COMPARISON OF DIFFERENT PARAMETERS OF SOLAR CELL USING PC1D SIMULATION SOFTWARE

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ABSTRACT

In order to build a solar cell that has a high degree of efficiency, it is necessary to conduct an in-depth investigation of the impact that a variety of physical and electrical qualities have on the overall efficiency of the cell. For the purpose of this investigation, a PC1D computer simulation was applied to evaluate the effect that altering key characteristics of a silicon solar cell has on the performance of the cell. For the purpose of determining the ideal values for the absorber, emitter, antireflection coating, and back surface field layers, we carried out a simulation. We paid particular attention to the doping levels as well as the thicknesses of each particular layer. A measured result acquired from an industrial scale manufactured solar cell that had the same specifications was used to assess the simulated solar cells that were produced as a consequence. There was a good degree of agreement between the results of the measurements and the data from the models. It is useful and practical to comprehend and forecast the impacts of these essential components and in order to get their ideal values through the utilization of a simulation tool, based on the research that has been undertaken and the discoveries that have resulted from it. This is necessary in order to design a solar cell structure that has a high efficiency.

KEY WORDS: Solar Cell, Simulation, Industrial Scale, Physical & Electrical Qualities, PC1D Computer Simulation.

INTRODUCTION

The plentiful solar energy that reaches the surface of the Earth has the ability to supply all of the energy requirements that mankind will have in the future and need in the present [1]. Solar cells that use photovoltaic technology are extremely efficient in converting sunlight into energy because they are able to capture and transform light particles. If we want to increase the amount of photovoltaic energy that is produced all over the world, one potential strategy is to improve the efficiency of solar cells. Crystalline silicon (c-Si) solar cells are responsible for 93 percent of the entire revenue generated by the solar cell industry, as indicated by studies carried out by the Fraunhofer Institute [2]. In the present day, the highest efficiency that has been demonstrated for mono-crystalline systems is 26.7%, whereas the efficiency for multi-crystalline systems is 21.9% [3-5]. For the purpose of further improving the efficiency of solar cells, it is essential to have a comprehensive understanding of the fundamental principles behind the working of semiconductors. Through the use of trustworthy simulation software, folks have the opportunity to acquire understanding regarding the relationship between the modification of the electrical and physical characteristics of various materials and the functioning of the device. The output of a device may be predicted by simulation software by modifying material parameters such as doping levels and layer thickness. This allows the program to make predictions about the performance of the device. A further benefit is that they are able to forecast the performance of a solar cell by combining mathematical concepts with experimental findings. A number of different modelling tools for solar cells are now available for use [6-8]. These packages include Silvaco TCAD, Sentaurus TCAD, AFORS-HET, and PC1D. Sentaurus TCAD is a solar cell modelling program that is extremely adaptable and has the ability to accurately forecast processes at the atomic level, even for objects with diameters that are less than 90 nm [9]. The expensive cost is a significant one of the disadvantages. It is possible to replicate typical solar cell materials like silicon and germanium by using PC1D, which is an alternative that is open-source. PC1D was developed by the Photovoltaics Special Research Centre at the University of New South Wales, which is widely recognized as a leading authority in solar cells on a global scale [8]. Through the manipulation of a number of factors, including temperature, doping levels, parasitic resistance, back surface fields, recombination, and carrier lifespan, it is possible to alter the overall performance of the device. The PC1D has the capability to graphically exhibit data, which includes curves that show the relationship between current and voltage (I-V), open circuit voltage (V_{oc}), short circuit current (J_{sc}), and other information that is relevant. In the event that an analysis is performed, the data may be employed for the purpose of planning the manufacture of technological devices.

