Development of graded band gap intrinsic layers for Single-junction a-Si:H solar cell

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***Abstract*— the influence of the absorber layer (i-layer) properties on the amorphous solar cells parameters has been an object of research since the 1980s. In this study, a numerical simulation was carried out to study the influence of the intrinsic layer by using a novel technique based on graded band gap for amorphous single junction solar cells. In this context, we use the software called AMPS-1D. The optimized properties of the different layers of a-Si:H solar cell, especially intrinsic layer, were suggested to obtain the maximum conversion efficiency. Indeed, the use of intrinsic multilayer can control the spectral overlap by employing band-gap grading which the potential initial conversion efficiency of single-junction solar cell reach to 11.52%.**

Keywords— Hydrogenated amorphous silicon, Absorber layer, graded band gap, Solar cells.

I. Introduction

The main objectives of the photovoltaic industries are to minimize costs and to increase the cell efficiency. One of the promising optoelectronic materials for applications in solar cells is hydrogenated amorphous silicon a-Si:H. so, a-Si:H has a high optical absorption coefficient (>105cm-1), a tunable band-gap (from 1.6 to 1.8 eV) and low temperature of deposition [1-2].

In order to create high-performance solar cells, it is important to be able to control and limit the diffusion of atoms in the intermediate i-layer in the solar cell production process. Some of the strategies to increase the use of the light in the intrinsic layer are to reduce the optic losses in the non active regions of the cell and increasing the light confinement [3].

Several simulations and experimental results have been approved the interrelation between the performances of a-Si:H solar cell (including charge carrier transport, recombination losses, and electric field distributions) and the properties of absorber layer [2-4]. Therefore, the intrinsic layer turns out to play a crucial role for solar cell optimization. Indeed, very small changes of the intrinsic layer design significantly affect initial solar cell performance and the stability upon light exposure. Intrinsic wide-band-gap layer improves the open-circuit voltage. However, these layers often provoke additional degradation due to a redistribution of the electric field. On the other hand, the using a-Si:H alloys (a-SiC:H, a-SiO:H, a-SiGe:H.....etc) for i-layer provide a good solution to enhance hydrogenated amorphous silicon i-layer properties..

II. Design and Simulation

One-dimensional AMPS numerical simulation of pin graded band gap a-Si:H thin-film solar cells is used in this work. It is a powerful tool to build a reasonable physical model to test the viability and numerical simulations that can help to predict any changes in cell performance resulting from the modified reasonable parameters.

The structure as designed is shown in figure 1. 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.

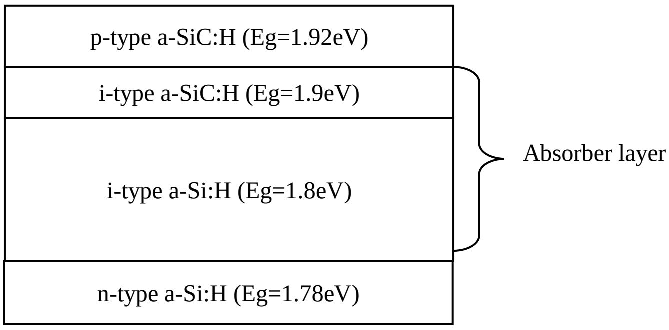

Fig. 1. Schematic view of a-Si:H single-junction solar cell.

TABLE I. PARAMETERS USED IN THE SIMULATION.

Parameters	**Structures layer**			
	p-aSiC:H	**i-aSiC:H**	**i-aSi:H**	**n-aSi:H**
Thickness [nm]	10	varied	570	12
Mobility gap [eV]	1.92	1.90	1.72	1.78
Electron mobility [cm2/Vs]	20	20	20	20
Hole mobility [cm2/Vs]	2	2	2	2
Effective DOS in CB [/cm3]	$2x10^{20}$	$1x10^{20}$	$1x10^{20}$	$1x10^{20}$
Effective DOS in VB [/cm3]	$2x10^{20}$	$1x10^{20}$	$1x10^{20}$	$1x10^{20}$

The basic solar cell performance parameters are the short circuit current density *Jsc*, the open circuit voltage *Voc* , the fill factor *FF* and the efficiency η. These parameters are briefly discussed below.

A. Short circuit current density Jsc

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 *Jsc*. By convention, we take *Jsc* as a positive quantity, and describe the actual current density at short circuit as either *+Jsc* or *-Jsc*, depending on the current reference adopted.

B. Open circuit voltage Voc

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 *Voc*.

