International Journal of Chemical and Biochemical Sciences
(ISSN 2226-9614)
Journal Home page: www.iscientific.org/Journal.html

Improvement of the performance of amorphous silicon solar cells: solar radiation effect

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Abstract

Renewable energy sources such as solar energy have received great attention and could substitute coal, diesel, and gas. Solar energy is called clean energy, was an example of renewable energy. Solar cells could convert sunlight into electrical energy. Amorphous silicon-based solar cells showed excellent absorption capacity, and the absorption frequency was found in the range of 1.1 eV to 1.7 eV. The advantages of these types of solar cells included highly flexible, resistant to shaking, low production cost and available in various shapes (hexagonal, square, and round). Generally, researchers have pointed out that the intensity of solar radiation affected the solar cell performance. In this work, an improvement of the solar cells was carried out through the antireflection layer and studied using 1-D SCAPS software. The obtained experimental results confirmed that the highest power conversion efficiency was 11.69% (with an antireflection layer of ZnO).

Keywords: Photovoltaic, renewable energy, amorphous silicon, energy efficiency, 1-D SCAPS software, clean energy.

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1. Introduction

Renewable energy sources such as solar energy could be used to replace coal, diesel, and gas due to higher production costs [1] and pollution problems [2]. Photovoltaic technologies (such as solar cell and solar panels) could convert sunlight to electrical energy [3] without emission of greenhouse gases [4]. The first step in the conversion of light into electric current is the generation within the semiconductor of the charge carriers which are the free electrons and the holes [5]. Electron-hole pairs must be separated to reach solar energy conversion purposes [6]. Researchers have described that several factors affected the performance of the solar cell such as deposition method [7], fabrication technology, material properties and specific design (p-n junction solar cells). The negative (n-type) and positive type (p type) materials have been created, and the polarity was prepared using boron and phosphorus. In the p-i-n junction silicon solar cells [8], thicker intrinsic layer could be found between the n-layer and p-layer. Because of amorphous silicon indicates a narrower depletion region area if compared to crystalline silicon. Photon will go through window layer (p-layer), absorbed in the intrinsic later, and finally excess photon reached n-layer. Solar modules produce electricity via the electron-hole generation process.

Amorphous silicon solar cells have received great attention [9] due to excellent absorption coefficient (more than 10^5 cm^{-1}), appropriate band gap value (1.7 eV) and low temperature deposition capability. There are several deposition methods [10-12] that have been used to produce absorber materials such as plasma-enhanced chemical vapor deposition (PECVD) method, sputtering process, photo-enhanced chemical vapor deposition technique and hot-wire chemical vapor deposition method. The PECVD method is the most important deposition method to synthesize absorber materials. Short circuit current could be improved through the light trapping scheme. While open circuit voltage could be enhanced via new device design techniques [13]. The electron was promoted to conduction band under illumination process. However, electrons were unable to move from valence band to higher state if did not adsorb sufficient energy. In this moment, solar cells cannot produce electricity (energy less than band gap), incident solar energy will be lost [14].

In this work, the influence of solar radiation on solar cell (amorphous silicon) performance was studied. In addition, the characteristics of the obtained solar cells were studied using different equations (Table 1).

Table 1: Characteristics of the prepared solar cells

Conditions/ parameters	Formula	Explanation
Current of the darkness	I= Is (exp(qv/KT)-1)	Is= saturation current
Current of illumination	I= Is (exp(qv/KT)-1)- Iph	Iph= photocurrent
Open circuit voltage	$V_{co} = \frac{kT}{q} ln\left(1 + \frac{I_{ph}}{I_S}\right)$	I_{ph}=photocurrent $\frac{kT}{q}$: represents thermodynamic potential. Q: electron charge (1.602 X 10^{-19} coulomb). K: Boltzmann constant (1.38 x10^{-23} J/K) I_{ph}: The photon current I_s: Saturation current. T: Absolute temperature (in kelvin).
Maximum power (Pm)	$\boldsymbol{Pm} = \boldsymbol{Vm} * \boldsymbol{Im}$ $\boldsymbol{Pm}= \boldsymbol{FF} \times \boldsymbol{Icc} \times \boldsymbol{Vc}$o	V_m=Maximum voltage I_m=Maximum current I_{cc}: short-circuit current. Voc: An open circuit voltage
Fill factor (FF)	$FF = \frac{P_m}{I_{cc}\times V_{co}} = \frac{I_m\times V_m}{I_{cc}\times V_{co}}$	
Yield (η)	$\eta = \frac{FF\times I_{cc}\times V_{co}}{P_{inc}\,S}$	$\boldsymbol{P_{inc}}$: Incident power S: surface (photovoltaic cells)

