Loss Analysis on Inline Processed Multi Crystalline Silicon Solar Cells

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ABSTRACT

Crystalline silicon solar cells are well positioned in the photovoltaic industry due to their electrical performance and reliability over other solar cells. Different types of process approaches (inline/batch) play significant roles in the PV cell performance and its reliability. In order to validate the cell performance with respect to the type of process, it is important to do a systematic analysis on partially processed cells and in completed cells as well. A Griddler Finite - Element model was planned and studied on the multicrystalline silicon solar cells fabricated by using inline process, which accurately defines the IV, Suns-V_{oc} and Photoluminescence data of the cells. The loss analysis on V_{oc}, J_{sc} and FF were studied and the performance of the cells were analysed. The studies revealed that FF values and the metal contact resistance are good and typical. It was found that there is a scope for improving V_{oc} and J_{sc}, and hence the efficiency of the cells by doing further process optimization.

INTRODUCTION

Crystalline silicon solar cells dominate PV technology, because of its ease of process technique and high efficiency achieved. However the cost of conversion is relatively high in production. In this circumstance, it is highly desirable to fabricate the high efficiency silicon solar cells at lower cost. PV technologists are continuously putting their efforts to show consistent improvement in silicon technology to produce high efficiency solar cells at lower cost. Silicon solar cell process involves many critical fabrication steps such as surface texturization, diffusion, antireflective coatings, contact formation and metallization.

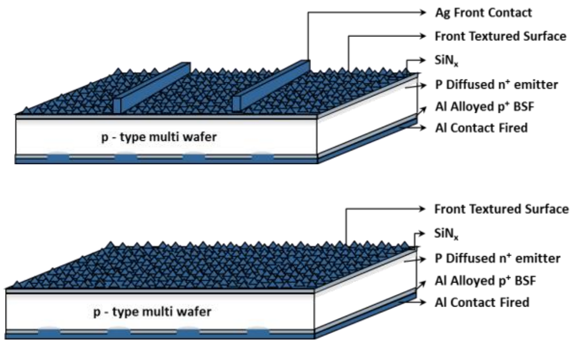

Figure 1 Schematic of the complete cell and partially processed Cell

Electrical parameters such as open circuit voltage, short circuit current and fill factor are the key factors in deciding the power conversion efficiency, which can be improved by fine tuning the cell manufacturing processes. However, the electrical parameters of the cells vary with respect to the process changes. In this context, it is important to understand the impact of various manufacturing steps on the finished solar cell's efficiency. This article narrates a Griddler Finite - Element model studies on IV, Suns V_{oc} and Photoluminescence of inline processed multi crystalline silicon solar cells. Schematic of the cells used for this study is as shown in Figure 1 and were fabricated by using conventional screen printing technology. IV characteristic of the cells were carried out and the median values of V_{oc}, FF, J_{sc} and Efficiency were 0.627mV, 78.93%, 35.43mA/cm^2 and 17.54% respectively.

RESULTS AND DISCUSSION

Complete loss analysis has been studied by using Griddler 2, a finite - element simulator, which describes the voltage distribution, current flow pattern in the solar cell front and rear planes [1]. This is important in quantifying both the magnitude and the effects of spatially dependent recombination, namely metal induced recombination [2], edge recombination, and peripheral non-uniformity [3]. Since current is the easiest parameter to improve significantly, it is important to quantify the sources of J_{sc} losses, which includes optical losses (shading, reflection, parasitic absorption) and collection losses (due to finite effective diffusion lengths in the base and emitter).

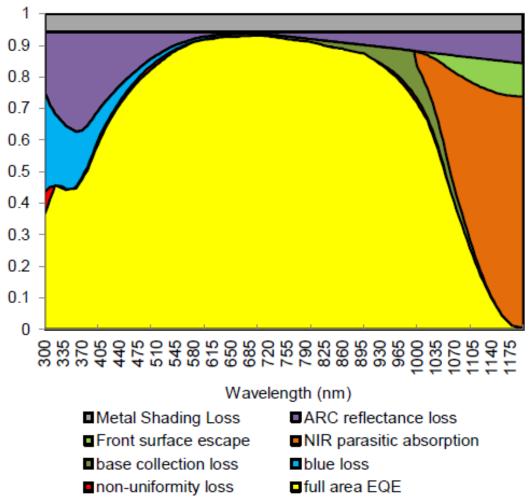

Figure 2 EQE of active area

Component	Loss (mA/cm^2)
ARC Reflectance	2.717
Front Surface Escape	0.484
NIR parasitic absorbance	3.388
Base collection loss	1.039
Metal shading loss	2.648
Blue loss	0.517

Table 1 EQE Loss Components

Figure 2 shows the External Quantum Efficiency (EQE) of active area of the cell. Compared to large beam EQE, small beam EQE showed that the shading was about 5.7%, which was consistent with the Griddler calculation of 5.1% considering the metallization geometry. Table 1 reveals that different J_{sc} loss components are fairly typical for multi Al-BSF cell and the only component which may need an improvement is the NIR parasitic absorption loss. Quality of rear internal reflector and better rear planarization help reduce NIR parasitic absorption loss by around 0.2 mA/cm^2. Similarly it has been observed that metal shading loss and ARC reflectance loss were also quite high. The metal shading loss was due to the print definition, which can be improved by finger width. Further, the reflection loss can be reduced by optimising SiN_x properties.

