Assessing the impact of front grid metallization pattern on the performance of silicon solar cells

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Research Article

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Abstract

The aim of this research work was to assess the impact of front and rear grid metallization pattern on the performance of silicon solar cells. We have investigated the effect of front grid metallization design and geometry on the open-circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF) and efficiency (ŋ) of silicon solar cells by using Griddler 2.5 simulation program. We used different number of metal fingers ranging from 80–120 having width of 60 µm and different number of busbars ranging from 1–5 busbars on the front and rear side of solar cells for optimization. We have also calculated the efficiency and fill factor at different values of front contact resistance ranging from (0.1–100) mohm-cm^2, front and rare layer sheet resistances ranging from (60–110) ohm/sq and different edge gaps. We found that the maximum efficiency and fill factor was obtained with those parameters, when front and rare contact resistances were taken as same. We have designed an optimized silicon solar cell with 115 number of fingers, 4 busbars, front and rare contact resistance of 0.1 mohm-cm^2 and front and rare layer sheet resistance of 60 ohm/sq. In this way we were able to successfully optimize the silicon solar cell having efficiency and fill factor of 19.49 % and 81.36 % respectively, for our best optimized silicon solar cell.

1. Introduction

Renewable energy sources are likely to be stable with respect to time because just the once they are built, they cost very minimum to operate and the fuel is considered almost free. Solar radiations are best source of electricity generation. These radiations can be transformed into heat or electricity according to requirements. Solar photovoltaic and solar thermal conversion are best known methods for electricity production. Over the last five years, the worldwide PV capacity has been increased over 55%. For construction of solar cell, silicon is mostly used material due to its small absorption coefficient and low and indirect band gap, its abundance and high efficiency make it fit for photovoltaic solar cells and arduous for other material to compete it. Silicon solar cell is cheapest way of producing electricity with excellent efficiency and fill factor by using semiconductor material. Electrons and holes that are charge carriers are allow to move in specific direction by electric field of semiconductor material which excited these electrons and holes so that they will be able to take part in electricity production. On solar panel or module, many silicon solar cells are connected electrically in which band of module are arranged together to make solar array [1].

