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Problem Analysis of Fabricated Monocrystalline Silicon Solar Cell in Bangladesh

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ABSTRACT

This paper discusses of the follow-up problem analysis of monocrystalline silicon solar cell fabricated in Bangladesh. For monocrystalline solar cell fabrication one and only laboratory is available in Atomic Energy Research Establishment (AERE), Savar, Bangladesh. The fabricated silicon solar cells in this laboratory have the efficiency of only 6.89% so far. It is very important to identify the problems of fabrication to enhance the efficiency. Problems like wafer bowing has been observed and measurement shows the peak height of wafer bowing is 315 micrometer. Busbars and grid fingers of the fabricated solar cell have been compared with standard solar cells and result shows that the busbars and grid fingers are not straight and smooth as they should be. Furthermore, micro cracks and silver paste degradation have been found in busbars. Dektak 150 Surface Profiling System measurement shows more unevenness and less aspect ratio in the locally fabricated solar cells. Moreover, oxygen and nitrogen gas has not been used in metallization process during fabrication, which is one of the reasons for wafer bowing and micro cracks in busbars.

Keywords: Wafer Bowing, Busbars and Grid-Fingers and Micro-Crack.

1. Introduction

On the 22nd of April, 2016 Bangladesh signed the Paris agreement [1], whose main goal is to reduce greenhouse gas emission and keeping global warming well below 2° Celsius [2]. Moreover, to ensure planetary habitability for todays and future generations the whole world is making steps to achieve 100 % renewable energy [3]. To go along with all these issues, in 2015 solar cell with efficiency 6.89% was fabricated in Bangladesh for the first time [4]. But the efficiency of the fabricated solar cell is lower than commercially available solar cells, so this paper discuss about the follow-up problem analysis of monocrystalline silicon solar cell fabricated in Bangladesh. It is expected that after finding the problems, appropriate measures can be adopted to improve the efficiency of solar cell.

Problems like wafer bowing are observed, and the peak height of wafer bowing has been measured. Straightness of the busbars and grid fingers have been analyzed, results are found not satisfactory. Optical microscopic analysis shows micro cracks in busbars. Dektak 150 Surface Profiling System has been used to measure surface roughness uniformity of grid fingers of overseas and solar cells fabricated in Bangladesh. Then result shows more unevenness in grid fingers of solar cells fabricated in Bangladesh. Also, no oxygen and nitrogen gas was used in the metallization process during fabrication as RTA (Rapid Thermal Annealing) Furnace does not have the option of providing oxygen and nitrogen gas.

Previously found problems [5] in clean room, CZ (Czochralski) wafer, low shunt resistance, high series resistance, edge isolation, Minority carrier diffusion length and anti-reflection coating (ARC) layer are also briefly discussed in this paper.

2. Fabrication process of monocrystalline solar cell

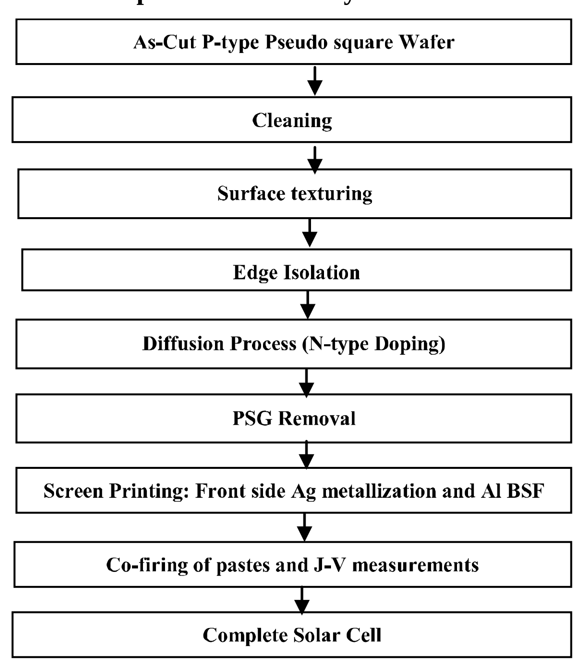

Fig. 1: Fabrication steps of solar cell

The one and only monocrystalline silicon solar cell fabrication laboratory has been operational since 2014 in Atomic Energy Research Establishment (AERE) Savar, Bangladesh. The main goal of this laboratory is to carry out fundamental research about monocrystalline silicon solar cells and finally manufacture high efficiency solar cells with low cost. So far the efficiency of the solar cell fabricated in Bangladesh is 6.89% (up to date), which is low compared to the commercially available solar cell around the world. So it is very important to identify the problems of fabrication to enhance the efficiency.