The characteristics I(v) in the dark pass through the origin and the formula for current flowing through the dark is given [15]. When the junction is excited by radiation, the characteristics do not pass at the origin because the photocurrent (Iph) must be considered according to the relationship [16]. When a short circuit occurs, the generated current reaches its maximum level (ICC), while in the case of an open circuit, the voltage (VCO=open circuit voltage) reaches its maximum. In both situations [17], no electrical energy is produced in the cell. However, when the voltage increases under all other conditions, the produced energy also increases. It first reaches the maximum power point (Pm) before dropping suddenly and approaching the open circuit voltage value [18].

The open circuit voltage of a cell is reached when there is no current passing through it. This voltage is influenced by the energy barrier and decreases as the temperature increases [19]. However, changes in light intensity have minimal impact on the open circuit voltage. The current obtained by short-circuiting the terminals of the cell is known as short circuit current [20]. This current shows a linear increase with the intensity of illumination of the cell and is influenced by several factors such as the surface area of the cell that is illuminated, the wavelength of radiation, the mobility of carriers, and the temperature [21]. The maximum power (Pm) of an illuminated photovoltaic cell is the essential parameter for evaluating its performance [22]. The values of voltage (Vm) and current (Im) at this point are also referred to as the maximum voltage and maximum current, respectively. Fill factor (FF) is an important parameter to define the quality of a cell [23]. This parameter (between 0 and 1) is expressed in % and qualifies the rectangular shape of the I-V characteristic of the solar cell. The yield (η**)** is described as ratio between maximum power produced by solar cells and power of solar radiation arriving on the solar cell [24]. The performance of prepared solar cells was represented by this value [25, 26].

2. Experimental

The influence of solar radiation on the performance of solar cells could be studied using several simulation software such as: AMPS, wxAMPS, PC1D, AFORS-HET, ASA, SILVACO, and SCAPS. In this work we will use SCAPS1D software which allows simulating any photovoltaic structure for the purpose of expressing the effect of light on solar cells. Also, simulation of the solar cells has been conducted in different conditions such as without anti-reflective layers, with the addition of ZnO and ITO layers. The information for each layer is summarized in the following table (Table 2):

Table 2: Simulation parameters of amorphous silicon solar cells.

Paramètres	Layer P	Layer I	Layer N	ITO	i-ZnO
Thickness (µm)	9	0.5	0.02	0.3	0.08
Band gap (ev)	1.8	1.8	1.8	3.65	3.4
Electronic affinity (ev)	3.9	3.9	3.9	4.8	4.55
Dielectric permittivity	11.9	11.9	11.9	8.9	10
State density	10^{20}	10^{20}	10^{20}	5.2 10^{18}	4 10^{18}
Effective state density of BC (cm^{-3})	10^{20}	10^{20}	10^{20}	5.2 10^{18}	9 10^{18}
Effective state density of BV (cm^{-3})	10^{20}	10^{20}	10^{20}	5.2 10^{18}	9 10^{18}
thermal velocity of electrons (cm /s)	10^{6}	10^{6}	10^{6}	2 10^{7}	10^{7}
Hole thermal velocity (cm/s)	10^{6}	10^{6}	10^{6}	10^{7}	10^{7}
Electronic mobility (cm^2/vs)	20	20	20	10	50
Hole mobility (cm^2/vs)	5	5	5	10	20
Donor density (cm^{-3})	10^{6}	10^{6}	10^{17}	10^{20}	5 10^{17}
Acceptor density Na (cm^{-3})	10^{17}	10^{5}	10^{5}	0	0