Crystalline silicon is a significant material for photovoltaic due to its low cost, greater and stable conversion efficiency and also because of its efficiently working capability for long time. Crystalline silicon has greater and deep acquisition and framework both for photovoltaic cells and integrated devices. Silicon based PV cells have better efficiency than other module used to convert solar energy into electricity. Under non concentrated sunlight, for commercial and laboratory solar cells efficiency gain is about 24–25%, while theoretically calculated efficiency is 29% [2]. Silicon based technology is significant contributor for energy production capacity of photovoltaic at present and also for anticipated future. Silicon is the only semiconductor material that forms a continuous participation to world energy use by sustaining the growth of photovoltaic into terawatt range per year [3]. For construction of solar cell, silicon is mostly used material, although it have small absorption coefficient and low and indirect band gap, its abundance and high efficiency make it fit for photovoltaic solar cells and arduous for other material to compete it. Cell thickness of substrate is usually about 100–500 μm for light entangling and efficacious surface passivation solar cells. Front surface is usually textured for multiple reflection of light so that maximum light coupled into cell. n-type emitter having ∼1μm thickness and doping level of 100 Ω/sq is used due to its better surface quality than p-type and is implanted at confront to absorb maximum light. All generated current cannot be conducted by silicon due to its tremendous resistivity, hence metal grid having fingers width of 20–200 μm and placed at 1–5 mm apart are used to take the current outside from surface. The simulative PV installations including off-grid have compound annual growth rate (CAGR) of about 35% in 2010–2019. In the year 2019 Si-wafer based PV technology accounted for 95% of total production. The mono-crystalline solar cell now contributes 66% of total production that is much higher compare to the year 2018 when it shares 45% of total production. In the year 2019 china win the battle with a share of 66% in PV module production while Europe devoted with a share of 3% and USA/CAN share 4%. There is the efficiency comparison of different type of solar cells. A record lab efficiency of about 46% is achieved by high concentration multi-junction solar cells According to the Fraunhofer report 2019; the mono-crystalline silicon solar cells have 26.7 % efficiency whereas multi-crystalline silicon solar cells have 22.3 % efficiency. The front grid design of solar cell is very crucial for extraction of maximum power from solar cell. Metallization could vary the performance of solar cell optically and electrically. Optical and electrical losses could lessen the performance of solar cell [4]. It was also reported that quick alloying of PV168 Ag paste on high sheet-resistance emitters of (100 Ω/sq) could produce high-quality Dupont screen-printed Ag contacts. It was explained that, in a belt furnace due to 900°C spike firing of the PV168 paste, excellent specific contact resistance of (1 mΩ - cm^2) with large fill factor (FF) of (0.775) was obtained on 100 Ω/sq emitters [5]. In 2011, it was investigated that 0.2 $\%_{abs}$ efficiency was attained for multi crystalline silicon solar cells by lowered the phosphorous doping concentration peak and increased the uniform emitter sheet resistance from (66–76) ohm/sq. According to them, to attain this bettered efficiency no extra time and steps are required [6]. The role of metallization on optical and electrical performance of solar cells was reviewed by Ebong *et al*. in their paper. They described that short circuit current affected optically due to grid line width which caused shading and electrically fill factor was strongly affected due to variation in series resistance through contact and gridline. They reviewed formation of contact in this paper and narrated that second most expensive step for fabrication of solar cell was metallization. They stressed to make photovoltaic industry less expensive through use of less metal for designing of contact [7]. A comprehensive overview about performance of solar cells with multi-busbars and modules was done by Braun *et al*. They metallized the front side of solar cell by fine line screen printing technology while there was full aluminum on rare side of solar cell. They also compared efficiencies and Ag metal consumption of three busbars and multi-busbars solar cells. In their research work they related the performance of four module multi-busbars solar cells with industrial type three busbars solar cells that showed average fill factor gain at module level of about 0.6 $\%_{abs}$. They also achieved about 50 $\%_{abs}$ decrease in Ag paste consumption during front grid screen printing metallization of solar cell with multi-busbars [8]. The parameters of front surface metallization of solar cells that could significantly affect the cell efficiency were also studied by Lorenz et al. They demonstrated the major goal of researchers that was to realize the narrow lateral fingers of less resistance. They also explained that lateral finger resistance could be lowered by enhancing roughness of textured surfaces and it was beneficial due to increase in fill factor of about $+ 0.24\ \%_{\text{abs}}$ [9]. Photovoltaic is one of the significant and dominant technologies to stop the problematic issues of environment without affecting the durable progress. However there is a need to minimize the efficiency and cost related issues of solar cells. In solar cell fabrication, metallization is second most expensive step. To achieve maximum efficiency and fill factor, we have to optimize the numbers, width, height of fingers and busbars and also spacing between them. Increasing the number of busbars and fingers reduce the efficiency and fill factor of cell due to shading losses effect and it also augments the expense of solar cells, as silver paste is used for making busbars. Researches revealed that efficiency and cost of solar cell rises by augmenting the number of busbars as maximum efficiency could be achieved with 4 busbars, above this no efficiency increase was reported due to increase in shading losses. It is important for us to reduce the use of silver paste during the cell fabrication by optimizing the numbers, width, height and spacing of busbars and fingers, so that maximum efficiency, fill factor and longer life span could be achieved with low cost. It will be more crucial and worth step for commercializing the solar cell. Low cost, longer life span and maximum conversion efficiency are three basic steps for commercializing the solar cell. The aim of this research work was to study the effect of front and rear grid metallization on the performance of multi-crystalline silicon solar cells. The different number of busbars and fingers, as (1–5) and (80–120) respectively were used in solar cells simulation by Griddler 2.5 [10]. The Griddler 2.5 is a finite element model (FEM) simulation program settled at SERIS. It is free, fast and efficient simulation program for solar cell metallization

2. Materials And Methods

Silicon solar cells were simulated by optimizing the front grid design of solar cell. This research work was done to calculate the efficiency (%), fill factor (%), short circuit current (mA/cm^2) and open circuit voltage (mV) for different numbers, and styles of fingers and busbars on the front and rare side of silicon solar cell. Griddler 2.5 simulation tool was used during this research work.

2.1 Input parameters used for silicon solar cell simulations

We have simulated silicon solar cells with different front grid designs by using Griddler 2.5 simulation tool. We have used this simulator to find the effect of front side metallization design and geometry on the efficiency (%), fill factor (%), open circuit voltage (mV) and short circuit current density (mA/cm^2) of silicon solar cells because it has built-in interface for front H-pattern design and back metal grids. We have used different number of finger and busbars for silicon solar cell optimization. We have used 1,2,3,4 and 5 number of busbars along with different number of fingers ranging from 80–120 on the front and rear side of silicon solar cell to check their effect on efficiency and fill factor of silicon solar cells.

Silicon solar cell was simulated on larger area (156 x 156) mm square shape silicon wafer having ingot diameter of 21 cm. We have used 15 probes or solder points on busbars having straight endings and also joined the ends in pairs. We have used two split style and single print method for front and back design of busbars having width of 1.3 mm. We used different number of metal fingers ranging from 80–120 having width of 60 μm on rear and front side of solar cells for the optimization study. We also used different edge gaps from 0.1- 1mm for cell optimization and also check their effect on open circuit voltage (V_{OC}), short circuit current density (J_{SC}), efficiency and fill factor of silicon solar cells. The front and rear diode parameters were kept fixed throughout simulation work that were 39.6 mA/cm^2, 1-sun illumination on front and back side of the silicon solar cells. The front J_{01} passivated area and J_{01} metallized contact value were 168 fA/cm^2 and 595 fA/cm^2 respectively. The front J_{02} passivated area and J_{02} metallized contact value were 3 nA/cm^2. The rare J_{01} passivated area and metallized contact value were 13.1 fA/cm^2 and 794.2 fA/cm^2 respectively.

