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Study the Effect of Doping and Thickness on I-V characteristic of Silicon Solar Cells Using PC1D Simulation

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ABSTRACT

Energy from renewable sources has developed significantly in the past few decades. Photovoltaics have played a crucial role in the technology employed to generate this type of energy. Technicians and researchers can benefit from systems that offer knowledge and data on the efficiency and performance of solar cells. In this work the I-V characteristic of photovoltaic of silicon was measured, and the influence of different n-type thicknesses was examined with their different doping concentration; this has been done by PC1D simulation, It would be appropriate for developing silicon single-layer without cost. The n-layer thickness and n-region doping are the factors responsible for a solar cell's efficiency and performance. In this context silicon is the ideal candidate due to the swift increase in their efficiency, and its dependability and stability. In the end, to draw a conclusion around the ideal parameters that a good solar cell has to have, the optimum external quantum efficiencies obtained from this design were (87.71 %) for mono layer front surfaces. The results from these simulation studies prove that it is possible to propose these design parameters for mono layer solar cell fabrication. By adjusting the effectively mentioned parameters, a great efficient and I-V characteristic solar cell has been achieved.

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دراسة تأثير التطعيم والسمك على خاصية I-V للخلايا الشمسية السيليكونية باستخدام محاكاة PC1D

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الملخص

تطورت الطاقة من المصادر المتجددة بشكل كبير في العقود القليلة الماضية. لعبت الخلايا الكهروضوئية دوراً مهماً في التكنولوجيا المستخدمة لتوليد هذا النوع من الطاقة. يمكن للفنيين والباحثين الاستفادة من الأنظمة التي تقدم المعرفة والبيانات حول كفاءة وأداء الخلايا الشمسية. في هذا العمل تم قياس خاصية I-V للخلايا الكهروضوئية للسيليكون، وتم فحص تأثير السماكات المختلفة من النوع n مشوبة بتراكيز مختلفة؛ تم ذلك عن طريق محاكاة PC1D، حيث انه من المناسب تطوير طبقة واحدة من السيليكون بدون تكلفة. سمك الطبقة n والتطعيم هي العوامل المسؤولة عن كفاءة الخلية الشمسية وأدائها. في هذا السياق، يعتبر السيليكون هو المرشح المثالي بسبب الزيادة السريعة في كفاءته، واعتماديته واستقراره. في النهاية ، لاستخلاص استنتاج حول المعلمات المثالية التي يجب أن تمتلكها الخلية الشمسية الجيدة، كانت الكفاءات الكمومية الخارجية المثلى التي تم الحصول عليها من هذا التصميم (٨٧,٧١ ٪) للأسطح الأمامية أحادية الطبقة. تثبت نتائج دراسات المحاكاة هذه أنه من الممكن اقتراح معلمات التصميم هذه لتصنيع الخلايا الشمسية أحادية الطبقة. من خلال ضبط المعلمات الفعالة المذكورة، تم تحقيق خلية شمسية ذات كفاءة عالية وخاصية I-V.

الكلمات المفتاحية: PC1D، الخاصية I-V ، الخلية الشمسية، تقاطع الوصلة p-n، الكفاءة.

1. Introduction

Since 1839 when French empirical scientist Antoine-Cesar Becquerel found the photovoltaic phenomenon, until recently, the efficiency and performance of all solar cells has been limited to roughly (29 %) in all scenarios of solar cell design. It is projected that energy-efficient solar cells will contribute a large amount of future energy investment; now, this sort of energy is extensively needed around the world due to its cleanness. Sometimes things (such as the solar system) are not visible and observations are problematic [1]. Furthermore, even minor changes in the photovoltaic cell manufacture technique might be prohibitively costly. Because changing any aspect of the process of production is a difficult task, simulation has grown in popularity in recent years. It allows designers to modify the various components of the system, allowing them to fabricate and observe the system's behavior. It also allows for theoretical investigation with minimal cost and provides comprehension of the system [2]. PC1D simulation is the most widely used modeling tool in the photovoltaic sector, specifically for solar cells made of silicon. The software offers additional physical models, therefore broadening the domain across that simulation outcome is acceptable. The solar cells are appealing because they offer an elegant solution to increased production at a cheaper material price. Front silicon solar cells provide multiple benefits, including low cost, reduced temperature, and clean energy. This choice was made due to the excellent results obtained from this structure. This structure is the simplest structure, most widely used method. PC1D has been chosen as a simulation tool for this research regarding its user-friendly system. PC1D is the most common and perhaps simplest simulation software. The quantity of electricity generated by solar cells is proportional to the amount of light falling on it. The solar cell designed with some basic parameters; the device area is (10 cm^2), and this study concentrated on a handful of factors such as thickness and doping concentration to see how they affect the I-V characteristics of silicon solar energy, other basic factors are fixed inside this inquiry, as demonstrated in the section below. This work included a thorough description of a front layer solar cell based on PC1D simulations [3-5].
The typical obstacles to providing electric energy are as follows: first, a very big geographical area is required in order to deploy high-efficiency solar cells; second, energy loss due to heat; and third, other energy sources, except for solar cells, are harmful to the environment. To reduce these issues, the team created a solar cell wafer in the micro range in order to overcome them at least partially. Indeed, the micro range design allows us to create a solar cell with small area, little energy loss, high efficiency, and a good I-V characteristic. This type of energy is pure and not damaging to the environment [6].