For the purpose of determining whether or not their designs were feasible, the researchers used PC1D to run simulations of a number of different kinds of solar cells. PC1D was utilized by Sepeai et al. [10] and Meenakshi et al. [11] in order to accomplish the simulation of solar cells with a variety of junction configurations. The PC1D technique was applied by both Belarbi et al. and Chuan et al. [12, 13] in order to investigate silicon solar cells. However, the modelling program that utilized a solar cell, regardless of whether it was developed experimentally or commercially, did not have validation to assure that it was accurate and reliable. The purpose of this study was to investigate the effect that a number of important characteristics, including device thickness, doping levels, emitter thickness, back surface field thickness, doping level, and antireflection coating, had on the performance of crystalline silicon solar cells. In order to successfully replicate and evaluate the performance of the device, PC1D made use of the manipulation of the aforementioned features. The result highlights how important it is to evaluate and determine the perfect value of each parameter in order to achieve the best possible efficiency from the device. One of the most impressive aspects of this research is that the optimized parameters of the simulated device were confirmed by comparing the findings to those of a commercially produced solar cell that had the same physical and electrical properties as the simulated device.

METHOD

The typical structure of a silicon solar cell, which is generally utilized in the industrial sector, is seen in Figure 1. It is essential to have a solid understanding of the effect that the various physical and electrical features of each layer have on the conversion efficiency in order to achieve high levels of efficiency. For the purpose of achieving the maximum possible conversion efficiency, the PC1D simulation tool was utilized to investigate the impact that a variety of device characteristics had on each layer within the system.

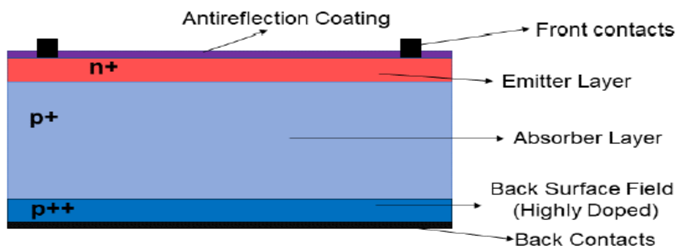


Figure 1. Basic structure of a conventional silicon solar cell with selective emitter

While the absorber, emitter, and rear surface field are responsible for producing and transferring mobile charge carriers, the front and back contacts are responsible for collecting them. The efficiency of solar cells may be improved by using an antireflection coating, which reduces the amount of surface reflection while simultaneously increasing the amount of light that is transmitted and absorbed. A silicon nitride antireflection coating with a refractive index of 1.873 was utilized in order to achieve the goals of minimizing the quantity of light that was reflected at wavelengths that had high spectrum irradiance and providing efficient surface passivation [14]. The standard specifications of the solar cell that was utilized in the experiment are presented in Table 1.

Table 1: Parameters of Solar Cell by Using PC1D

Internal optical reflectance	Enabled
Emitter Sheet Resistance	71.85 Ω/sq
Front surface texture depth	3 μm
Shunt Resistance	50000 Ω
Intrinsic concentration @300k	1×10^{10} cm^{-3}
Front diffusion (N-type)	2×10^{20} cm^{-3} peak
Thickness (Absorber Layer)	180 μm
Rear diffusion (P-type)	3×10^{18} cm^{-3} peak
Front SRV	2×10^{5} cm/s
Bulk recombination	$\tau_n = \tau_p = 30$ μs
Device Area	1 cm^2
Rear SRV	1×10^{7} cm/s
Temperature	25^oC

THICKNESS OF THE ABSORBER LAYER AND ITS IMPACT ON SOLAR CELL EFFICIENCY

When determining whether or not to manufacture a photovoltaic device, one of the most important considerations to take into account is the cost of the materials used in semiconductors [14]. In order to save expenses while simultaneously optimizing the efficiency of the gadget, it is essential to use materials that have the thickness that is most appropriate on the market. When it comes to the process of converting light into mobile charge carriers, the absorber layer, which is the component of commercial silicon solar cells that is the thickest, makes a significant contribution. These charge carriers are then transmitted and collected by the contacts, which results in the generation of energy by the process [15]. When it comes to improving efficiency, a bigger absorber layer is not useful because of the contradicting effects it has on Voc (open-circuit voltage) and Jsc (short-circuit current). In this part of the article, we examined a solar cell that had absorber layers of varying thicknesses. The performance of the device is analyzed in Table 2, which displays the impact that different bulk thicknesses of silicon have on the device. As can be observed in Figure 2, the thickness of the absorber layer has an effect on several parameters, including V_{oc}, J_{sc} (Figure 2a), and efficiency (Figure 2b). The parameters 'T_{bulk}', 'FF', and 'η' are used to represent the bulk thickness fill factor, and conversion efficiency, respectively.