We have also completed front and rear metallization by using front sheet resistance of 2.82 mohm/sq and rear sheet resistance of 10 mohm/sq. We have used different values front and rear contact resistance for solar cell metallization ranging from 0.1–100 mohm-cm^2. We have completed our simulations by using different contact resistances on the front and rear surface of solar cells and studied the efficiency and fill factor of silicon solar cells as well by keeping them same. Then we have also changed the front and rear layer sheet resistance from 60–110 ohm/sq. At first have calculated the efficiency, fill factor FF, open circuit voltage (V_{OC}) and short circuit current (J_{SC}) with 1, 2, 3, 4 and 5 number of busbars having width of 1.3 mm. We used these busbars with different number of fingers ranging from 800 – 120 having width of 60 μm. We have simulated silicon solar cells by using the following parameters:

Front contact resistance = 2 mohm-cm^2,

Rare contact resistance = 5 mohm-cm^2

Front and rare layer sheet resistance = 80 ohm/sq

Front sheet resistance = 2.82 mohm/sq

Rare sheet resistance = 10 mohm/sq

Then we selected those fingers and busbars for which maximum efficiency and fill factor was achieved and did further optimization of front grid design of silicon solar cells by varying the front and rare contact resistance from 0.1–100 mohm-cm^2 and keeping all the other variables constant. The simulations were repeated by varying edge gap between 0.1-1 mm. The input parameters used in silicon solar cell simulations by Griddler 2.5 are given in Table 1.

Table 1
Input parameters used for modelling [10]

Parameters	Values	Parameters	Values
Cell shape	Square	Front finger contact resistance	2 mΩ-cm2
Cell length	156 mm	Front layer sheet resistance	80 Ω/sq
Cell width	156 mm	Rear finger sheet resistance	10 mΩ/sq
Ingot diameter	21 cm	Rear finger contact resistance	5 mΩ-cm^2
Number of busbars	4	Rear layer sheet resistance	80 Ω/sq
Busbar width	1.3 mm	Temperature	25°C
Style	Two split	Front $J_{01\ passivated}$	168 fA/cm^2
Busbar ending	Straight	Front $J_{01\ metal}$	595 fA/cm^2
Print method	Single print	Front $J_{02\ passivated}$	3 nA/ cm^2
Number of fingers	115	Front $J_{02\ metal}$	3 nA/ cm^2
Solder/probe points	15	Rear $J_{01\ passivated}$	13.1 fA/cm^2
Finger width	60 um	Rear $J_{01\ metal}$	794.2 fA/cm^2
End joining	Pairs	Edge gap	0.5
Finger sheet resistance	2.82 mΩ/sq	Front illumination	1 sun

2.2 Silicon solar cell simulations by using (1–5) number of busbars and (80–120) fingers

We have calculated the efficiency, fill factor, open circuit voltage V_{OC} and short circuit current J_{SC} by using 1, 2, 3, 4 and 5 number of busbars for different number of fingers ranging from 80–120. We draw a graph between numbers of fingers, efficiency and fill factor.

2.3 The effect of front contact resistance on performance of silicon solar cells

We have calculated the efficiency, fill factor, open circuit voltage V_{OC} and short circuit current J_{SC} by using 4 busbars and 110,115 and 120 fingers for different contact resistances 0.1, 0.5, 1, 5, 10, 50 & 100 mohm-cm^2.We draw a graph between contact resistance, efficiency and fill factor. All other input parameters were kept constant throughout this simulation.

2.4 The effect of equal value of front and rare contact resistance on the performance of silicon solar cells

We have done further optimization of silicon solar cells by keeping the front and rare contact resistance same at a time. We have find out the efficiency and fill factor of solar cells with 4 busbars and 100,115 & 120 fingers at different front and rare contact resistances ranges from (0.1–100) mohm-cm^2. We have used the values of front and rare contact resistance as 0.1, 0.5, 1, 5, 10, 50 and 100 mohm-cm^2.

2.5 The effect of equal value of front and rare layer sheet resistance on performance of silicon solar cells

We have also changed the front and rare layer emitter sheet resistances values same at a time to calculate the efficiency and fill factor of solar cell by keeping all other parameters constant. We varied the front and rare layer sheet resistance value from (60–110) ohm/sq for 4 number of busbars and 110, 115 and 120 number of fingers. All other input parameters were kept constant throughout this simulation.

