ISSN 2347 - 3983
Volume 12. No.1, January 2024
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter031212024.pdf
https://doi.org/10.30534/ijeter/2024/031212024

To Enhance the Performance of Silicon Solar Cells: A Comprehensive Analysis of Effective Parameters Using PC1D Simulator

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Received Date: November 28, 2023 Accepted Date: December 21, 2023 Published Date : January 07, 2024

ABSTRACT

The aim of this work was to investigate the effect of some important parameters on the performance of silicon solar cell. Simulation of solar cell was conducted using Personal Computer One Dimensional (PC1D) software. Electric parameters of solar cell such as short circuit current, open circuit voltage and maximum power were obtained from the PC1D for different values of bulk thickness, emitter doping concentration, and base resistivity. Further, fill factor and conversion efficiency of the silicon solar cell were obtained from the simulation results.

Key words: PC1D, simulation, efficiency, bulk thickness, doping concentration, base resistivity.

1. INTRODUCTION

The majority of the world's electricity is currently generated from fossil fuels such as coal, oil, and natural gas. However, the growing energy demand and the depleting fossil fuel reserves necessitate exploration of alternative methods for energy production. The sun, as the primary energy source on Earth's surface, provides an abundant energy supply capable of meeting global energy demand [1]. Solar cells represent an efficient means of harnessing sunlight by absorbing photons and converting them into usable electric energy. The main challenge with solar cell is the low efficiency. With the substantial technological advancements and high conversion potential, the efficiency of crystalline silicon solar cell has reached 26.7% [2]. Theoretical limitations, including band gap constraints and various recombination processes, impact conversion efficiency of solar cell [3-5]. Addressing losses, such as optical, carrier, and electrical losses, is essential for maximizing solar cell efficiency [6].

Simulation plays a significant role in optimizing device performance by adjusting various parameters such as device area, thickness, doping concentration, temperature, etc. In the field of PV technology, numerical modeling is increasingly used to obtain insight into the electrical and optical properties. Over the years various solar cell modeling tools have been developed such as: AMP, SCAPS, AFORS-HET, Silvaco TCAD, and PC1D [7-9]. Among all, PC1D simulator is widely (more or less) accepted as standard in the field of PV technology. PC1D is open source widely used software for simulation of solar cells. This software was developed by the Photovoltaics Special Research Centre of University of New South Wales, Australia. This provides liberty to modify various parameters such as device area, thickness, doping concentration, temperature, parasitic resistance, back surface fields, recombination, carrier lifetime, etc. PC1D contain two files "one-sun.exe" and "scan-qe.exe", the "one-sun.exe" file gives short circuit current, maximum power, and open circuit voltage while the "scan-qe.exe" file gives reflectance, internal quantum efficiency, and external quantum. This program also accepts the reflectance as an external file, which provides an opportunity to include the desired reflectance file [10]. X. Cai et al used PC1D to study the optimal magnitude of emitter thickness, base thickness, emitted dopant density and base dopant density on silicon solar cell [11]. The study of the affecting power and efficiency of the monocrystalline solar cell using PC1D was done by G. Hashmi et al [12]. R Sharma et al [13] studied the effect of SLARCs and DLARCs on the performance of silicon solar cell using PC1D. Another simulation using PC1D has been also described in the literature [14-16].

In this work, an attempt has been made to study the effects of parameters such as bulk thickness, base resistivity, and emitter doping concentration on the performance of silicon solar cell by using PC1D simulation software.

2. DEVICE SIMULATION

PC1D simulation software was used to study the effect of various device parameters to achieve the maximum possible conversion efficiency. Figure 1 show the basic structure of conventional silicon solar cell and table 1 outlined the device parameters used in this study. The emitter, absorber and back surface field are responsible for generating and transporting charge carriers whereas front and back contacts collect these mobile charge carriers. An antireflection coating (ARC) using silicon nitride with refractive index 2.0 and thickness of 75 nm was applied to minimize reflection and enhance surface passivation.is [10].

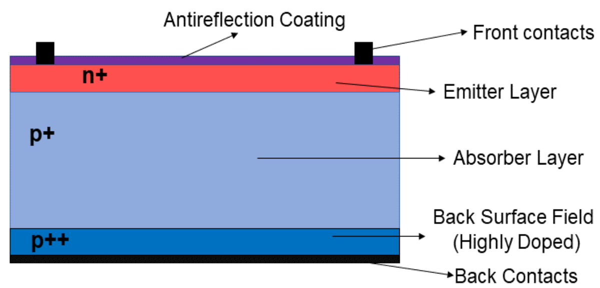


Figure 1: Basic structure of conventional silicon solar cell.