The fabrication steps (as shown in Figure 1) of monocrystalline silicon solar cell along with all fabrication procedure has been thoroughly investigated and some major problems has been identified. The problems and solutions were discussed earlier by Galib *et al*. [5]. Now this paper discusses about the problems which were not discussed before by Galib *et al*.

3. Problem analysis of previous work

3.1 Clean Room: Although, according to the International Standards Organization (ISO), ISO 5 – ISO 6 class clean room environment is the minimum requirement for solar cell fabrication [5-7], by using met one a2400 laser particle counter it is seen that clean room ISO class falls between ISO 7 and ISO 8 in Bangladesh.

3.2 Raw Wafer: Even though, FZ (Float Zone) wafer is superior over CZ (Czochralski) wafer, p-type CZ wafer were used in case of Fabrication. The p-type, as-cut monocrystalline CZ wafer were manufactured by ReneSola Company and procured from Gratings Inc. USA. According to the specification, the thickness of the wafer is 200µm and sheet resistivity lies in the range of 1-3 Ω.cm.

3.3 Solar Cell Parameter Values: Measurement shows high series resistance, 6.197 $\Omega.cm^2$ (world standard is between 0.3 $\Omega.cm^2$ to 1 $\Omega.cm^2$ [8]), low shunt resistance, 234 ohm (should be more than 1000 ohm [9]), and minority carrier diffusion length, 88 µm (typical value is 100-300 µm [10]).

3.4 Edge Isolation: Edge isolation is done normally after diffusion process, but here in AERE, edge isolation is done before the diffusion process. Edge isolation paste (specification unknown) is used on the borders of the top side of the wafer. After application of the edge isolation paste, the wafers goes through diffusion process. It is expected that, in the edge isolated area phosphorus will not diffuse. Now, the first problem is, all the edges that is all the sides must be covered with edge isolation paste. This has not been done here. Also, this edge isolation paste is thought to be one kind of flux rosin (which may remove diffused area) has been used before diffusion process. Suggestion is to use microwave plasma system for edge isolation process. So one of the main reason for achieving low efficiency solar cell in Bangladesh is edge isolation.

3.5 ARC Layer: Although, anti-reflection coating (ARC) layer reduces reflection and increases efficiency of solar cell, no anti-reflection coating layer was applied in fabricating solar cell in the research concerned in AERE.

4. Follow-up problem analysis

4.1 Wafer bowing:

Wafer bowing is bending of solar cell. The wafer bows and forms a convex or concave shape instead of flat surface when heating in the RTA (Rapid Thermal Annealing) furnace or when cooling the solar cell after metallization process [11]. Wafer bowing has a direct impact on the efficiency of solar cell [12]. So one of the most critical processing step is firing process (metallization process) where wafer bowing may happen. Although there are a number of factors that can affect the shape of a monocrystalline silicon wafer, here wafer being thin (wafer thickness is 200 µm), and external influences like improper temperature during metallization process were the main reasons for the wafer to become concave or convex [13]. Wafer bowing has been observed in the solar cell fabricated in Bangladesh as shown in Figure 2.

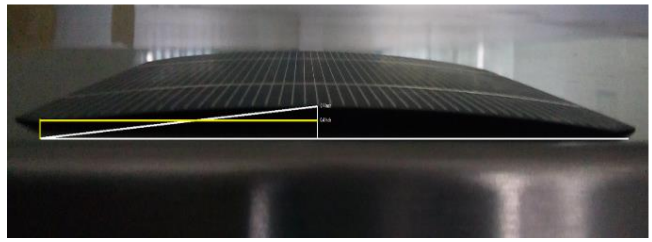

Fig. 2: Bowed solar cell

Height increase of bowed solar cell has been measured from Figures 2 & 3.