3. Results And Discussion

3.1 Silicon solar cell simulations by using (1–5) busbar and fingers ranging from 80–120

The results are shown in Fig. 1. It showed that when the number of fingers is varied from 80–120, there is an increase of efficiency from (9.49–12.61) %. The open circuit voltage was 658 mV and remained same for all these fingers ranging from 80–120. The short circuit current density decreased from (38.03–37.45) mA/cm^2. The fill factor was increased from 37.92 % to 51.17 % by increasing number of fingers on front and rare side of solar cells for 1 busbar design.

The results are shown in Fig. 2. It showed that as number of fingers is varied from 80–120, there is an increase of efficiency from (17.02–18.12) %. The open circuit voltage was 657 mV for 80 and 85 fingers and decreased for all other fingers and was 656 mV. The short circuit current density decreased from (37.74–37.15) mA/cm^2. The fill factor was increased from 68.68 % to 74.33 % by increasing number of fingers on front and rare side of solar cells for 2 busbars design.

The results are shown in Fig. 3. It showed that as the number of fingers is varied from 80–120; there is an increase of efficiency from 18.61–19.07%. The open circuit voltage was 656 mV and remained same for all these fingers ranging from 80–120. The short circuit current density was decreased from (37.43–36.83) mA/cm^2. The fill factor was increased from 75.84% to 79.02 % by increasing number of fingers on front and rare side of solar cell from 80–120 for 3 busbars design of silicon solar cell.

The results are shown in Fig. 4. It showed that as the number of fingers is varied from 80–120; there is an increase of efficiency from 19.01–19.26%. We have obtained maximum efficiency at 4 busbar and 115 fingers. The open circuit voltage was 655 mV for 80–115 and was 654 mV for 120 fingers. The short circuit current density decreased from (37.11–36.52) mA/cm^2. The fill factor was increased from 78.27 % to 80.56 % by increasing number of fingers on front and rare side of solar cell from 80–120 for 4 busbars design of silicon solar cell.

The results are shown in Fig. 5. It showed that as the number of fingers is varied from 80–120, there is an increase of efficiency from 19.09 % to 19.23%. The open circuit voltage was 654 mV and remained same for all these fingers ranging from 80–120. The short circuit current density decreased from (36.8–36.21) mA/cm^2. The fill factor was increased from 79.39 % to 81.25 % by increasing number of fingers on front and rare side of solar cell from 80–120 for 5 busbars silicon solar cell design

3.2 The effect of front contact resistance on the performance of silicon solar cells

We concluded that maximum efficiency and fill factor was obtained with 4 busbars and 110–120 fingers solar cells design. We have done further optimization at these numbers of fingers and busbars for different contact resistances ranging from (0.1–100) mohm-cm^2. All other inputs parameters that were kept same as given in Table 1.

Front contact resistance = 0.1–100 mohm-cm^2

3.2.1 Silicon solar cell simulations by using 4 busbars and 110, 115, 120 fingers for contact resistance of (0.1–100) mohm-cm ^{2}

The results are shown in Fig. 6. It showed that as the contact resistance varied from (0.1–100) mohm-cm^2, there is a decrease of efficiency from 19.31–16.61%. The open circuit voltage was also decreased from (655–652) mV for 110 fingers and 4 busbars at different front contact resistance values. The short circuit current density remained constant and was 36.67mA/cm^2. The fill factor was decreased from 80.44 % to 69.45 % by increasing front contact resistance.

The results are shown in Fig. 7. It showed that as the contact resistance varied from (0.1–100) mohm-cm^2, there is a decrease of efficiency from 19.31–16.75%. The open circuit voltage was decreased from (654–652) mV for 115 fingers and 4 busbars at different front contact resistance. The short circuit current density remained constant and was 36.59 mA/cm^2. The fill factor was decreased from 80.62 % to 70.15 % by increasing front contact resistance.

The results are shown in Fig. 8. It showed that as the contact resistance varied from (0.1–100) mohm-cm^2, there is a decrease of efficiency from 19.3 % to 16.86 %. The open circuit voltage was decreased from (654–652) mV for 120 fingers and 4 busbars at different values of front contact resistance. The short circuit current density remained constant and was 36.52 mA/cm^2. The fill factor was decreased from 80.78 % to 70.75 % by increasing front contact resistance.

3.3 The effect of equal value of front and rare contact resistance on the performance of silicon solar cells

We concluded that maximum efficiency and fill factor was obtained with 4 busbars and 110–120 fingers silicon solar cell design. We have done further optimization at these number of fingers and busbars for front and rare contact resistances variation ranging from (0.1–100) mohm-cm^2. We have done optimization by keeping contact resistances on the front and back side of solar cell as same. All other inputs parameters used in simulation were same as given in Table 1.