Table 1: Parameters of silicon solar cell model - PC1D.

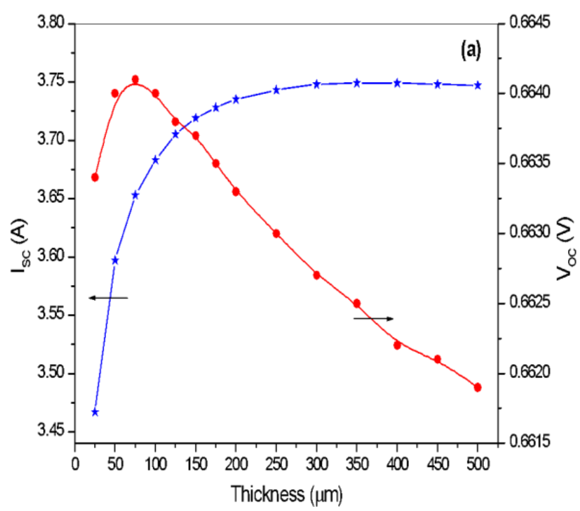
Parameter	Value
Device Area	100 cm^2
Front Surface	Textured
Texturing depth and angle	3 µm and 54.74°
Emitter contact	$1\times10^{-6}\Omega$
Base contact	$1.5\times10^{-3}\Omega$
Internal conductor	0.3 S
Thickness	200 µm
Dielectric constant	11.9
Band gap	1.124 eV
Intrinsic conc. at 300 K	1×10^{10} cm^{-3}
P-type background doping	5×10^{16} cm^{-3}
First front diffusion (N-Type)	5×10^{19} cm^{-3}
First rear diffusion (P-type)	5×10^{19} cm^{-3}
Bulk recombination	100 µs
Front surface recombination	10000 cm/s
Rear surface recombination	10000 cm/s
Temperature	25 °C

3. RESULTS AND DISCUSSION

3.1 Effect of Absorber Layer Thickness

A solar cell with varying absorber layer thickness was studied in this section. The absorber layer is the thickest part of the solar cell which absorbs light and generates mobile charge carriers that are transported to and collected by the contacts to generate electricity [17]. Thicker absorber layer does not mean high efficiency due to conflicting effects on I_{sc} and V_{oc}. To study the effect of the absorber layer, the bulk thickness was varied from 25 – 500 µm and the value of I_{sc}, V_{oc}, fill factor, and conversion efficiency was measured. Figure 2 shows the effect of absorber layer thickness on I_{sc}, V_{oc}, fill factor, and conversion efficiency.

From figure 2(a) one can observe that I_{sc} first increases sharply with increase in bulk thickness attaining maximum value of 3.749 A at 350 µm and then decreases gradually whereas V_{oc} exhibits inverse relation. Figure 2(b) shows correspondingly the efficiency of solar cell is maximum (19.72 %) for thickness 300 µm.



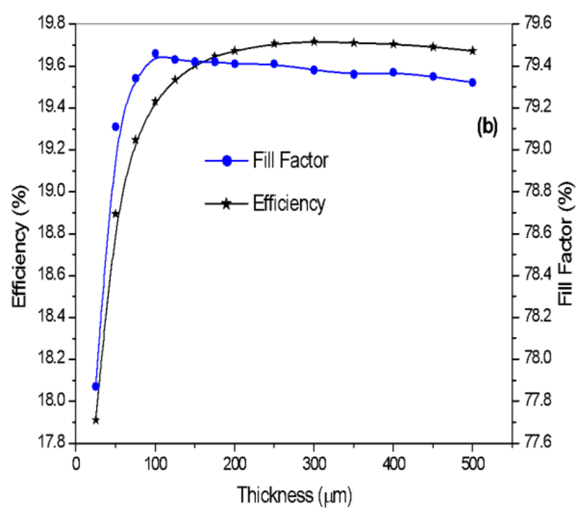


Figure 2: Plot shows effect of bulk thickness on (a) I_{sc} & V_{oc} and (b) fill factor & conversion efficiency of solar cell.

3.2Effect of Emitter Doping Concentration

Emitter doping concentration plays a significant role in solar cell performance. High concentration is needed to aid the drift transport mechanism and achieve low sheet resistance (R_{sheet}). Experimentally, emitter doping concentration can be changed by controlling the parameters such as gas flow rate, temperature, time and structure. For simulation, the emitter doping concentration (D_{conc}) was changed from 5×10^{17} to 1×10^{21} cm^{-3}.

Table 2: Solar cell parameters such as I_{sc}, V_{oc}, R_{sheet}, fill factor and efficiency corresponding to emitter doping concentration.