3. Results and discussions

Influence of wavelength on the I-V characteristic of solar cells has been highlighted (Figure 1). We note that there is a progressive decrease until it reaches the maximum power point, which varies according to the wavelength of the structure PIN without the antireflection layer, with the ZnO layer, or with the antireflection layer of ITO. Also, a rapid decrease in current could be observed after the maximum power point (as a function of voltage). In addition, it was noticed that a higher current value (wavelengths $\lambda = 400$ nm to $\lambda = 600$ nm) could be found in these samples.

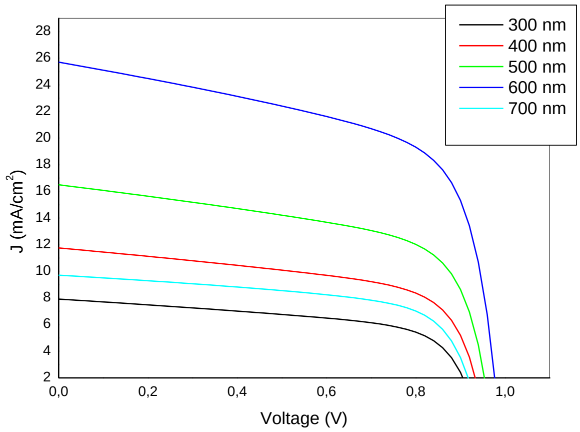

Figure 1(a): Influence of wavelength on the I-V characteristic of a cell without antireflection

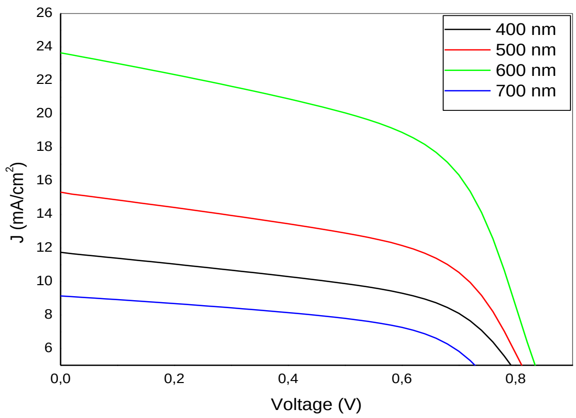

Figure 1(b): Influence of wavelength on the I-V characteristic of a cell with antireflection coating with ITO.

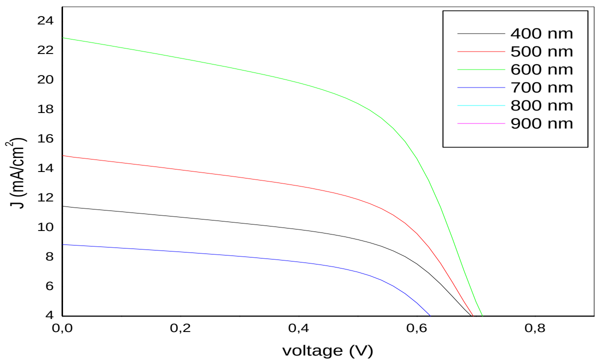

Figure 1(c): Influence of wavelength on the I-V characteristic of a cell with antireflection coating with ZnO.

The study of the effect of the wavelength on short circuit current (ICC) has been described (figure 2). It was noticed that the ICC character increases (wavelengths λ=400 nm to 600 nm), until reached maximum value (λ=600 nm). Then, a decrease in the short circuit current (ICC) could be seen (up to 800 nm), eventually, the ICC current is almost zero (800 nm to 900 nm).