C. Fill Factor FF

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

$$FF = \frac{J_m V_m}{J_{SC} V_{OC}} \qquad (1)$$

where *Jm* and *Vm* are respectively the values of current density and voltage at the maximum power condition. Again, *Jm* is treated as a positive quantity; the actual current at maximum power then is ± *Jm* depending on the current *reference.*

D. 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}

$$\eta = \frac{J_m V_m}{P_{inc}} = \frac{J_{SC} V_{OC} FF}{P_{inc}} \qquad (02)$$

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/m2 and a cell or module temperature of 300°K.

E. J-V 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 *J-V* characteristic is then described by:

$$J = J_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] - J_{SC} \qquad (3)$$

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

$$V_{OC} = \frac{nkT}{q}\ln\left(\frac{J_{SC}}{J_0} + 1\right) \qquad (4)$$

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 one in 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:

$$J = J_0\left[\exp\left(\frac{q(V - JR_S A)}{nkT}\right)\right] + \frac{(V - JR_S A)}{R_{sh} A} - J_{SC} \qquad (5)$$

The single junction p-i-n a-Si:H solar cell performances depends on the following factors:

- Number of photons with energies higher than the band gap;
- Absorption coefficients;
- Properties of the layers, particularly the absorber i-layers.

Generally, the single junction a-Si:H cell uses p-type layers of a-SiC:H semiconductor deposited on n-type a-Si:H semiconductor, which is an intermediate intrinsic layer between p- and n-type layers. To improve the efficiency of this solar cell, the main attention should be paid mainly to obtaining a high short-circuit current Jsc by developing light traps as well as a higher open-circuit voltage Voc [6]. There are several ways to increase the performances of solar cells which the use of different alloys of a-Si in absorber layer, each of which uses a certain part of the spectrum of solar radiation for the production of electric current.

In a-Si:H p-i-n solar cell, the intrinsic layer can play a key role in improvement solar cell performances. The most important task in optimizing the i-layer is to understand the relation of its properties and deposition conditions, and the controllable range of the properties as a whole. The number of absorbed photons can be controlled by adjusting the gap width of each layer, the absorption coefficient of the material also depends on the characteristics of the material constituting each layer. Consequently, the current of each layer can be controlled by varying the layer thickness. For example, if the number of photons entered in each layer is the same, the layers with low coefficient of absorption must be thicker than the other, to absorb the same number of photons as the other layers, as well as produce the same number of electron-hole pairs. The optical and electrical properties of the a-Si:H intrinsic layer are of prime importance in the performance of a-Si solar cells. Recent studies have shown the following important facts concerning the relation between the absorber layer properties and solar cell performance and their improvements [7].

Another way to increase the efficiency of solar cells is the use of such layers, each of which uses a certain part of the spectrum of solar radiation for the production of electric current [10-12]. The strategies to increase the use of the light in the intrinsic layer are to reduce the optic losses in the non active regions of the cell and increasing the light confinement by redesign the intrinsic layer structure in using a-Si:H alloys like a-SiC:H and a-SiGe:H or µc-Si:H to have an intrinsic tandem, multi- or hetero-layer [11].

III. RESULT AND DISCUSSION

This paper attempts to show a solar cell simulation that is based on graded band-gap (intrinsic multilayer) in single junction. Modelling and analysis has been shown numerically that absorber multi-layer structure can enhance the efficiency of solar cell at the same thickness of single intrinsic layer. The optimization of the characteristics of intrinsic layer can improve significantly the solar cell parameters Voc, Jsc , FF, and efficiency.

In order to evaluate the effect of i-layer thickness on the solar cell performances, short-circuit current density (Jsc), open-circuit voltage (Voc), fill factor (FF) and conversion efficiency (η) are simulated as a function of i-layer thickness, seen fig 2.