2. Simulation method for silicon solar cell

Computer-based models are essential in the design, construction, and operation of photovoltaic cells. Device simulation methods significantly save both time and money by optimizing production processes and selecting materials such as silicon. Solar cell devices and combinations were modeled and configured using PC1D program in this investigation. The PC1D comprises library files containing the properties of crystalline semi-conductive materials such as silicon, which are employed in solar power cell technology. In general, this study has four essential elements (device part, region part, excitation part, and outcome part) and the last configurations that worked on it are shown in the Figure (1) [7].

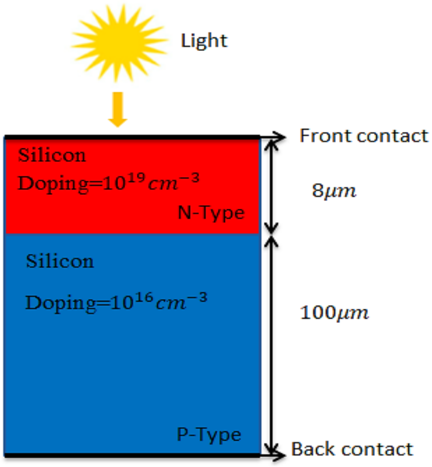

Figure 1: Silicon solar cell device schematic using PC1D

According to the above configuration the silicon material used, the device consist two main region, n-type layer with high doping concentration and p-layer with low doping concentration. The sunlight directed to the front (n-layer) with ($\frac{0.1\text{W}}{\text{cm}^2}$). It concentrated on two factors: n-type layer thickness and n-layer doping by constant other parameters. Establish the process factors influencing the device's performance, it showed in the Table (1).

Table 1: The main basic parameters of PC1D are as follows

Parameters	Value	Parameters	Value
Device area	10 (cm^2)	n-type intrinsic conc.at 300 k	1×10^{10} (cm^{-3})
n-thickness	8 (μm)	p-type intrinsic conc.at 300 k	$1 \times 10^{10}(cm^{-3})$
p-thickness	100 (μm)	N-region. Bulk recombination	$\tau_n = \tau_p = 1000$ (μs)
n-doping	10^{19} (cm^{-3})	P-region. Bulk recombination	$\tau_n = \tau_p = 1000$ $(\mu s$
p-doping	$10^{16}(cm^{-3})$	Wavelength	Monochromatic: 800 (nm)
Band gap of silicon	1.124 (eV)	Secondary light source	disable
Intrinsic con.at 300 K	10^{10} (cm^{-3})	Max base power out	0.2055 $(watts)$
Dielectric constant	11.9		
Excitation form	-Darkiv.exc -primary light source: enable	Open circuit V_b:	0.678 $(volts)$
Constant intensity	$0.1(W/\text{cm}^2)$		

3. Result and Discussion

Extensive simulation studies of I-V characteristics of single-face photovoltaic cells were carried out to get a better knowledge of the parameters impacting solar cell efficiency. Gaining electrical energy and performance needs all of the solar energy cell's factors to be included; however, for simplification and understanding the influence of the parameters, some of the factors, such as texturing and dielectric constant, etc. are fixed. An ideal silicon solar cell with n-type surface thickness is changed, typically ranging from (1 to 18 m) but the p-type layer does not change which is displayed in Table (2).