Table 2: Device performance depends on absorber thickness

J_{sc}	V_{oc}	η (%)	T_{bulk}	FF (%)
36.94	619.4	17.75	280	77.56
37.03	620.3	17.83	250	77.62
37.11	621.5	17.91	220	77.65
37.18	622.9	17.99	190	77.66
37.21	624.5	18.04	160	77.64
37.20	626.4	18.12	130	77.76
37.10	628.7	18.16	100	77.86
36.66	632.3	18.09	60	78.06
35.50	635.0	17.64	30	78.25

Figure 2 (a)

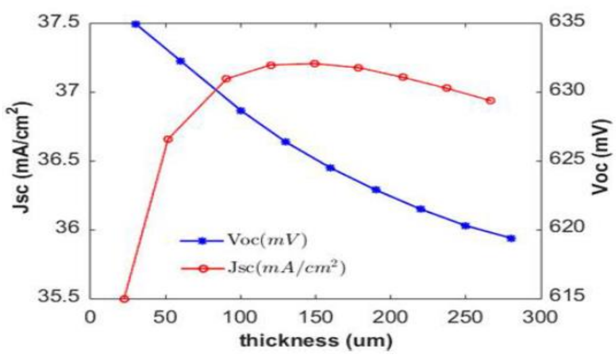
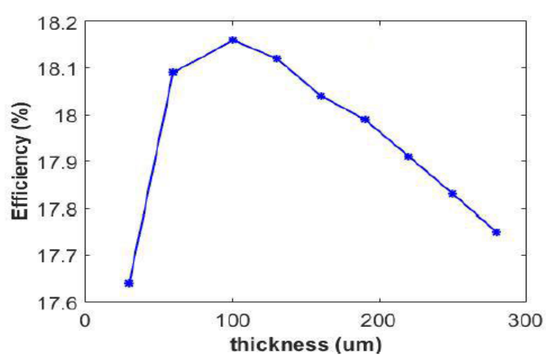


Figure 2 (b)



Within the region of 30 to 280 µm, the V_{oc} value exhibits a connection that is inversely proportional to the thickness. On the other hand, the J_{sc} value exhibits a direct correlation with thickness up until the bulk thickness reaches 160 µm, at which time the relationship reverses itself. If the thickness of the device is greater than 100 µm, the overall efficiency of the device will decrease. Due to physical constraints, such as the bending impact of conventional aluminium back surface fields and the difficulties associated with handling such a minuscule device, manufacturers frequently opt for devices with a thickness exceeding 150µm. This is despite the fact that devices with a thickness of 100µm have a higher efficiency than those with a thickness of 150µm. When anything is being manufactured, it is essential to take into consideration characteristics such as dependability, longevity, and resistance to adverse weather conditions.

