INVENTOPIA 2025

FBM-SEREMBAN INTERNATIONAL
INNOVATION COMPETITION (FBM-SIIC)

INNOVATION IN ACTION: TURNING IDEAS INTO REALITY

Chapter 5
Influence of Doping Concentration and Thickness of N- and P-Type on the Efficiency Performance of Si Solar Cell Using Simulation Approach

Nurul Hidayah Murni Jamaludin & *Madhiyah Yahaya Bermakai

Faculty of Applied Sciences, Universiti Teknologi MARA, 02600 Arau, Perlis

*madhiyah@uitm.edu.my

ABSTRACT
This thesis explores the influence of n- and p-type doping concentrations and thicknesses on silicon solar cell efficiency. To address this, a range of software options for investigating photovoltaic cells, such as the Silvaco tool, Midian, and PC1D software. However, to complete this investigation, PC1D software was chosen. Personal Computer One Dimensional (PC1D) is ideal for any solar cell simulation. The goal of this paper is to examine insights into the numerical modelling of silicon solar cells using the PC1D programme, the design of silicon solar cells with high efficiency by changing ideal features, and the impact of parameters on the IV characteristic of silicon solar cells. Furthermore, the goal of this study is to identify the best efficiency in the design of silicon solar cells by adjusting parameter values such as doping concentration and thickness of n- and p-type value on I-V characteristic. To maximise design efficiency, surface area of 100 cm^2, a respective doping concentration and thickness with 1×10^{17} cm^{-3} and 0.05 µm for the n-type, and $1 \times 10^{17} cm^{-3}$ and 290 µm for the p-type. The final design's efficiency is 22.58%, and the maximum power output is 2.258 watts.

Key Words: Silicon, Solar Cells, Doping Concentration, Thickness, PC1D.

1. INTRODUCTION

Silicon solar cells are a silicon semiconductor-based photovoltaic (PV) cell. These types of solar cells are commonly used in the market since they are inexpensive and have a lifespan of more than 25 years without requiring extensive maintenance (Bouich, 2023). Crystalline silicon PV cells have a maximum efficiency in converting energy of 25%. However, apart from excellent high efficiency cells capable of efficiencies greater than 20%, regular industrial cells are limited to 15-18% (Saga, 2010). Because of this large increase in efficiency, the power rating of a common size panel increased from 250 W to more than 420 W. Silicon's band gap is somewhat low enough for an ideal solar cell, and because it is an indirect material, it has a relatively small absorption coefficient.

It is utilised near the front of the cell, where the majority of the light is absorbed because n-type silicon has a greater surface quality as an emitter dopant than p-type silicon. As a result, the negative terminal is at the top and the positive terminal is at the bottom of the cell. Typically choose emitters with a thickness of less than 1 µm because a significant percentage of the light is absorbed on the front surface. By making the front layer extremely thin, a significant fraction of the carriers created by the light that comes in are formed within a diffusion length of the p-n junction. Additionally, the front connection has a doping level at which the generated power can be conducted away without resistive losses. But too much doping lowers the quality of the material to the point where carriers recombine before they reach the junction (Kharchenko, 2019).

The purpose of this study holds immense significance within the realm of solar cell technology. This study was to understand the influence of doping concentration and thickness of n- and p-type layers on the efficiency performance of silicon (Si) solar cells using a simulation-based approach for advancing renewable energy sources. This study aims to quantify the relationship between dopant concentration, layer thickness and the resulting photovoltaic efficiency of Si solar cell. The findings will provide insight into optimizing the design and performance of Si solar cells for enhanced energy conversion in photovoltaic applications. This could lead to the development of more efficient solar cells, thus contributing to the goal of making renewable sources more accessible and economically viable.

2. METHODOLOGY

Table 1 shows the value of parameter that becomes basic parameter to be use in this study. This fundamental parameter has been obtained from (Belarbi et al., 2014). Only a few parameters, such as n-type doping, p-type doping, and thickness on the n- and p-regions will be manipulated in this study.