Table 2: Data of solar cell current and voltage with various n-type thickness layers

Voltage	Current L=1 µm	Current L=4 µm	Current L=8 µm	Current L=12 µm	Current L=16 µm	Current L=18 µm
0.05	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.1	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.19	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.24	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.29	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.34	-0.56	-0.52	-0.41	-0.307	-0.221	-0.187
0.37	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.4	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.46	-0.56	-0.52	-0.417	-0.307	-0.221	-0.187
0.5	-0.56	-0.52	-0.417	-0.3071	-0.221	-0.187
0.55	-0.56	-0.52	-0.415	-0.3049	-0.218	-0.184
0.6	-0.56	-0.51	-0.400	-0.2896	-0.203	-0.169
0.65	-0.52	-0.43	-0.298	-0.184	-0.098	-0.064
0.7	-0.32	0.096	0.372	0.509	0.597	0.63
0.74	0.49	2.23	3.0	3.27	3.37	3.40
0.75	0.98	3.47	4.57	4.853	4.95	4.99

The I-V characteristics were obtained from $(1\ to\ 18\ \mu m)$ n-type thickness, the highest current curve being $(4.99\ A\ at\ 18\ \mu m)$ and the minimum current was about $(1\ A\ at\ 1\ \mu m)$, that means the thickness have a great impact on I-V characteristics, it's as shown in Table (2). During the observation, the thickness had no longer an influence on the I-V characteristic; as seen in Figure (2), above $(16\ \mu m)$ the variation in current was extremely slight and nearly constant because the material goes to bulk material so that the recombination carrier reduced; Table (3) illustrates this [8-11]. It means there was a limit thickness effect on the I-V characteristic which is seen in Figure (2).

Table 3: Maximum current silicon solar cell with various n-type thickness layers

Thickness (μm)	Maximum Current (A)
1	0.98
4	3.47
8	4.57
12	4.85
16	4.95
18	4.99

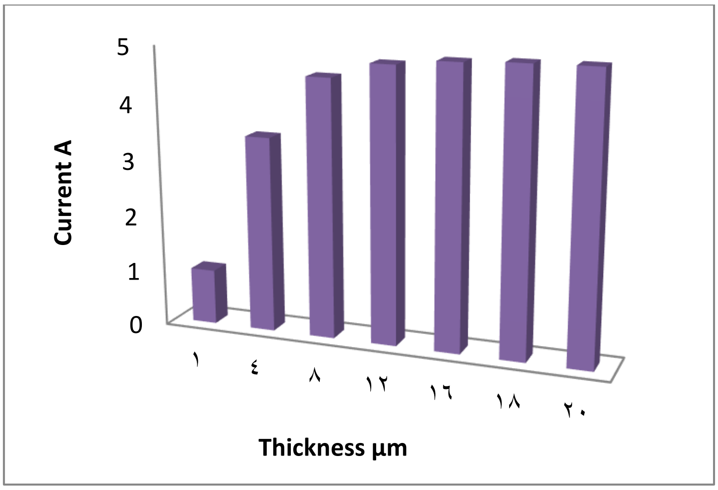

Figure 2: Relation between n-layer thickness and current

A large fraction of light is absorbed close to the front surface. By making the front layer very thin, a large fraction of the carriers generated by the incoming light is created within a diffusion length of the p-n junction. The I and V reported around $(3.47\ A\ and\ 0.75\ V)$ in the $(4\ \mu m)$ thickness, whereas the equivalent result recorded approximately $(3.25\ A\ and\ 0.62\ V)$, $(3.8\ A\ and\ 0.68\ V)$ in [12,14] respectively.
The n-type silicon doping concentration was varied to determine the optimal doping concentration and its influence on the I-V properties of silicon in the solar cell, while the p-type concentration remained constant at was $(1 \times 10^{16}\ \mathrm{cm}^{-3})$. The I-V curves for various doping doses were drawn and are depicted in Figure (3).