D_{conc} (cm^{-3})	I_{sc} (A)	V_{oc} (V)	R_{sheet} (Ω/sq)	FF (%)	η(%)
5.0×10^{17}	3.741	0.6243	4508	77.95	18.2
7.5×10^{17}	3.740	0.6294	3387	78.20	18.4
1.0×10^{18}	3.740	0.6327	2796	78.37	18.5
2.5×10^{18}	3.739	0.6424	1572	78.78	18.9
5.0×10^{18}	3.739	0.6489	1030	79.01	19.2
7.5×10^{18}	3.738	0.6524	801.4	79.13	19.3
1.0×10^{19}	3.738	0.6547	668.5	79.20	19.4
2.5×10^{19}	3.737	0.6608	363.8	79.35	19.6
5.0×10^{19}	3.735	0.6633	220.3	79.41	19.7
7.5×10^{19}	3.733	0.663	161.3	79.42	19.8
1.0×10^{20}	3.731	0.6615	128.3	79.39	19.6
2.5×10^{20}	3.709	0.6479	59.26	79.09	19.01
5.0×10^{20}	3.652	0.6317	31.88	78.74	18.2
7.5×10^{20}	3.593	0.6235	21.94	78.63	17.6
1.0×10^{21}	3.544	0.6192	16.76	78.64	17.3

Figure 3 shows the effect of emitter doping concentration on short circuit current (a), open circuit voltage (b), and conversion efficiency (c). From the figure one can observe that short circuit current (I_{sc}) decreases continuously whereas open circuit voltage (V_{oc}) as well as conversion efficiency (η) first increases with increasing concentration and then decreases. Data shows the maximum efficiency is 19.8% corresponding to the doping concentration 1.7×10^{19} cm^{-3} for the model under consideration. Emitter doping concentration also has a huge impact on the sheet resistance. Table 2 shows sheet resistance decreases from 4508 to 16.76 (Ω/sq) for doping concentration from 5×10^{17} to 1×10^{21} cm^{-3}.

3.3 Effect of Base Resistivity

One of the inherent characteristics of wafer is the resistivity (or base resistivity) and depends upon the doping concentration at the time of wafer fabrication [1]. To achieve high efficiency solar cell a specific base resistivity is required. Therefore, it is important to study the variation of bulk resistivity on the performance of silicon solar cell.