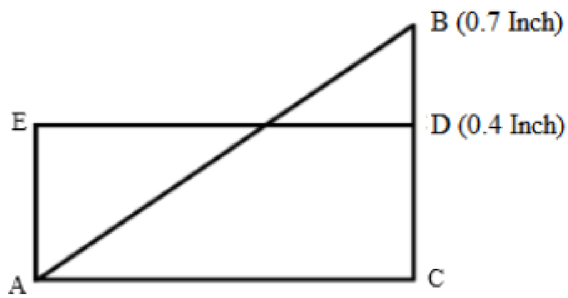

Fig. 3: Measurement of increased height

In Figure 2, peak height of the bowed wafer is named as Point B and from the Point B a straight line is drawn with respect to the ground (Point C). From the image, distance from peak point B to the ground has been measured and the measured value is 0.7 inch as shown in Figure 3. Again, in Figure 3, Point D represents peak point of a solar cell which is not bowed. Image measurement shows the distance from peak Point D to the ground is 0.4 inch. The distance between point B and Point D is 0.3 inch, which indicates the increased in height of bowed solar cell. Now, by using a dial indicator experimentally the peak height D of the solar cell has been measured, which is 180 µm. So, the image equivalent point D height 0.4 inch is actually equal to 180 µm. That means actual increased height by bowing of solar cell is 135 µm and peak height of the bowed wafer (point B) is 315 µm. The calculated angle are 4°, 86° and 90°.

4.2 Micro-cracks in busbars:

A micro-crack is microscopic crack in a material. Micro cracks increase mechanical wafer breakage [14] and micro cracks in busbars and grid fingers hinder electric current flow thus reducing the power and efficiency [15].

Various methods like scanning acoustic microscopy, resonance ultrasonic vibration (RUV), optical microscopy are used to detect micro cracks in solar cell [16]. As optical microscope is easy and non-destructive technique, it has been used to determine the micro cracks of locally fabricated solar cells. Figure 4 shows micro cracks in busbar in the tested solar cell. Micro cracks presence in busbars are one of the reasons that results in low efficiency.

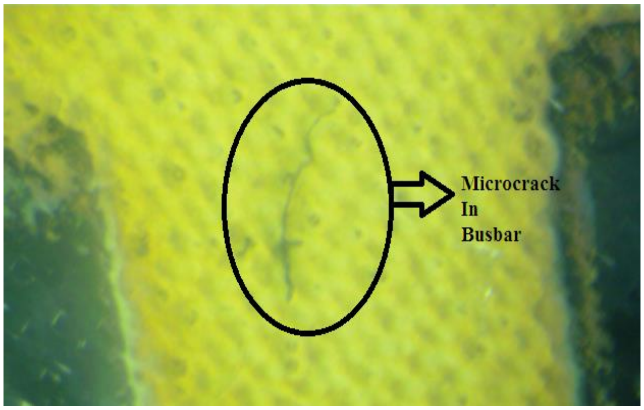

Fig. 4: Micro crack in busbar of locally fabricated solar cell

4.3 Busbars and Grid-Fingers:

Metallic top contacts are essential for collecting the current generated by a solar cell. The metallic top contacts with of wide strips and vertical in arrangement are called busbars. The external wires are directly connected to the busbars. In addition to busbars, the narrow lines of metallization which are perpendicular to the busbars are called grid fingers. The grid fingers are finer areas of metallization which collect current for delivery to the busbars [17]. Both busbars and grid fingers are shown in Figure 5.