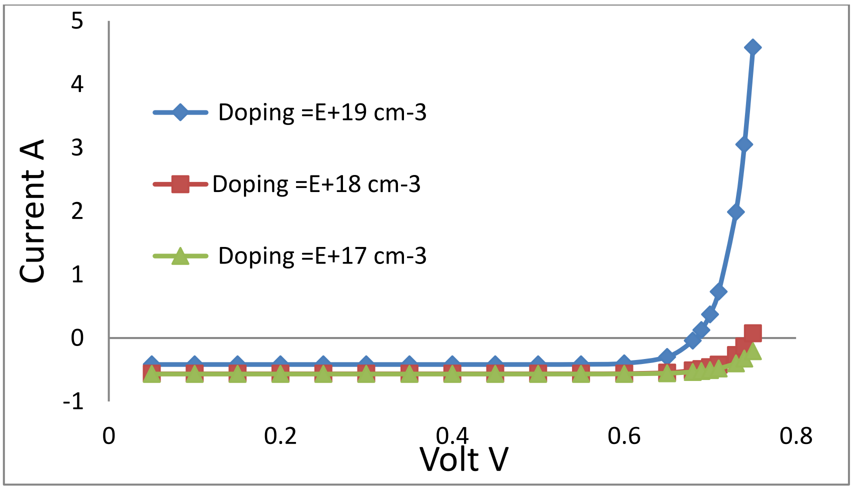

Figure 3: I-V characteristic relation for various Doping

As can be indicated increasing doping concentration doesn't always result in a good I-V characteristic. The output current drops dramatically as the n-type silicon doping concentration approaches the p-type wafer concentration. Because of the equalization doping in both regions, the minority carrier contributed to carrier diffusion length. Hence no enough carriers move from side to side, that why the minimum current is at minimum n-concentration. The front conjunction is doped to a degree that allows the produced power to be conducted away without resistive losses. Excessive doping, on the other hand, degrades the material's quality to the point that carriers recombine before reaching the junction. Eventually there is a strong relation between current and doping this relation is shown in Figure (4). The n-type doping concentration is steadily increased from $(10^{15}\ to\ 10^{19}\ cm^{-3})$, and the current and voltage increase gradually as well. The highest values were $(4.49\ A\ and\ 0.75\ V)$ respectively at $(10^{19}\ cm^{-3})$, while the p-type doping concentration was held constant at $(10^{16}\ cm^{-3})$. The same outcomes were obtained, which were $(2.3\ A\ and\ 0.68\ V)$ at $(10^{19}\ cm^{-3})$ in [14,15]**.** Larger doping concentrations result in increased carrier recombination or a decreased minority carrier lifetime. Radiative recombination plays no impact at doping levels

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less than (10^{17} cm^{-3}), but Auger recombination becomes predominant for doping levels more than (10^{19} cm^{-3}) [14].

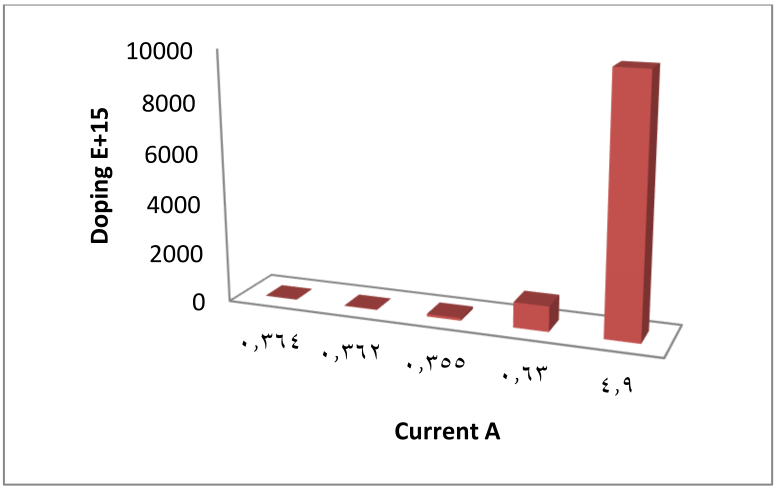

Figure 4: Relation between n-type doping concentration and current

Finally, efficiency is to be predicted in an everyday life solar panel manufacturing scenario. It may be argued that the main achievement was extensively researching an alternative approach, all things that researchers have done is just to get high efficiency in solar cell. Solar cells research continues to enhance efficiency, with goals aiming at the currently recognized limit of (29 – 30 %). The external quantum efficiency, fill factor, and efficiency have been investigated. That discovered that the highest external Quantum efficiency was achieved at the low thickness n-type layer, shown Figure (5) and Table (4). According to Figure (5), increasing thickness does not continuously generate more efficiency.

Table 4: External Quantum Efficiency with various n-type thickness layers

Thickness (μm)	External Quantum Efficiency (%)
1	87.71
4	81.97
8	64.75
12	47.68
16	34.34
18	29.05

The more efficient a PV module is, and thus the more cost-effective it becomes, the more attractive photovoltaic will be as an electricity source for both domestic and industrial use. The researchers have a plan to obtain high efficiency with minimum cost.

