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Computation and Validation of Series Resistance of Crystalline Silicon Solar Cell

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ABSTRACT:Series resistance of solar cell losses contributes to around 20% of the total input power. The series resistance of solar cell degrades fill factor and cell efficiency. So, it is necessary to reduce series resistance to a small value to keep the resistive element low. The series resistance of cell is a sum of several components such as Emitter layer resistance, Metal semiconductor contact resistance, Metal bus bar resistance, Metal finger resistance and Bulk semiconductor resistance. The series resistance of a module is the sum of interconnect tin copper ribbon resistance, busing ribbon resistance and junction box resistance. The reduced series resistance improves the fill factor and minimizes the cell to module conversion loss. In this project the detailed estimation of the solar cell series resistance is established and compared the calculated values with measured values.

KEYWORDS: Series resistance, Fill Factor, Cell to module conversion loss

I.INTRODUCTION

Research is proceeding to enhance the efficiency up to its theoretical point which could be accomplished by diminishing solar cell losses which are very high when compared with conventional energy sources. Solar cell produced by the industrial processing has efficiency of the range 15-18% this exhibits around 85 to 83% losses happen in the solar cell. If the loss is overwhelmed, increased efficiency can be achieved. The main losses of solar cell are:

Reflection loss: The reflection loss happens from front surface of the solar cells which gets the radiation. Reflection lessens the absorption of carriers and so the I_{sc}. Therefore it is important to enhance the absorbing capacity and decrease reflectivity to enhance I_{sc}. For silicon without anti-reflective coating these losses represent around 30%. To decrease the reflectivity of solar cells a typical approach is, by applying an antireflective coating deposited using PECVD on front surface of the solar cells. This loss occurs in the solar is 15% for properly done texturization and with anti- reflective coating. The decreased reflection increases the absorption of carriers.

Recombination loss: Photon hits the solar cell produces electron- hole pairs these generated pairs are called carriers. Carriers generated should be detached before they try to recombine, with emission of energy. Recombination causes reduction of carriers and influences the cell performance. Open circuit voltage V_{oc} of the cell is influenced by carrier recombination. As recombination builds the V_{oc} diminishes. Different methods are utilized to decrease the recombination that occur in solar cells and enhance Voc. The generated carriers are in the whole volume of the solar cell material. The carriers produced near space charge region are isolated out rapidly as they escape by the 'electric field introduced in the depletion region'. Though the carriers which are produced far away the space charge region or depletion region that is in the base region at back surface or at the front surface have less likelihood of getting isolated. These carriers get lost and do not add up to the short circuit current if would they recombine.

Series resistance: Series resistance losses would contribute to around 20% of the total input power. But this loss increase extremely at high intensities. Losses in the cell are because of the series resistance which is directly proportional with the square of concentration ratio. Hence high concentration ratio makes losses to increase, reducing fill factor and efficiency. Series resistance includes bulk resistance, emitter layer resistance, metal finger resistance,

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metal busbar resistance and metal semiconductor resistance. All the components contribute more losses except the bulk resistance.

Thermal loss: A major part of loss in solar cell occurs because of heat. Photons absorbed by the cell have more energy than that is needed for production of electron-hole pair. This additional energy is emitted in the form of heat. This thermal energy leads to increase in temperature of a cell. The affected parameters due to rise of temperature are diffusion length, band gap energy, intrinsic carrier density, minority carrier lifetime. When there is increase in minority carrier concentration, diffusion length and intrinsic carrier concentration and when there is decrease in band gap energy leads to increased reverse saturation current. The increased in reverse saturation current minimizes open circuit voltage which makes the efficiency to the cell to reduce.