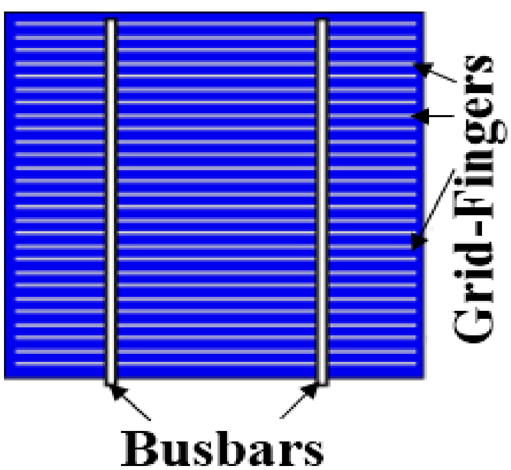

Fig. 5: Busbars and Grid-fingers

4.3.1 Optical analysis

Busbars and fingers are supposed to be straight and of uniform width and height. Unevenness of busbar and grid fingers increase series resistance and reduce the power and efficiency. An International Commercial Solar Cell (provided by Gratings Inc. [18]) busbars and grid-fingers uniformity has been analyzed using optical microscope. The busbar edge and grid-finger of an International Cell is shown in Figure 6 and Figure 7.

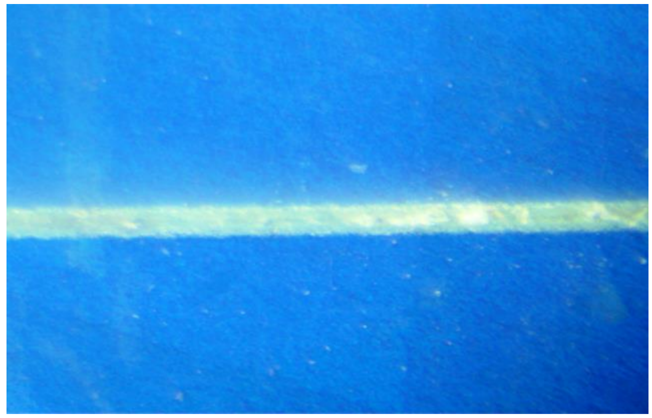

Fig. 6: Grid-finger of International Commercial Solar Cell

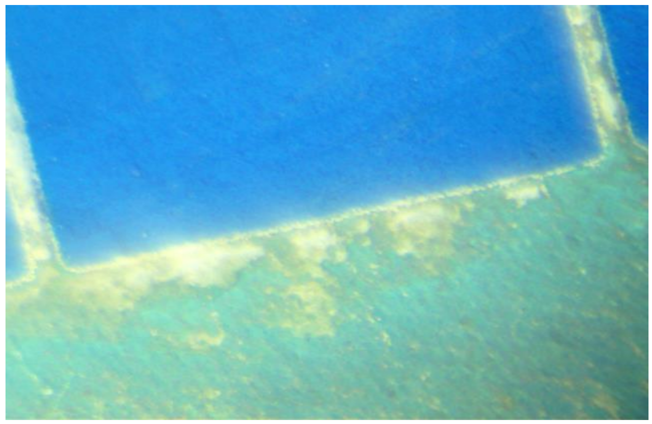

Fig. 7: Busbar edge of International Commercial Solar Cell

Figures 6 and 7 show that busbars and grid fingers are uniform and straightforward. Magnifying more, comparing busbars between an International standard solar cell and an Indian solar cell (Tata BP Solar Ltd.[19]) it is seen that the silver paste are less dispersed and more straight in the International Standard Solar Cell than the Indian Cell. The busbar of International Standard Solar Cell and Indian Cell are shown in the Figure 8 and Figure 9 respectively.

Fig. 8: Busbar of International Standard Cell

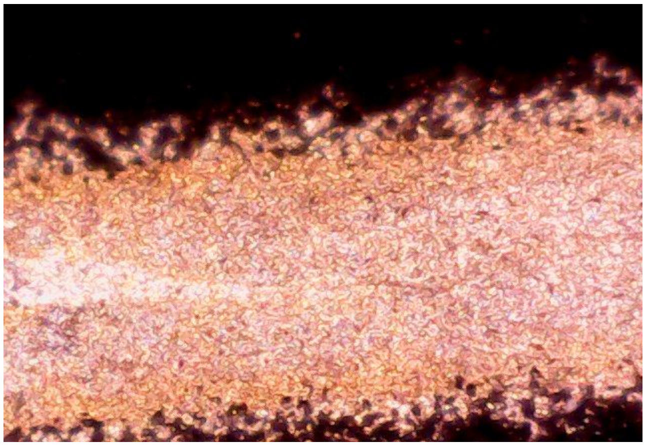

Fig. 9: Busbar of Indian Cell

Upon inspection of the Busbar edge of a solar cell fabricated in Bangladesh, highest silver paste disperse is seen as shown in Figure 10.