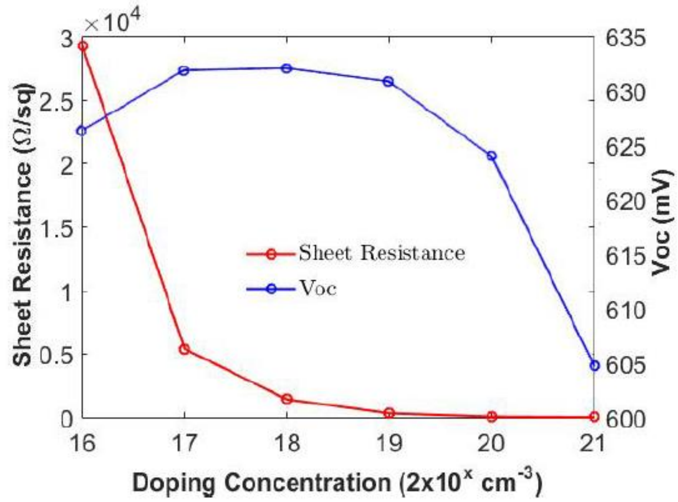
OPTIMISING DEVICE PERFORMANCE WITH VARYING EMITTER DOPING CONCENTRATIONS

A considerable amount of the light is absorbed at the surface of the solar cell, which provides the solar cell with the ability to produce a high output rate. In order to achieve the highest possible level of light absorption, it is essential to make precise adjustments to the thickness of the emitter as well as the doping concentration. It is possible for an increase in the concentration of doping in these layers to result in a drop in efficiency due to a decrease in light transmission and absorption as well as an increase in the rate of recombination [17]. However, in order to make the drift transport process easier and to get a reduced sheet resistance, it is also important to have a concentration that is suitably high. Table 3 illustrates the effect that different doping concentrations have on the sheet resistance as well as the overall performance of the device. The relationship between the concentration of emitter doping and the resistance of the emitter sheet and V_{oc} is seen in Figure 3. Doping concentration (C_{dop}) and sheet resistance (R_{sht}) are two examples of measures that are extremely important in this industry.

Table 3: Sheet resistance & device performance as a function of emitter doped concentrations

J_{sc} (mA/cm^2)	**V_{oc} (mV)**	**η (%)**	**R_{sht} (Ω/sq.)**	**C_{dop} (cm^{-3})**	**FF (%)**
34.33	604.3	17.75	8.7	$2X10^{21}$	77.48
37.22	623.6	17.83	71.85	$2X10^{20}$	77.70
37.49	630.5	17.91	421.7	$2X10^{19}$	77.80
37.52	631.7	17.99	1751	$2X10^{18}$	77.79
37.52	631.5	18.04	7852	$2X10^{17}$	77.78
37.52	625.9	18.12	79650	$2X10^{16}$	77.73

Figure 3: Impact of Concentration of Emitter Doping on Emitter Sheet Resistance & V_{oc}



Because of its low sheet resistance, a device with a thickness of 150 µm and an emitter doping concentration of 2×10^{20} cm^{-3} was selected for this study. Both the sheet resistance and the overall performance of the device are significantly influenced by the thickness of the emitter layer. Each of these factors is important. Table 4 illustrates the performance of the device with a range of different emitter thicknesses. "T_{emt}" is an abbreviation that stands for the word "emitter thickness."

Table 4: Impact of emitter thickness on the efficiency of the device

J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)	T_{emt} (µm)	R_{sht} (Ω/sq.)	FF (%)
29.04	612.5	14.14	0.7	10.26	79.49
30.39	613.0	14.79	0.6	11.98	79.39
31.88	613.6	15.49	0.5	14.37	79.18
33.43	614.3	16.23	0.4	17.96	79.01
34.91	615.3	16.93	0.3	23.95	78.83
36.15	617.0	17.55	0.2	35.93	78.68
36.95	619.7	18.03	0.1	71.85	78.76

When the thickness of the emitter is increased and the sheet resistance is decreased, the values of J_{sc} & V_{oc} fall. This is because the value of Jsc decreases when the sheet resistance decreases. In spite of the fact that a device with a low emitter sheet resistance is believed to be the best option, thick emitters may have major drawbacks. This is because the thick and severely doped emitter layer is unable to allow light to pass through it, which in turn has an influence on the creation of charge carriers. As a result, the device's efficacy is reduced.

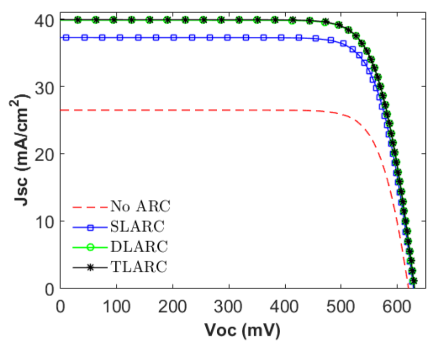
ANTIREFLECTION COATING: AFFECTS ON DEVICE FUNCTION

The antireflection coating, which is also commonly referred to as ARC, is an important component that is necessary for improving the efficiency of solar cells, a thin coating of dielectric material is put to the surface of a solar cell in order to increase the amount of charge carriers that an individual solar cell is capable of producing. Because of this coating, the overall reflectance of the light that is coming in is decreased, and the transmission is improved [16]. In current solar cells, ARCs are made up of stacked layers of dielectric materials that have various refractive indices. These layers can be either single-layered or double-layered, depending on the application need.