In this work, it is more focused on series resistance of a solar cell. It's a sum of busbar resistance, front finger resistance, Metal-semiconductor resistance, emitter sheet resistance, bulk substrate resistance. It degrades the fill factor and thus the efficiency of solar cell. So it's necessary to understand the importance of all the components of the series resistance and reduce series resistance value as low as possible

II.LOSSES OF SERIES RESISTANCE IN A SOLAR CELL

Series resistance of a solar cell includes,
1. Emitter resistance
2. Front and back contact resistance
3. Metal busbar and finger resistance
4. Bulk resistance

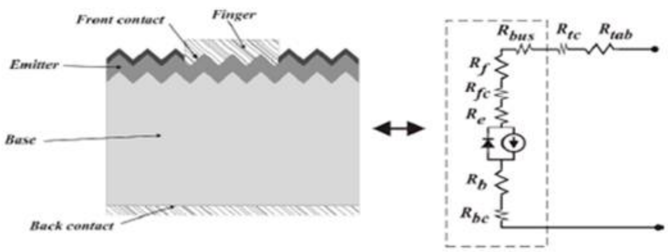

Fig 1: Series resistance losses in solar cell

In the figure 1, it shows the solar cell model and the components of the solar cell which are in series has to be calculated to find out the total series resistance.

Emitter layer resistance: Emitter layer resistance is the measure of thin films resistance. Emitter layer resistance of solar cell is the most dominant component of series resistance. Emitter resistance can be experimentally measured using four point probe method and it is favorable to have resistance value ranging from 85-100Ω/square. Emitter resistance increases because of thin layer thickness of emitter. One technique to reduce emitter resistance is by optimizing the p-n junction thickness. This thickness can be accomplished by appropriate concentration of doping. And also depends on the technology used for front contact placing that is photolithography or screen printing.

Metal-semiconductor contact resistance: A major component of series resistance is the metal-semiconductor contact resistance. Metal contacts are needed in the solar cells to collect the generated carriers and transport them to deliver power to the load. Solar cells have metal contacts at front surface as well as back surface. The front surface contact is of form of fingers or grids and busbars whereas the back surface contact is of form of metal plate which covers whole back area of the solar cell. The metal-semiconductor contact resistance depends on the contact area. High the area, low is the contact resistance and low the area, high is the contact resistance. Finer the width of finger will have more fingers in the front surface contact. This will increase collection of current and minimize metal-semiconductor contact resistance. This is because of reduced current crowding at the edges of the contact.

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Metal finger and busbar resistance: A considerable loss occurs in the Metal busbar and finger resistance of the solar cell. On the back side and front side of the solar cell the metal contacts are have been placed for the collection of carriers and transport them to deliver power to the load. The fine fingers or gridlines and the busbars cover as the front contact surface whereas the metal plate covers the entire back contact surface. The fingers or gridlines and bus bars on the front surface cause shading. This reduces the collection of carriers. The shading can be avoided by many different techniques such as inter-digitated back contact in which whole front surface is exposed to sun and both the contacts are put at the back surface of the solar cell. Conventional screen printed contacts solar cells having H-finger structure that can be modified by using various other fingers design to avoid metal resistance and shadow loss.

Bulk resistance: Bulk substrate of crystalline silicon is widely used in the current photovoltaic market. Appropriately band gap of silicon is little low for a better solar cell. Silicon has a low absorption co-efficient and this can be overcome by trapping of light. Silicon is very difficult to grow into sheets. However silicon is available in plenty and is dominating the semiconductor industry as it is difficult for other materials to compete.

III.ESTIMATION OF SERIES RESISTANCE

The calculations of the series resistance to evaluate the components of series resistance are calculated using the summarized equations:

Resistance of Bulk:

$R_{Base} = \rho_{base} * W_{base} / L^2$

Resistance of Emitter:

$R_{emitter} = S^2 / 24L*Re / (L/2-W_{bus})$

Resistance of Front Contact:

$R_{Front\ contact} = S*R_{front\ paste} / L* (W_f * L+2W_{bus}*(S-W_f))$

Resistance of Finger:

$R_{finger} = S/24L * \rho_{metal} / W_f H_f * (L/2-W_{bus})$

Resistance of Back Contact:

$R_{back\ contact} = R_{back\ paste} / L^2$

Resistance of Bus:

$R_{bus} = \rho_{metal} / 24n^2 * L / W_{bus} H_{bus}$

The parameters of the different materials are ρ_{base} (bulk resistivity of the wafer), ρ_{metal} (resistivity of the semiconductor in Ωcm^2), $R_{frontpaste}$ and $R_{backpaste}$ (resistivity of the metallic grid in Ω-cm), parameters of the process and wafer are Re (Emitter layer resistance Ω/sq.), L (wafer size) and W_{base} (base width), front contact design parameters are W_{bus}, W_f, S (width of buses, finger and spacing between fingers), n (no of buses). It is taken according to the industry parameters

The above parameters are used in the equations of different components of the series resistance of a solar cell to estimate the total series resistance and to find out the magnitude of different components.