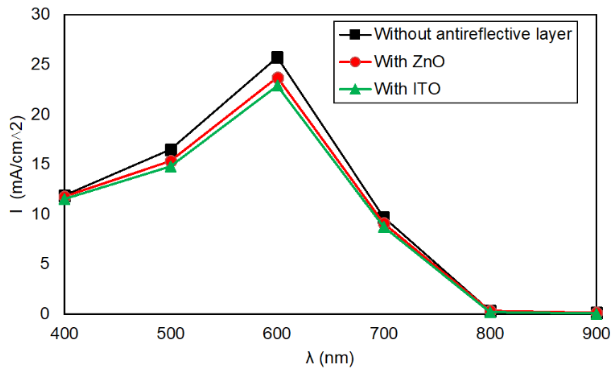

Figure 2: Variation of short-circuit current (ICC) as a function of wavelengths.

The influence of the wavelength on the open circuit (VOC) has been reported. Obviously, it was observed that the VOC character (figure 3) almost the same for the case without antireflection layer and the case of adding a layer of ZnO (λ=700 nm to 900 nm), but for layer of ITO, the VOC character will be superior compared to the other two previous cases.

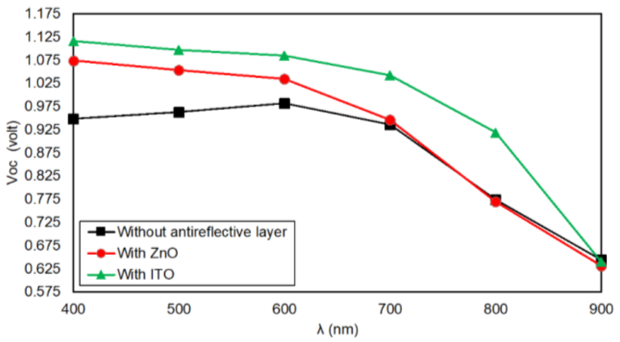

Figure 3: Variation of open circuit voltage (VOC) as a function of wavelength.

The influence of anti-reflective coating on the performance of solar cells has been discussed. Generally, an increase in the yield (400 nm to 600 nm) could be seen until reaching a maximum value (600 nm) in these samples. Experimental results highlighted that the highest yield value (15.4847%) was obtained in the solar cell without antireflection layer (figure 4). Also, solar cells with an antireflection layer of ZnO have a maximum efficiency value (11.6909%) if compared to antireflection layer of ITO (9.4223%). Then, we observe a gradual decrease in the yield (600 nm to 750 nm), and lastly it stops (800 nm – 900 nm).

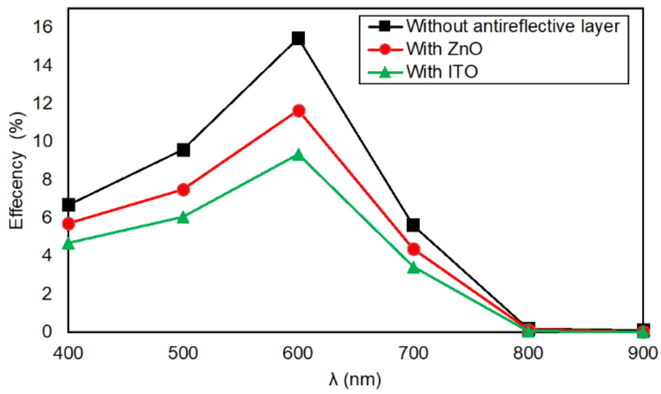

Figure 4: Influence of anti-reflective coating on the performance of solar cells.

4. Conclusions

In this work, the performance of the amorphous silicon solar cells has been studied using one-dimensional solar simulator SCAPS-1D. The obtained results confirmed that intensity of solar radiation affected the performance of cells. The Staebler-Wronski effect, caused by the creation of defects in the amorphous silicon film because of exposure to solar radiation, reduces the efficiency of solar cells. The use of multijunction solar cells and thin film based solar cells can overcome these issues. Researchers have concluded that the highest power conversion efficiency reached 11.69% using antireflection layer of ZnO in the solar cells.

Acknowledgements:

One of the authors (HO SM) would like to thank you to INTI International University, Malaysia for the financial support.

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