Table 1 The value of basic parameter for simulation of silicon solar cell

Parameter	Value
Device area	100 cm^2
Exterior front reflectance	10%
Region 1	n-type
Thickness	10 µm
Dielectric constant	11.9
Band gap	1.124 eV
Intrinsic concentration at 300K	1 x 10^{10} cm^{-3}
N-type background doping	1 x 10^{19} cm^{-3}
Bulk recombination	1000 µs
Region 2	p-type
Thickness	100 µm
Dielectric constant	11.9
Band gap	1.124 eV
Intrinsic concentration at 300K	1 x 10^{10} cm^{-3}
N-type background doping	1 x 10^{16} cm^{-3}
Bulk recombination	1000 µs
Excitation	One-sun

Source: (Belarbi et al., 2014)

Figure 2 below shows the schematic diagram of light-trapping (LT) schemes with planar surface and a p-n junction. The doping value of n-type and p-type will be varied between 10^{15} cm^{-3} to 10^{22} cm^{-3}. The same procedure was applied with the varies thickness of n- and p-type with the rage of 0.05 μm to 0.95 μm and 20 μm to 290 μm respectively. The results for short-circuit current density (I_{sc}), open circuit voltage (V_{oc}) and maximum power output were tabulated.

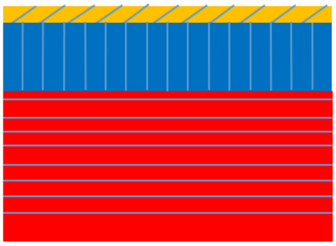

Figure 2 Schematic diagram of light trapping schemes of solar cell

3. RESULT & DISCUSSION

3.1. Influence of doping concentration at n- and p-type region

The value of doping at the n-type was continually altered from 10^{15} cm^{-3} to 10^{22} cm^{-3}. Meanwhile, the doping at the p-type gradually increased from 10^{15} cm^{-3} to 10^{22} cm^{-3}. The findings are presented in Table 2.

Table 2 influence of doping at n- and p-type region

N doping (cm^{-3})	I_{SC} (A)	V_{OC} (V)	P_{max} (W)	FF	η (%)
10^{15}	-3.425	0.7454	2.064	-0.8085	20.64
10^{16}	-3.425	0.7456	2.071	-0.8110	20.71
10^{17}	-3.425	0.7461	2.075	-0.8120	20.75
10^{18}	3.372	0.7290	2.008	-0.8169	20.08
10^{19}	-1.578	0.6547	0.8474	-0.8202	8.47
10^{20}	-0.7784	0.6062	0.3912	-0.8290	3.91
10^{21}	TCF	TCF	TCF	-	-
10^{22}	-2.934	-0.6858	SCF	-	-
P doping (cm^{-3})	**I_{SC} (A)**	**V_{OC} (V)**	**P_{max} (W)**	**FF**	**η (%)**
10^{15}	-3.425	0.7454	2.064	-0.8085	20.64
10^{16}	-3.425	0.7478	2.138	0.8348	21.38
10^{17}	-3.423	0.7590	2.225	0.8564	22.25
10^{18}	-3.279	0.7141	1.982	0.8465	19.82
10^{19}	-2.762	0.6800	1.573	0.8375	15.73
10^{20}	-2.558	06485	1.384	0.8343	13.84
10^{21}	-2.527	0.6192	1.291	0.8251	12.91
10^{22}	-1.443	0.3918	SCF	-	-

One issue that may occur when applying PC1D simulation is transient convergence failure (TCF) and steady convergence failure (SCF). Several reasons can come into play, such as the normalized error limit being set too low. Doping concentration at 10^{17} cm^{-3} has the maximum efficiency. Additionally, the highly doped emitter is considered a dead layer, occurring between 10^{18} cm^{-3} and 10^{20} cm^{-3} with substantial carrier recombination. High recombination rates can have an influence on efficiency. The findings are consistent with previous research by Mandong et al.