Front and rare contact resistance = (0.1–100) mohm-cm^2

3.3.1 Silicon solar cell simulations by using 4 busbar and 110, 115, 120 fingers for front and rare contact resistance of (0.1–100) mohm-cm ^{2}

The results are shown in Fig. 9. It showed that as the front and rare contact resistance is varied equally from (0.1–100) mohm-cm^2, there was a decrease of efficiency from 19.44 % to 14.15 %. The open circuit voltage was decreased from (654–653) mV for 110 fingers and 4 busbars at different (front and rare) contact resistance values. The short circuit current density remained constant and was 36.67 mA/cm^2. The fill factor was decreased from 81.02 % to 59.08 % by increasing front and rare contact resistance.

The results are shown in Fig. 10. It showed that as the front and rare contact resistance varied equally from (0.1–100) mohm-cm^2, there is a decrease of efficiency from 19.44 % to 14.38 %. The open circuit voltage was decreased from (654–653) mV for 115 fingers and 4 busbars at different front and rare contact resistance values. The short circuit current density remained constant and was 36.59 mA/cm^2. The fill factor was decreased from 81.17 % to 60.17 % by increasing front and rare contact resistance.

The results are shown in Fig. 11. It showed that as the front and rare contact resistance is varied equally from 0.1–100 mohm-cm^2, there is a decrease of efficiency from 19.43 % to 14.57 %. The open circuit voltage was decreased from (654–653) mV for 120 fingers and 4 busbars at different front and rare contact resistance. We used different values of front and rare contact resistance from (0.1–100) mohm-cm^2. We picked a specific value from this range for front and rare contact resistance. The short circuit current density remained constant and was 36.52 mA/cm^2. The fill factor was decreased from 81.31 % to 61.11 % by increasing front and rare contact resistance.

3.4 The effect of front and rare layer sheet resistance on the performance of silicon solar cells

We have used different values of front and rare layer sheet resistances for further optimization of silicon solar cells. We have used 4 busbars, 100, 115 and 120 fingers for this optimization. We have checked the effect of front and rare layer sheet resistances on the efficiency and fill factor of silicon solar cell.

Front and rare layer sheet resistance = (60–110) ohm/sq

3.4.1 Silicon solar cell simulations by using 4 busbars and 110, 115, 120 fingers for front and rare layer sheet resistance of (60–110) ohm/sq

The results are shown in Fig. 12. It showed that as the front and rare layer sheet resistance is varied from 60–110 ohm/sq, there is a decrease of efficiency from 19.32 % to 19.15 %. The open circuit voltage was decreased from (655–654) mV for 110 fingers and 4 busbars at different front and rare sheet resistance. We have used different values of front and rare layer sheet resistance from (60–100) ohm/sq. We picked a specific value from this range for front and rare layer sheet resistance. The short circuit current density remained constant and was 36.67 mA/cm^2. The fill factor was decreased from 80.44 % to 79.83% by increasing front and rare layer sheet resistance

The results are shown in Fig. 13. It showed that as the front and rare layer sheet resistance varied from (60–110) ohm/sq, there is a decrease of efficiency from 19.32 % to 19.17 %. The open circuit voltage was decreased from (655–654) mV for 115 fingers and 4 busbars at different front and rare sheet resistance. We have used different values of front and rare layer sheet resistance from (60–100) ohm/sq. We picked a specific value from this range for front and rare layer sheet resistance. The short circuit current density remained constant and was 36.59 mA/cm^2. The fill factor was decreased from 80.61 % to 80.07 % by increasing front and rare layer sheet resistance.

The results are shown in Fig. 14. It showed that as the front and rare layer sheet resistance is varied from (60–110) ohm/sq, there is a decrease of efficiency from 19.31 % to 19.17 %. The open circuit voltage was decreased from (655–654) mV for 120 fingers and 4 busbars at different front and rare sheet resistance. We have used different values of front and rare layer sheet resistance from (60–100) ohm/sq. We picked a specific value from this range for front and rare layer sheet resistance. The short circuit current density remained constant and was 36.52 mA/cm^2. The fill factor was decreased from 80.75 % to 80.27 % by increasing front and rare layer sheet resistance.

3.5 The final optimized silicon solar cell

We have found the optimized efficiency and fill factor of silicon solar cell by using all the best vales of contact resistance, emitter sheet resistance, and edge gap at the same time for 4 busbars 120 fingers design. At first we have done our calculations by changing a single resistance while keeping all other parameters constant. We have changed front and rare contact resistance from (0.1–100) mohm-cm^2 and varied the front and rare layer sheet resistances from (60–110) ohm/sq to calculate efficiency and fill factor of silicon solar cells. Then we have selected those values of resistances at which we have attained maximum efficiency and fill factor. Then we used these values together at the same time to calculate efficiency and fill factor. We have designed the front and rare surface of silicon solar cell by using front and rare contact resistance of 0.1 mohm-cm^2 and front and rare layer sheet resistance of 60 ohm/sq. We have used edge gap of about 0.5 mm with two split style. The open circuit voltage was 656 mV and short circuit density was 37 mA/cm^2. The efficiency and fill factor are 19.49 % and 81.36 % respectively for the optimized pattern of silicon solar cell.