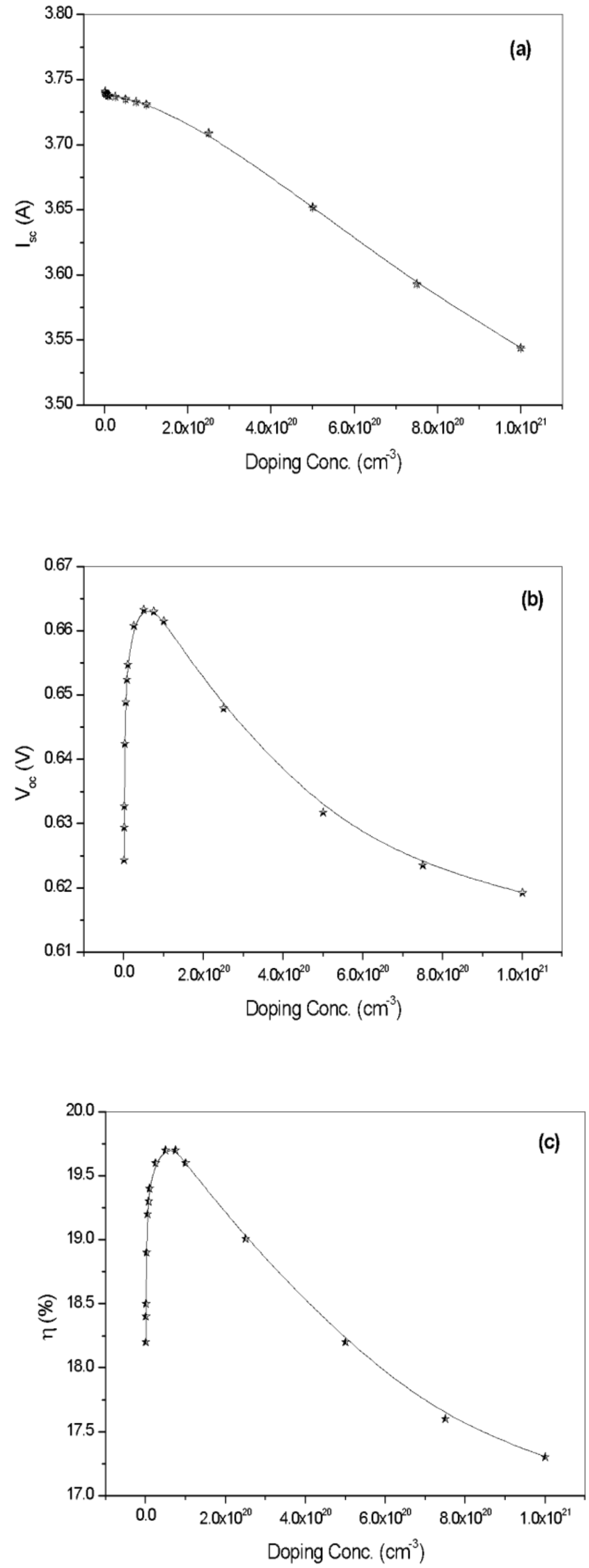


Figure 3: Plot shows variation of short circuit current (a), open circuit voltage (b), and conversion efficiency (c) as a function of emitter doping concentration.

Variation of short circuit current (I_{sc}), open circuit voltage (V_{oc}), and conversion efficiency of solar cell as a function of base resistivity is shown in figure 4. From plots one can observe that short circuit current increases with increase in resistivity whereas open circuit voltage decreases with increasing resistivity. Also, the maximum value of efficiency is observed against resistivity 0.5 Ω cm.

The plotted data inferred that the base resistivity should be in the range of 0.1-3 Ω cm and produce a sharp maximum at ~ 0.5 Ω cm. Thus the heavily bulk doping (resistivity less than 0.5 Ω cm), lead to increase carrier recombination that leads to reduced minority carrier lifetime and diffusion length, subsequently reduce the performance of the solar cell.

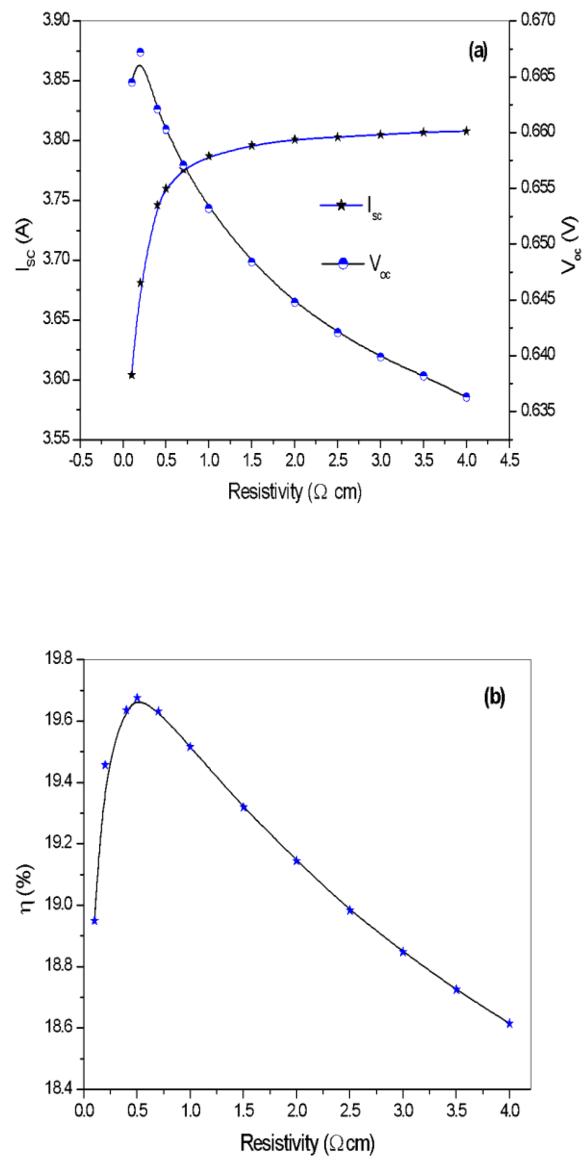


Figure 4: Plot shows variation of short circuit current & open circuit voltage (a) and conversion efficiency (b) as a function of base resistivity.

4. CONCLUSION

In the present work, the simulation of a silicon solar cell has been done by using the PC1D simulator. Results obtained from PC1D, including short circuit current, open circuit voltage, and maximum power were analyzed for varying values of bulk thickness, emitter doping concentration, and base resistivity. The analysis reveals that the optimal performance obtained with emitter doping concentration of 5×1019 cm-3, base resistivity of 0.5 Ω cm, and bulk thickness of 300 µm resulting in efficiency of 19.67%, 19.68%, and 19.72% respectively. Consequently, the solar cell simulated with emitter doping of 5×1019 cm-3, bulk thickness of 300 µm, and base resistivity of 0.5 Ω cm yield efficiency 19.8%.

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