3.2. Influence of the n- and p-type region thickness

Table 3 demonstrates the impact of thickness at the n-type on I_{sc}, V_{oc}, P_{max}, FF and efficiency. The thickness at the n-type varied from 0.05 µm to 0.95 µm, while the thickness at the p-type ranged from 20.0 µm to 350.0 µm. The thickness of n-type at 0.05 µm has the highest performance (18.85%), while the thickness at 0.95 µm has the lowest (17.19%). While p-type thickness of 290 µm has the highest efficiency (21.62%) and the lowest efficiency (20.0 µm) is 18.85%. The thickness of the emitter and base layer can also significantly affect the fill factor and overall performance of the device. According to Belarbi et al., the n- and p-type is responsible for manufacturing most of the electron, which contribute to the electrical conditions. At the same time, electrons must travel some distance to reach the external circuit through the cathode, and the shorter this distance, the greater the chance that more electrons will exit the cell and contribute to conduction. The thin top layer allows more light energy to reach the depletion region. As base thickness increases, the cell absorbs more photons, which excites more electrons into the conduction band, resulting in a greater I_{sc}. A base thickness of 10 µm results in the lowest cumulative photogeneration. Then it grows slowly as the base thickness increases, eventually reaching its peak at the thickest point. In short, a particular base thickness is necessary to collect enough photons to activate electron-hole pairs. However, a thicker cell results in more resistance and cost. The base thickness should be approximately 100 µm (Xiyang Cai et al., 2018).

Table 3 Influence of thickness in n- and p-type region

N thickness (µm)	I_{SC} (A)	V_{OC} (V)	P_{max} (W)	FF	η (%)
0.05	-2.879	0.7689	1.885	0.8515	18.85
0.25	-2.882	0.7426	1.820	0.8504	18.20
0.45	-2.884	0.7269	1.785	0.8483	17.85
0.65	-2.883	0.7210	1.760	0.8467	17.60
0.85	-2.880	0.7147	1.739	0.8449	17.39
0.95	-2.887	0.7120	1.729	-0.8441	17.29
P thickness (µm)	**I_{SC} (A)**	**V_{OC} (V)**	**P_{max} (W)**	**FF**	**η (%)**
20	-2.879	0.7689	1.885	-0.8639	18.85
80	-3.350	0.7501	2.116	-0.8421	21.16
140	-3.474	0.7389	2.142	-0.8345	21.42
200	-3.539	0.7307	2.145	-0.8295	21.45
290	-3.595	0.7212	2.162	-0.8339	21.62
350	-3.618	0.7161	2.162	-0.8345	21.62

4. CONCLUSION

A good efficiency for silicon solar cells can be achieved by referring to the maximum performance from each parameter. In this modest effort, the ideal qualities that need to be set as the basic cell to achieve high efficiency are doping of n and p-type at 1 x 10^{17} cm^{-3} each. Whereas the thickness of n and p-type that yield a highest efficiency are at 0.05 µm and 290 µm respectively.

REFERENCES

Belarbi, M., Benyoucef, A., & Benyoucef, B. (2014). Simulation of the solar cells with PC1D, application to cells based on silicon. *Advanced Energy: An International Journal (AEIJ)*, *1*(3).

Bouich, A., Pradas, I. G., Khan, M. A., & Khattak, Y. H. (2023). Opportunities, challenges, and future prospects of the solar cell market. *Sustainability*, *15*(21), 15445.

Cai, X., Zhou, X., Liu, Z., Jiang, F., & Yu, Q. (2018). An in-depth analysis of the silicon solar cell key parameters' optimal magnitudes using PC1D simulations. *Optik*, *164*, 105-113.

Kharchenko, V., Nikitin, B., Tikhonov, P., Panchenko, V., & Vasant, P. (2019). Evaluation of the silicon solar cell parameters. In *Intelligent Computing & Optimization 1* (pp. 328-336). Springer International Publishing.

Mandong, A. M., & Abdullah, Ü. Z. Ü. M. (2019). Analysis of silicon solar cell device parameters using pc1d. *Sakarya University Journal of Science*, *23*(6), 1190-1197.

Saga, T. (2010). Advances in crystalline silicon solar cell technology for industrial mass production. *npg asia materials*, *2*(3), 96-102.