-layer thickness of 0.3µm.

The decrease of V_{oc} with the increase of the i-layer thickness can be explained by the relationship between the electric field, and hence the voltage, with the i-layer thickness [10]. However for J_{sc} the i-layer is the active region of the absorption and the photogeneration. Then, increasing the i-layer means that more photons are absorbed and more free carriers are generated which lead to an enhancement in the photocurrent [11].

FF is the percentage of the collected pairs compared to created one. Since the a-Si: H has many defect states, many pairs are trapped and fewer are collected. Therefore when the i-layer thickness increases, the generation-recombination balance causes a general decrease of FF. On the other hand, the series resistance increases with the thickness of the i-layer which reduces the fill factor [11].

Finally and as result of the contribution of all previous parameters, the conversion efficiency η of the cell presents an optimum value of 12% for the i-layer thickness of 0.3µm . The a-Si:H intrinsic layers contains a smaller density of states in the gap than the doped layers, allowing the transport of carriers charge over distances of several hundred nanometers against a few nanometers doped layers. However, we needed to create a space charge region in the structure, but their thickness is reduced to a minimum in order to not deteriorate the collection of carriers.

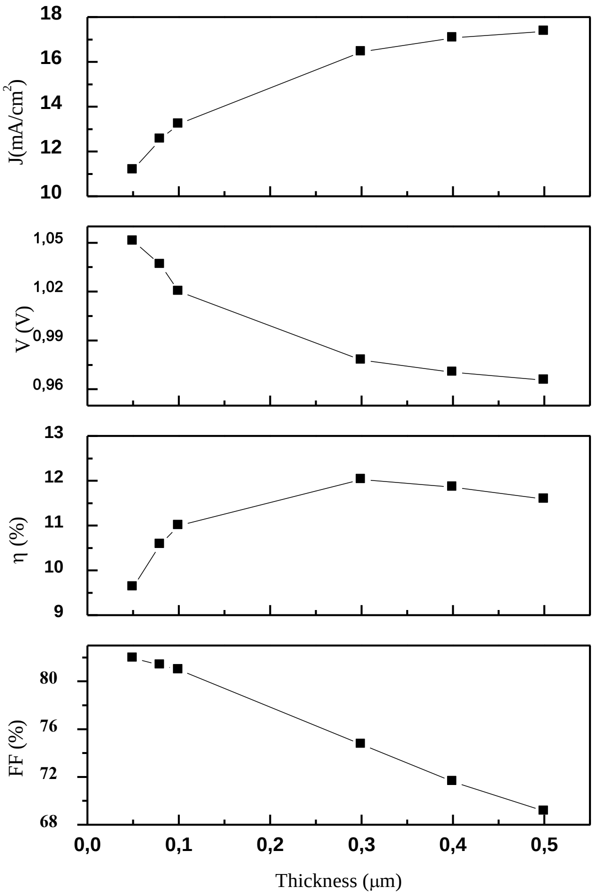

Fig. 3. Simulated photovoltaic parameters of the a-Si:H solar cell as a function of the i- layer thickness, (a) Open circuit voltage, (b) short circuit current density, (c) Fill factor, (d) Efficiency.

4. Conclusions

Hydrogenated amorphous silicon (a-Si : H)-based solar cells and modules are considered potential candidates for economically viable large-scale photovoltaic applications.

We have presented a simulation study of hydrogenated amorphous silicon PIN solar cells.

The J-V characteristic is simulated under AM1.5 spectrum using a new version of the numerical solar cell simulator SCAPS and compared with experiments. An acceptable agreement is obtained.

The effect of the i-layer thickness on Jsc, Voc, FF and the cell efficiency η is presented. J_{sc} increases while V_{oc}, FF decreases with a layer thickness ranging from 0.05 to 0.4µm.

The efficiency has a maximum value of 12 %, corresponding to a intrinsic layer thickness of 300 nm.

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References

[1] D. L. Staebler, C. R. Wronski, Appl. Phys. Lett. **31**, 292 (1977), J. Appl. Phys. **51**,

3262 (1980), doi: 10.1063/1.89674.
[2] A. Niemergeers, S. Gillis, M. Burgelman, in Proceedings of the Second World Conference on Photovoltaic Energy Conversion (Wien, Osterreich, 1998), p. 1071, doi:.
[3] M. Burgelman, P. Nollet, S. Degrave, Thin Solid Films **361**, 527 (2000), doi: 10.1016/S0040-6090(99)00825-1
[4] M. Burgelman, P. Nollet, S. Degrave, Applied Physics A **69**, 149 (1999), doi: 10.1007/s003399900063
[5] K. Decock, M. Burgelman, SCAPS Version 2.9.02, June 2010,doi: 10.1016/j.egypro.2010.07.009.
[6] R. E. I. Schropp, M. Zeman, Amorphous and Microcrystalline Silicon Solar Cells: Modeling, Materials, and Device Technology, Kluwer Academic Publishers, Boston, MA, USA, 1998, doi:10.13140/RG.2.1.1429.0001
[7] M. Orgeret, Les Piles Solaires, Edition Masson, 185, 1985.
[8] S. M. Sze, Physics of Semiconductor Devices, John Wiley & Sons, 1981.
[9] A . Ricaud, Photopiles solaires, première édition, Lausane, Suisse, 1997.
[10] www.crosslight.com, Simulation of silicon based thin-film solar, 1995-2008.
[11] A. Fantoni, M. Vieira, R. Martins, Simulation of hydrogenated amorphous and microcrystalline silicon optoelectronic devices,1999, doi10.1016/S0378-4754(99)00055-5