Table 2
The fill factor and efficiency of final optimized silicon solar cell

No of Fingers	No of Busbars	Front and rare contact Resistance of (mohm-cm^2)	Front & Rare layer Sheet Resistance (ohm/sq)	V_{oc} (mV)	J_{sc} (mA/cm^2)	Fill Factor (%)	Efficiency (%)
115	4	0.1	60	656	37	81.36	19.49

4. Conclusion

In this research work we have studied the effect of front grid metallization pattern on the performance of silicon solar cells. We have used different number of fingers, busbars, contact resistance, sheet resistance and edge gap for silicon solar cells optimization. We have designed an optimized silicon solar cell with 115 number of fingers, 4 busbars, front and rare contact resistance of 0.1 mohm-cm^2 and front and rare layer sheet resistance of 60 ohm/sq. We have used edge gap of about 0.5 mm with two split style. At last we were able to successfully optimize the silicon solar cells. The efficiency and fill factor comes out 19.47 % and 81.26 % respectively, for our best optimized silicon solar cell.

Declarations

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Conflict of interest:

The authors declare that they have no conflict of interest.

Author contribution:

Sofia Tahir: She did the analysis of the whole data given in the manuscript.

Saba Siraj: She completed the whole simulation work on Griddler 2.5.

Adnan Ali: He helped in the editing of the manuscript.

Availability of data and material:

The data and material is available in this manuscript.

Compliance with ethical standards:

This chapter does not contain any studies with human participants or animals performed by any of the authors.

Consent to participate:

Informed consent was obtained from all individual participants included in the study.

Consent for publication:

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Figures

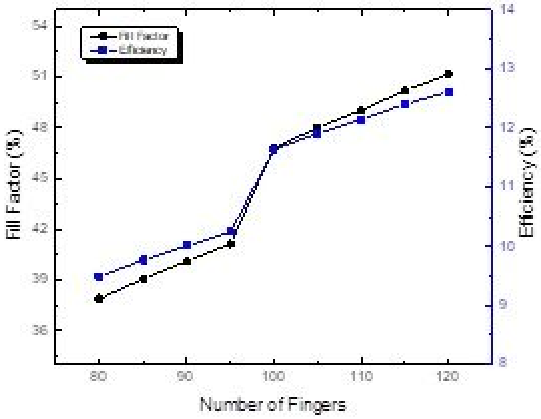

Figure 1

The effect of 1 bubars and 80-120 fingers on efficiency and fill factor

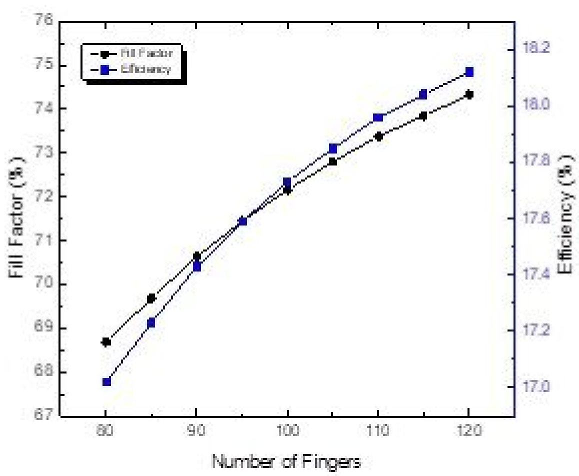

Figure 2

The effect of 2 bubars and 80-120 fingers on efficiency and fill factor

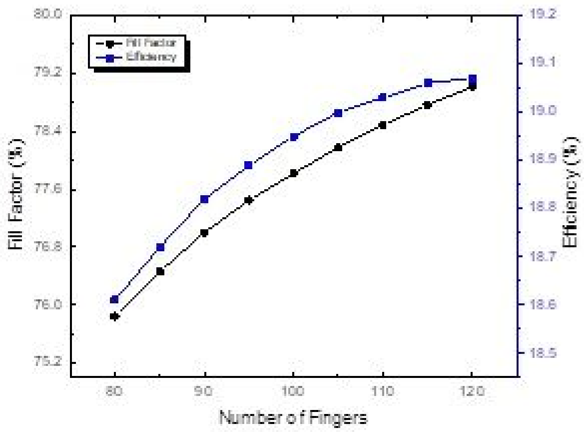

Figure 3

The effect of 3 bubars and 80-120 fingers on efficiency and fill factor

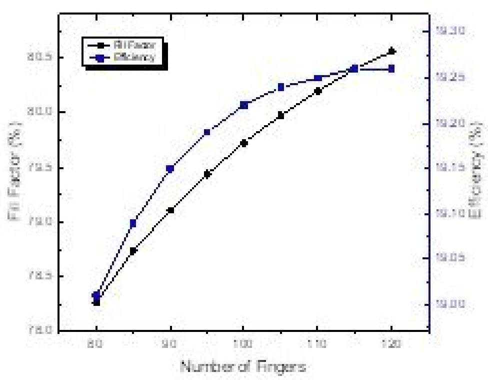

Figure 4

The effect of 4 bubars and 80-120 fingers on efficiency and fill factor

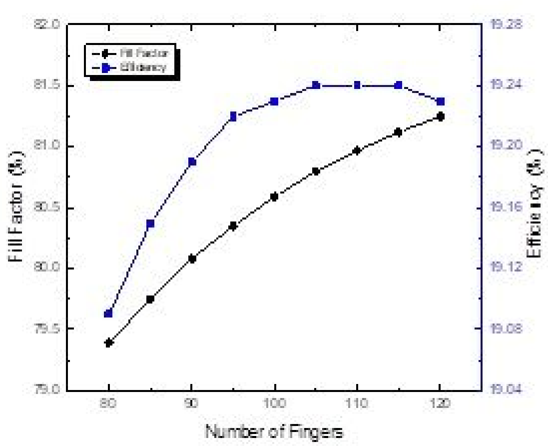

Figure 5

The effect of 5 bubars and 80-120 fingers on efficiency and fill factor

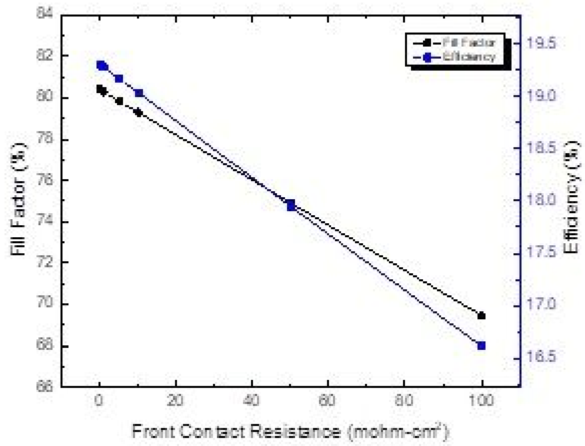

Figure 6

Effect of different contact resistance on efficiency of solar cell having 4 busbars and 110 fingers

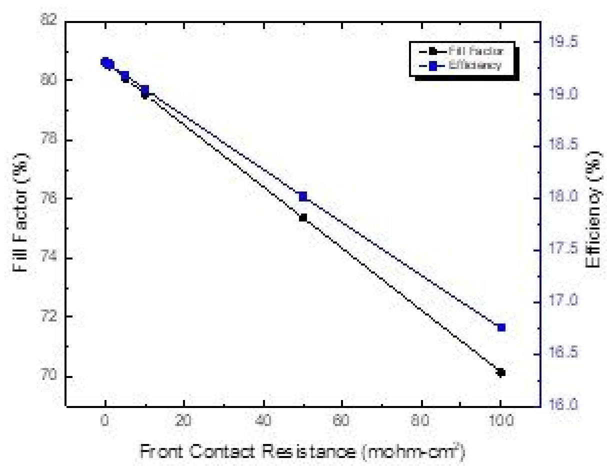

Figure 7

Effect of different contact resistance on efficiency of solar cell having 4 busbar and 115 fingers

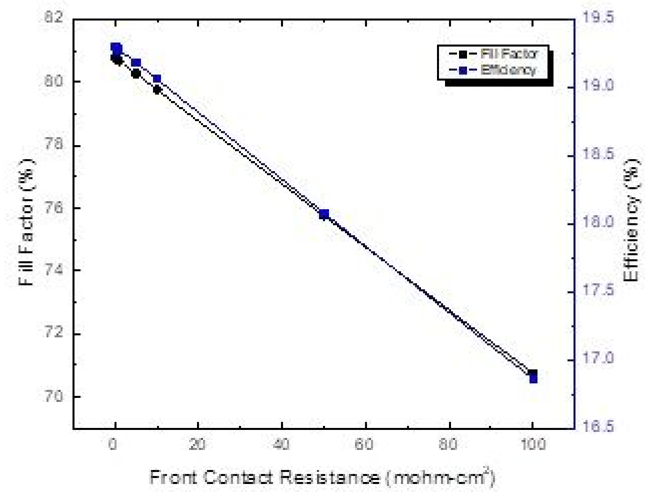

Figure 8

Effect of different contact resistance on efficiency of solar cell having 4 busbars and 120 fingers