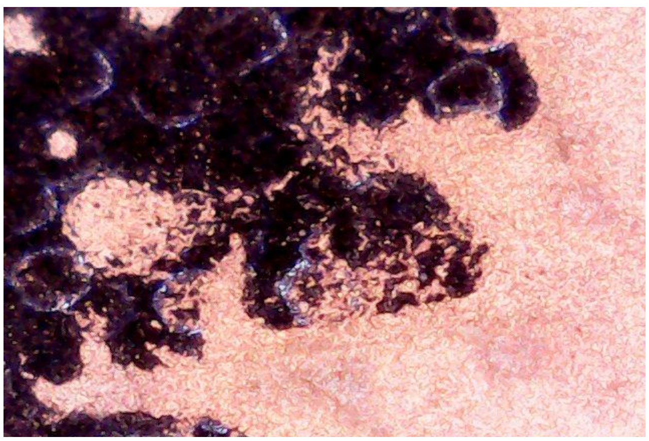

Fig. 10: Busbar showing dispersed silver paste in the solar cell fabricated in Bangladesh

The grid-fingers of the solar cell fabricated in Bangladesh are less straight forward and in some places degenerate silver paste has been seen as shown in the Figure 11 and Figure 12.

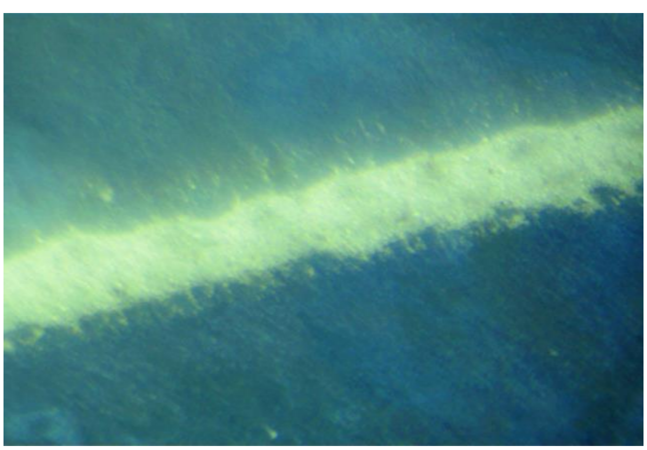

Fig. 11: Less straight forward busbar

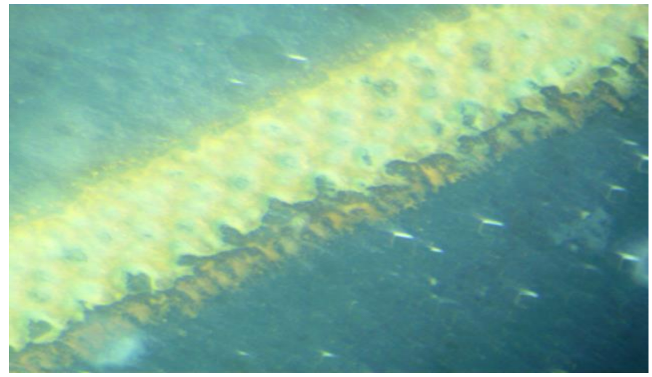

Fig. 12: Degenerate silver paste in grid- fingers of solar cell fabricated in Bangladesh

4.3.2 Surface profile analysis

Surface profilometer or surface profiling system is an instrument used to measure the roughness of a surface [20]. In a surface profiling system a stylus run along the sample surface and the up-and-down movements of the stylus are measured. Here a Dektak 150 Surface Profiling System has been used to measure the grid- fingers surface height uniformity. In the upper part of Figure 13 shows Dektak 150 data of the standard solar cell grid-fingers, whereas the lower part of the Figure 13 shows the grid-fingers of the locally made solar cell. Also, the X-axis rand Y-axis represents the distance and height in micrometers in the Figure 13. From Figure 13, it is seen that the standard solar cell grid-fingers are a lot thinner in width than locally made solar cell. Measurement shows the maximum height of the standard solar cell grid-fingers are 10 µm.