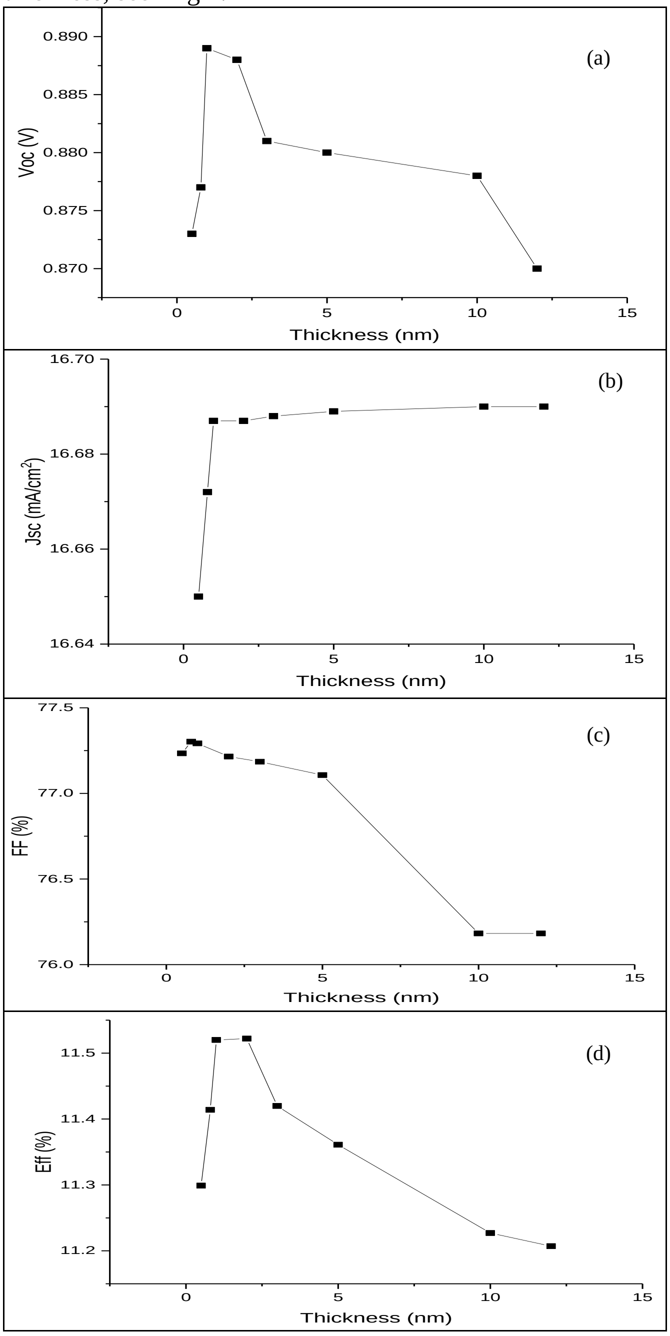

Fig. 2. Photovoltaic parameters of a-Si:H solar cell as a function of a-SiC:H i-layer thickness, (a) Open circuit voltage, (b) short circuit current density, (c) Fill factor, (d) Efficiency.

The fill factor FF and open circuit voltatge Voc of the solar cell under AM1.5 illumination represented on fig.2 (a) initially increase until achieving its maximum value in the range 1-3nm and then slightly decreases with the increasing of the a-SiC:H i-layer thickness. However, the short circuit current density (Jsc) increase as a function of a-SiC:H i-layer thickness to reach 16.69mA/cm^2 f or thickness from 2 to 10nm. As a result, the highest efficiency (Eff) can be achieved in the range 1-3nm of buffer layer thickness. On the other hand, a significant drop in efficiency in the range 3-10nm is due to the decline in V_{OC} and rapid deterioration of the FF when the thickness is over 5nm.

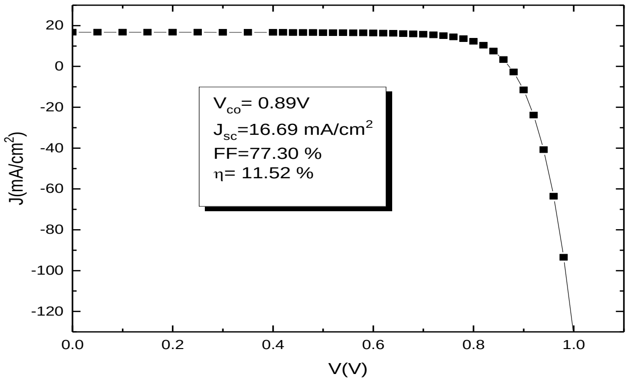

Fig. 3. *Simulated current-voltage characteristics of the (p) a-SiC:H/(i)a-SiC:H/(i)a-Si:H/(n)a-Si:H structures.*

In this paper, we verified that the best characteristics of p-i-n solar cells are when the value of the open-circuit voltage (Voc), short-circuit current density (Jsc), fill factor (FF), and efficiency (η) are 0.89 V, 16.69 mA/cm2, and 77.3%, respectively for grading band-gap a-SiC:H/a-Si:H/a-Si:H of 1.92eV, 1.9eV 1.8eV and 1.78eV, respectively. Thus, the graded bandgap was significantly performed compared with other studies of simple solar cell [2-4. After a numerical analysis of a single-junction a-Si:H solar cells and its optimizing, the best efficiency achieved is 11.52% that is the highest efficiency in comparison to a maximum value of the similar solar cell efficiency [11-12],.

IV. CONCLUSIONS

The optimized p-a-SiC:H/i-a-SiC:H-buffer/i-a-Si:H/n-a-Si:H single-junction solar cell has been designed numerically to investigate the design validation for higher efficiency. The simulation results demonstrate the effect of i-a-SiC:H layer into the absorber layer due to the variation of thickness thus the best efficiency achieved is 11.52% for grading bandgap a-Si:H solar cell. These results indicate that a-SiC:H intrinsic layer is a promising candidate for use as a top cell in tandem and multi junction solar cells.

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