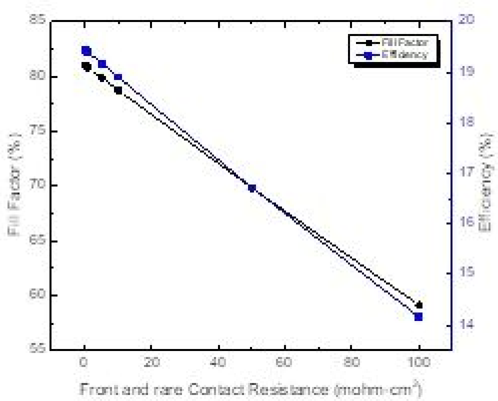

Figure 9

Effect of different Front and rare contact resistance on efficiency of solar cell having 4 busbar and 110 fingers

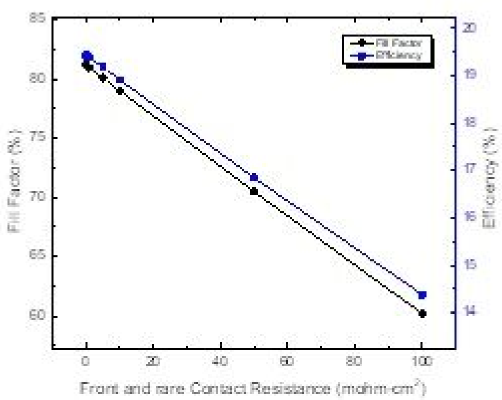

Figure 10

Effect of different Front and rare contact resistance on efficiency of solar cells having 4 busbar and 115 fingers

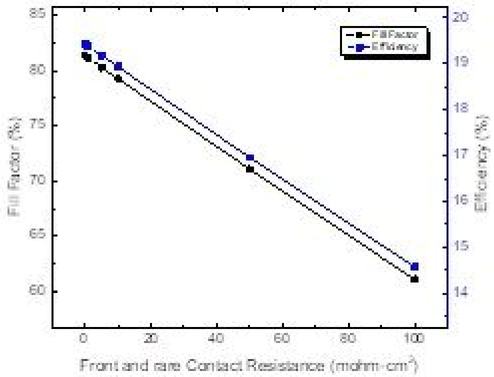

Figure 11

Effect of different Front and rare contact resistance on efficiency of solar cells having 4 busbar and 120 fingers

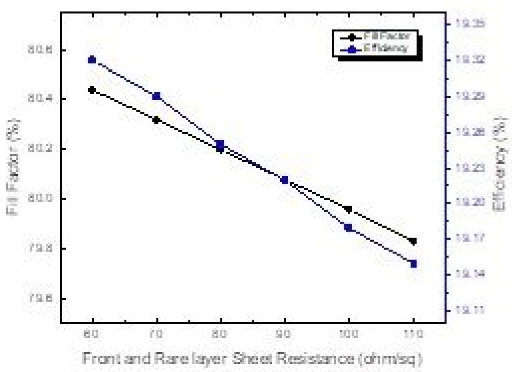

Figure 12

Effect of different Front and rare layer sheet resistance on efficiency of solar cells having 4 busbars and 110 fingers

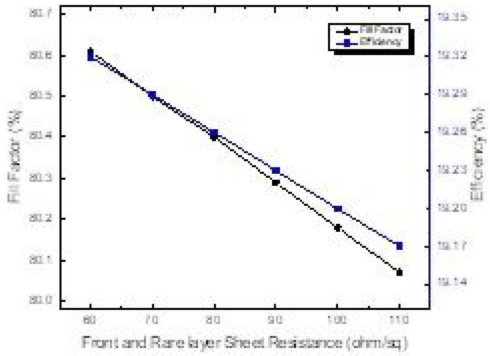

Figure 13

Effect of different Front and rare layer sheet resistance on efficiency of solar cells having 4 busbar and 115 fingers

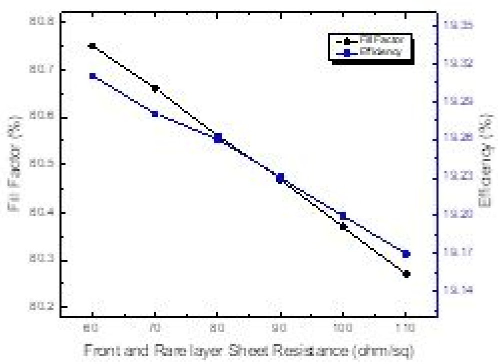

Figure 14

Effect of different Front and rare layer sheet resistance on efficiency of solar cells having 4 busbars and 120 fingers