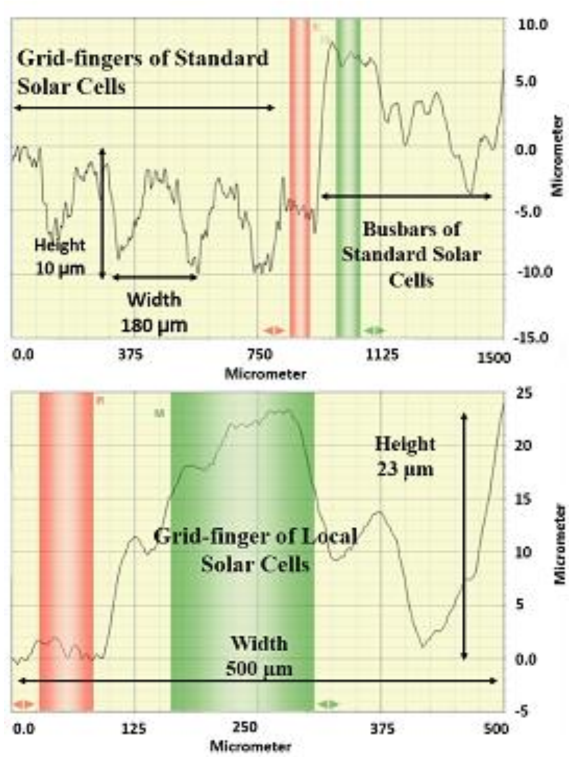

Fig. 13: Grid-fingers of standard and local solar cells showing height, width and uniformity

Moreover, the width of grid-fingers are 180 micrometer and aspect ratio which is defined as the height to width ratio (shown in Figure 14) is 0.0556 for the standard solar cell. On the other hand, again from Figure 13 it is seen that maximum height of the grid-fingers are 23 µm, width is 500 µm and aspect ratio is 0.046 µm for locally made solar cell.

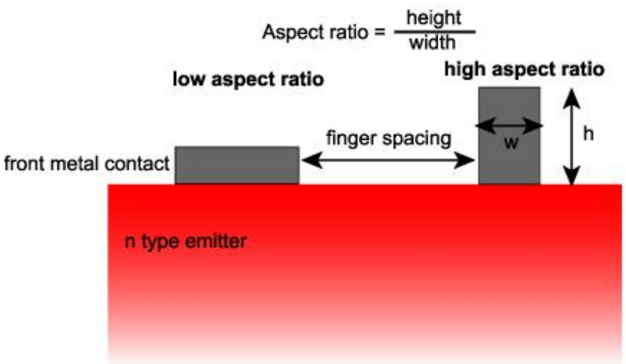

Fig. 14: Aspect Ratio

High aspect ratio is required for better efficiency [21], although from the obtained data, it is clearly seen that locally made solar cell aspect ratio is little bit lower than the standard solar cell.

Busbars of both locally made and standard solar cells surface has been analyzed to determine the surface uniformity. It is seen that more hills and valleys exits in locally made solar cell, maximum 23 µm variation is observed whereas 8 µm variation is observed in the standard solar cell as shown in Figure 15.

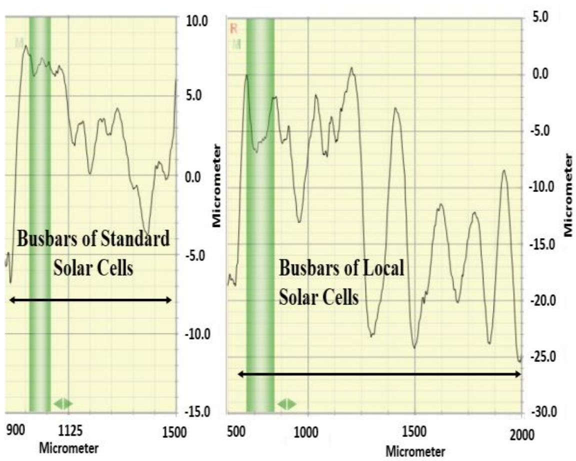

Fig. 15: Busbars of standard and local solar cells showing height, width and uniformity

It confirms the lacking and degeneration of silver paste in busbars observed using optical microscope analysis as shown in the Figure 10.