Table 5: Effect of different levels of ARC on device performance

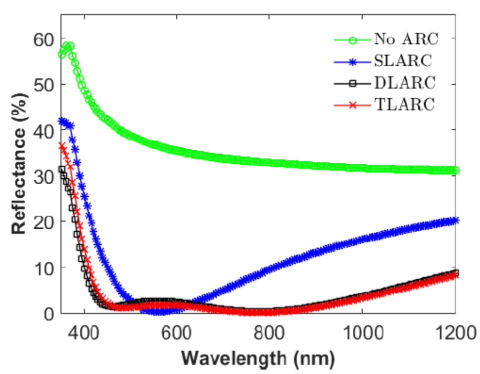
J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)	ARC	FF (%)
39.96	630.6	19.79	TLARC	78.53
39.90	630.6	19.77	DLARC	78.56
37.30	628.8	18.5	SLARC	78.88
26.50	619.8	13.1	None	79.79

By simulating silicon samples with no anti-reflective coating (ARC), one layer of ARC, two layers of ARC, and three layers of ARC, researchers were able to study the effect that applying varying numbers of ARC layers had on the performance of the device. We made use of a single layer of anti-reflective coating (ARC), which was made up of titanium dioxide (TiO_2) and had a thickness of 67 nanometers. The refractive index of this coating was 2.116. Both magnesium fluoride (MgF_2) and zinc sulphide (ZnS) were utilised in the production of the double layer antireflection coating (DLARC), which had refractive indices of 1.39 and 2.371, respectively. The thickness of the DLARC was 107 nm for magnesium trifluoride and 60.5 nm for zinc sulphide, respectively.



(a)

Figure 4 (a)



(b)

Figure 4 (b)

Triple layer anti-reflective coating, also known as TLARC, was made up of three distinct materials: magnesium fluoride, silicon dioxide, and titanium dioxide. It was determined that the refractive indices of these materials were 1.39, 1.48, and 2.453, respectively. For each of the materials, the coating had a thickness of 80 nanometers, 30 nanometers, and 60 nanometers. The findings of each device's performance are presented in Table 5, which may be seen here. The I-V curve and reflectance spectra are depicted in Figure 4a and 4b, respectively, for solar cells that include ARC and those that do not contain ARC.

EVALUATION OF THE BEST MODELLED AND REALISED SOLAR CELL

To ensure that the results of the simulation are accurate, the actual measurements of solar cells were compared to the measurements of a virtual device that had the same characteristics as the real one. There is a comparison of the electrical properties of a real solar cell and a simulated solar cell that is presented in Table 6.

Table 6: Analysing the electrical characteristics of a manufactured solar cell in comparison to an ideal simulated one

J_{sc} (mA/cm^2)	V_{oc} (mV)	η (%)	Type of Data	FF (%)	Pseudo η (%)
37.3	628.8	18.5	Simulated	78.88	-
36.6	617.0	17.7	Real	78.30	18.48

This is demonstrated by the data that is presented in Table 6, which reveals that the simulation results have the capacity to accurately anticipate the actual cell values. When compared to the real cell values, the simulated results were shown to be considerably more favourable overall. The doping concentration of the cell's emitter was found to be 5×10^{20} cm^{-3}, while the doping concentration that was wanted for a uniform emitter in the simulation was found to be 2×10^{20} cm^{-3}. The diameters of the emitters in the cell were 0.6 micrometres and 0.1 micrometres, respectively. When recombination losses are kept to a minimum, even a minor improvement in the performance of the simulated cell has the potential to fall within a range that is considered acceptable. Once resistive losses have been eliminated, the simulation is able to produce an accurate assessment of the cell's potential efficiency, which was found to be 18.48% by the use of the Suns-V_{oc} measuring tool.

CONCLUSION

According to the findings of this study, in order to achieve the best possible conversion efficiency, it is necessary to investigate and determine the settings that are most beneficial for each device parameter. The use of PC1D simulation software is what allows this to be performed. When utilising simulation software, it is of the utmost importance to take into consideration the features of the device. These qualities include the device's stability, durability, capacity to withstand circumstances of severe weather, and the constraints of the manufacturing process. Overall, this study demonstrates that it is possible to use PC1D and other simulation software as a practical alternative throughout the research and development stage of making crystalline silicon solar cells. This is due to the fact that these software programmes are accurate and reliable.

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