IV.RESULT AND DISCUSSION

The series resistance obtained from the equations must be validated to check whether theoretical value and measured valued are correct. The measured value is measured using tester which has lamp of intensity 1000 W/m^2 at 25°C and traces I-V curve using four point probes.

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THEORETICAL CALCULATION

The calculation of series resistance of a crystalline silicon solar cell is done for 156 X 156 mm^2 wafer size, 85 ohm/sq. sheet resistance, 95 fingers, 40µm finger width, four busbar, screen printed solar cell. The values of the parameters of a solar cell are used in the above equations. The theoretical value obtained is as follows:

Components of series resistance	Theoretical value of series resistance (m Ohm)
Resistance of bulk	0.16026
Resistance of emitter	0.79988
Resistance of front contact	0.79414
Resistance of fingers	0.64539
Resistance of busbar	0.72204
Resistance of back contact	0.03287
Total series resistance	**3.15458**

Table 1: Theoretical value of series resistance

In the table 1, it shows the theoretical value of the series resistance which is calculated using the above equations and is checked with the measured value.

Theoretical value	Measured value
3.154 m Ohm	3.154 m Ohm

Table 2: Comparison between theoretical and measured value of series resistance

In the table 2, it is observed that theoretical value and measured value are exactly matching and the calculation can be further continued for other design patterns to check for the approximate.

The theoretical calculation at different sheet resistances, fingers and busbars are performed to estimate the lower value series resistance using screen printing process. The graphical representation as follows:

1. **Series Resistance versus Sheet Resistance and fingers**

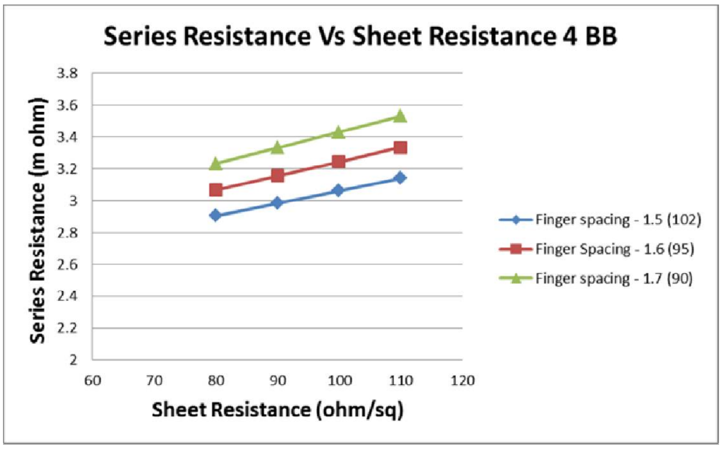

Fig 2: Graphical representation of series resistance versus sheet resistance and fingers.

In the figure 2, it shows that the series resistance increases as the sheet resistance is increased and series resistance decreases as the number of fingers are increased.

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2. **Finger width versus Series Resistance at 95 fingers**

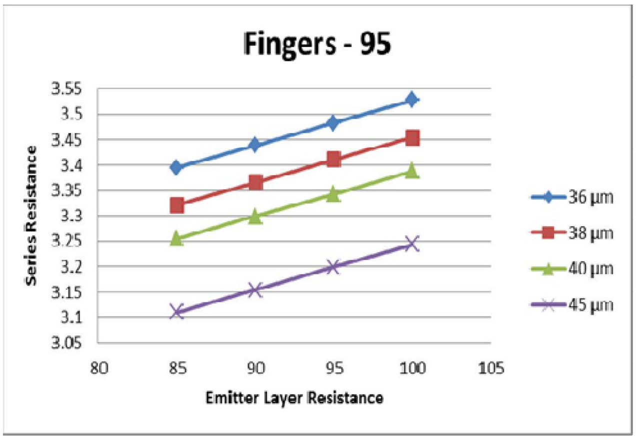

Fig 3: Graphical representation of series resistance at 95 fingers.

In the figure 3, it shows that the series resistance increases when the width of the finger is decreased because of the current crowding at the ends of the fingers.