4.4 Metallization problem

Metallization is a very important step for solar cell fabrication because it strongly affects the efficiency of solar cell. If optimum temperature and environment is not met in the RTA (Rapid Thermal Annealing) furnace during metallization process cracks formation, bending of the wafer, high series resistance, low shunt resistance etc. are produced and that leads to an increase in leakage current therefore performance of the solar cell is reduced.

From I-V curve of locally fabricated solar cell high series resistance (6.197 $\Omega.cm^2$) and low shunt resistance (234 Ω) has been observed. Wafer bowing and micro-cracks are also observed and has been discussed earlier in this paper. The reasons for these circumstances are: during metallization process no oxygen and nitrogen gas were used in the RTA furnace, moreover RTA furnace has no option for providing O_2 and N_2 gas [22].

4.5 Doping concentration of P-type wafer

P-type wafers with various doping concentration are found in today's world, for different application like, IC fabrication, solar cell fabrication etc. Here in Bangladesh, Rene-Sola p-type, as-cut, commercial monocrystalline silicon wafers have been used to fabricate solar cell. Specification says that sheet resistance of p-type as-cut monocrystalline silicon should be within 1-3 Ω-cm. However, from four point probe measurement it is seen that the sheet resistance lies between 1.03 Ω-cm to 9.79 Ω-cm. So greater variation in sheet resistance is observed and it is very difficult to take an average sheet resistance. As the sheet resistance varies doping concentration of p-type wafer also varies. Using PC1D simulation software it is seen that for 1.03 Ω-cm to 9.79 Ω-cm doping concentration varies from 1.465×10^16 cm^{-3} to 1.398×10^15 cm^{-3}. For high efficiency solar cell p-type wafers sheet resistance is 0.1 Ω-cm to 0.5 Ω-cm [23]. That is doping concentration lies between 2.341×10^17 cm^{-3} to 3.255×10^16 cm^{-3}. So the p-type wafers used during fabrication, its doping concentration is lower than high efficient solar cell. Moreover, 0.1 Ω-cm to 0.2 Ω-cm type wafer are commercially found but these type of wafers were not used during solar cell fabrication in Bangladesh.

5. Discussion

From the previously found problems (discussed in section 3) and follow-up problem analysis (discussed in section 4) it is seen that, these problems exist because of the following reasons.

1. Not having ISO standard clean room.
2. Improper raw wafer selection (depending upon thickness, p-type doping uniformity, sheet resistance, p-type doping concentration and impurity concentration)
3. Improper edge isolation technique and not having microwave plasma system.
4. Not applying anti-reflection coating because of not having sufficient equipment and gaseous materials.
5. RTA furnace does not have any options for providing N_2 and O_2 gas. Because of this, micro-cracks are seen in busbars. Also unevenness in busbars and grid-fingers are seen for this reason.

6. Improper temperature is used during metallization process in the RTA furnace so the aluminum and silver paste does not stick with solar cell and dispersed silver and aluminum silver paste is seen.
7. Low grade aluminum and silver paste has been used.

6. Conclusion

In this paper follow-up problem analysis of locally made monocrystalline silicon solar cell has been discussed. Problem like wafer bowing, micro-cracks in busbars, dispersed and degenerated silver paste in busbars, no straight and smooth grid-fingers and busbars has been observed. Dektak 150 surface profileometer shows unevenness is more in locally fabricated solar cell than standard solar cell. Also aspect ratio is little bit lower in the locally fabricated solar cells. Moreover, no oxygen and nitrogen was used during metallization process as Gratings Inc.'s RTA furnace does not provide any kind options to provide these gas. These are few of the reasons for achieving low efficiency also previously found problems are discussed briefly in this paper.

Even though locally fabricated solar cell efficiency is low, problem analysis will help and promote the scientists and researchers to identify and rectify the problems thus increasing efficiency of locally made solar cells in the near future.

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