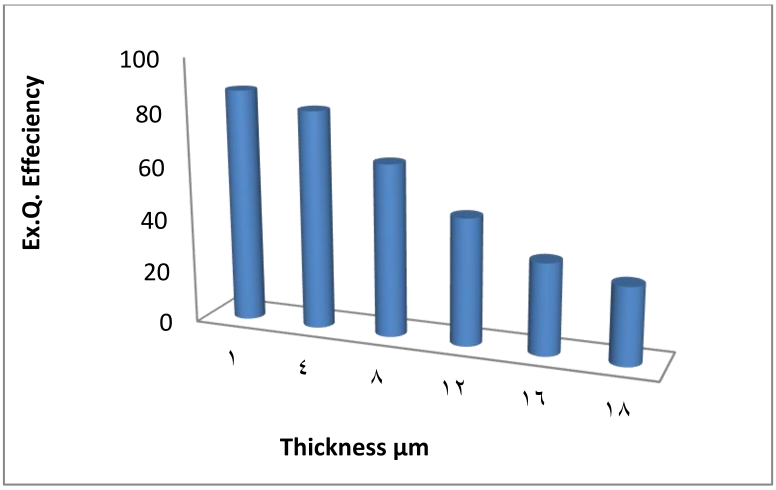

Figure 5: Relation between n-type thickness and external quantum efficiency

The External Quantum Efficiency can be noticed in the Figure (5). The curve is gradually lowered by increasing thickness from the emitter level of n-type, and a similar pattern can be seen in [15]. A number of parameters, such as fill factor and efficiency, would be computed to demonstrate the performance of the solar cell. The "fill factor," abbreviated "FF," is a quantity that, along with V_{oc} and I_{sc}. The FF is defined as the ratio of the maximum power produced by a solar cell to the product of V_{oc} and I_{sc}, such that:

$$FF = \frac{P_{mp}}{V_{oc} \, I_{sc}} \quad (1)$$

$$FF = \frac{P_{mp}}{V_{oc} \, I_{sc}} = \frac{0.21w}{0.67*0.36} \text{X100 \%} = 83\ \%$$

The efficiency is the most commonly used parameter to compare the performance of one solar cell to another. Efficiency is defined as the ratio of energy output from the solar cell to input energy from the sun. In addition to reflecting the performance of the solar cell itself, the efficiency depends on the spectrum and intensity of the incident sunlight and the temperature of the solar cell. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$\eta = \frac{P_{out}}{P_{in}} \text{ x } 100\% = (V_{oc} \, I_{sc} \, FF)/P_{in} \quad (2)$$

$$\eta = \frac{0.2w}{0.1\frac{w}{cm^2}*10cm^2} \text{ x } 100\% = 20\%$$

η: Efficiency, P_{out}: power out, P_{in}: input power. FF: fill factor, P_{mp}: maximum power, V_{oc}: voltage open circuit and I_{sc}: current short circuit. At a particular thickness of n-type layer, the efficiency and fill factor are around (20 % and 83 %) respectively. that may compare our results to the efficiency and fill factor, which were (13.62 % and 72.28 %) respectively [15].

4. Conclusion

There are many parameters that potentially influence the silicon solar system performance, PC1D program for simulation was used to study them. Firstly, investigations revealed that an n-type thickness of ($1\ \mu m$) yielded the highest external quantum efficiency of (87.71 %). The electrical I-V properties of a silicon-crystalline solar cell were investigated using a low-cost device at various thicknesses. It was obvious that n-type thickness is a critical factor that has a significant impact on the increasing gain of electrical energy and the performance of the solar cells system. The investigation discovered that as thickness grows, the electric current increases until a limit point ($I = 4.95\ A\ at\ 16\ \mu\ m$), beyond this the current remains constant, implying that increasing thickness has been effective less. As for n-type doping, it had a major effect on the I-V characteristics of the system, the best doping that is ($1 \times cm^{-3}$) for emitter I-V characteristics were observed which were ($4.95\ A\ and\ 0.75\ V$). The more appealing photovoltaic will be as a source of power for both household and industrial usage. The researchers have devised a strategy to achieve maximum efficiency at the lowest possible cost. The challenge will be to achieve maximum efficiency at the lowest possible cost.

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