3. **Finger width versus Series Resistance at 95 fingers**

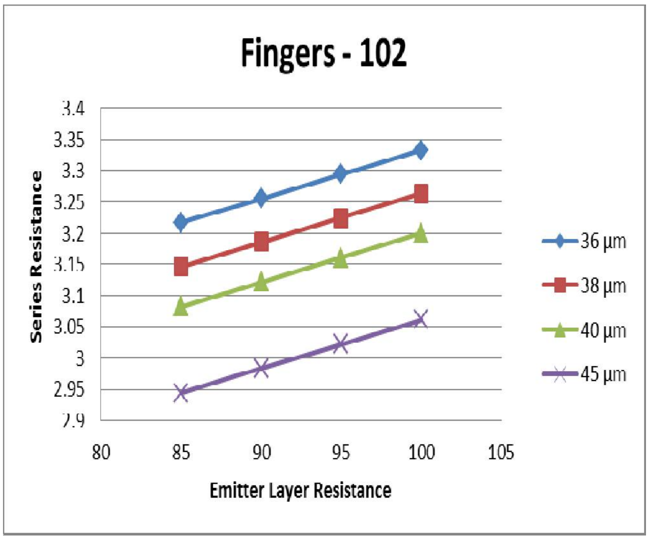

Fig 4: Graphical representation of series resistance at 102 fingers.

In the figure 4, it shows that the series resistance decreases when the fingers are increased from 95fingers to 102 fingers.

From the above graphical representation it is noticed that narrow gridlines are desirable to reduce shadow losses, but narrower gridlines or fingers also exhibits increased resistance associated with the front grid. So it is required to increase number of finger if the finger width is reducing. Simultaneously increase in finger number should be balanced with higher sheet resistance to maintain the overall performance of solar cell.

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EXPERIMENTAL VALIDATION

The experiment is performed with wafer size of 156 X 156 mm^2, 102 fingers, 36 µm finger width and 95 ohm/sq. sheet resistance. The advanced metal paste is used for screen printing process with resistivity of silver of 1.59 x 10^{-8}whereas the baseline is 95 fingers, 40 µm finger width and 85 ohm/sq. sheet resistance.

Theoretical value	Measured value
3.29 m Ohm	3.47 m Ohm

Table 3: Comparison between theoretical and measured value of series resistance

From the above experiment it is noticed that the theoretical value is very close to the measured value and it is clear that this theoretical calculation methodology can implemented to for new front contact design before carrying out the experiment.

V. CONCLUSION

Series resistance calculation method is established and verified with the experimental results. Using standard formulas of resistance calculated Bulk, emitter, front contact, back contact and fingers resistance. All the parameters considered for calculation from the industry standard values. Keeping bulk resistance same varied the emitter resistance and number of fingers to understand the correlation of these two on series resistance. Similar study carried out to understand the effect of number of fingers and finger width on series resistance, keeping emitter resistance constant. Finally verified the theoretical calculations with experimental results for selected front contact design and found 95% agreement between theoretical and experimental results. So the present calculation methodology can be used to simulate series resistance of any new design before carrying experiment. This can save the time and cost for the industry.

REFERENCES

[1] Daniel L Meier and Dieter K Schroder,“Contact resistance – Its measurement and relative importance to power loss in a solar cell” ,Issue Date: 1984, Publisher: IEEE Transactions on electron devices.

[2] E.A Good, D L Meier, R A Garcia, B L Bingham, S Yamanaka, V Chandrasekaran and C Bucher, “Determining components of series resistance from measurement on a finished cell”, Issue Date: 2006, Publisher: IEEE

[3] SreenivasaMurtyDasari, “Optimization of cell to module conversion loss by reducing the resistive losses”, Issue Date: 2013, Publisher: Elsevier

[4] Sebastian Gatz, Thorsten Dullweber and Rolf Brendel, “Evaluation of series resistance losses in screen printed solar cells with local rear contacts”, Issue Date: 30 August 2011, Publisher: IEEE

[5] L.J Caballero, P Sanchez Friera and B Lalaguna , “Series resistance modeling of industrial screen printed mono-crystalline silicon solar cells and modules including the effect of spot soldering”, Issue Date: 15 January 2007, Publisher: IEEE