V_{oc} loss analysis can be obtained by finding the magnitudes of emitter, base and BSF, front and rear metal contact, peripheral non-uniformity, and wafer edge recombinations. Since the Griddler model doesn't differentiate individual recombination, the wafer (J_{01},J_{02}), front metal area (J_{01},J_{02}), rear metal area (J_{01},J_{02}) and edge J_{01} were varied as fitting parameter to quantify the V_{oc} loss. On the experimental side, Suns-V_{oc} and Suns-PL were performed on the representative finished cell. These samples were chosen from their respective groups having near the median 1-Sun PL intensity and thus should be representative samples. Suns-V_{oc} was done by probing the cell open circuit voltage on the middle busbar, at different laser illumination intensities varying from 3.6 Suns down to 0.04 Suns, in the BT Imaging PL tool. Suns-PL was done by capturing the PL images at the same illumination conditions. The internal V_{oc} can be obtained from their camera PL count via the relation [4] where c is a calibration constant which is obtained by setting the internal V_{oc} equal to probed V_{oc} at the lowest illumination intensity.

PL count = c × exp (qV_{oc}/kT)

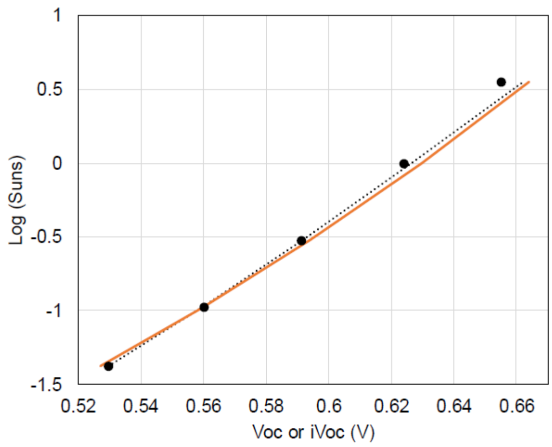

Figure 3 Probed Voc and internal Voc (iVoc) converted from PL intensity

Figure 3 shows the converted probed V_{oc} and internal V_{oc} plots against light intensity. These are called Suns-V_{oc} and Suns-PL plots. It is interesting to note that for the finished cell, the Suns-V_{oc} and Suns-PL plots converge at low intensity, but the Suns-PL internal V_{oc} values become generally higher than the probed V_{oc} at high intensity. This is because the probed points are at the metal busbars where shading and metal induced recombination contribute to lower voltages. The Griddler simulations are aimed to fit these curves. Figure 4 shows that the "effective J_{01}" values which are consistent with the 1-Sun V_{oc} values of the different samples. Also, the effective J_{01}s in a pie chart, gives the relative importance of different recombination currents at 1-Sun. From figure 4 it has been observed that the low V_{oc} (below 630 mV) of the cell before metallization is due to wafer bulk, rear, and passivated emitter regions. From quantum efficiency measurements, it has been observed that the base diffusion length is 0.67mm, which is typical for Al-BSF cell and should contribute J_0 = 500 fA/cm^2 for a bulk doping of 1-2 Ωcm.

Fill factor loss in silicon solar cells are due to series resistance, shunt resistance and non-ideal recombination. Non-ideal recombination includes a wide variety of effects, including depletion region recombination and its enhancement by metal contact, edge recombination, and localized recombination. The median value of Rs (extracted by comparing the light and dark IV curves) and Rsh (extracted from dark IV) are 0.528 Ωcm2 and 47 kΩcm2 respectively.

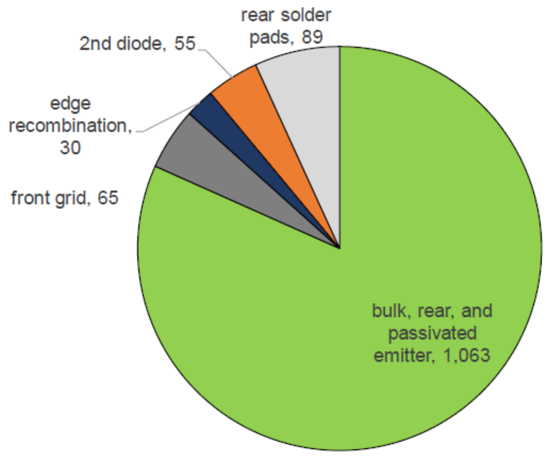

Figure 4 Extracted saturated recombination current densities related to various regions

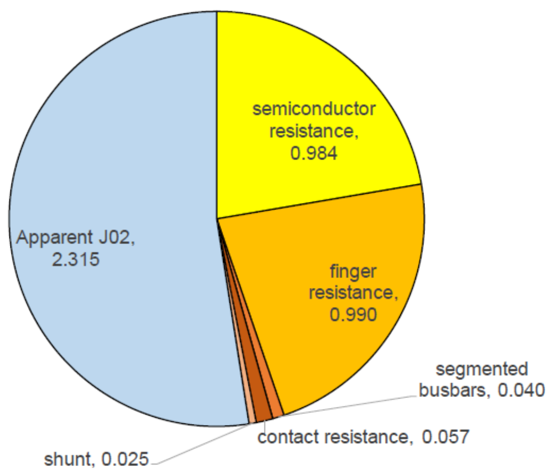

Figure 5 Griddler model for fill factor loss

By calculating the impacts of series and shunt resistors on the FF, and comparing these values with the value of the difference between the ideal FF and measured FF, we can infer the impact of non-ideal recombination, say apparent J_{02}. Median values of calculated fill factor loss due to R_s, R_{sh}, and apparent J_{02} are 2.87%, 0.025% and 1.52 % respectively but the loss due to the apparent J_{02} is quite large (values around 1% is achievable). Figure 5 shows the Griddler model for fill factor losses, with R_s loss broken down to semiconductor resistance, finger resistance, segmented busbars and contact resistance of the cell. From Fig 5 it is clear that Griddler estimates a higher loss due to apparent J_{02} than the I-V parameter method. Higher J_{02} loss is due to edge recombination, peripheral non-uniformity, injection level dependent lifetimes, SRVs, and depletion region recombination.

CONCLUSIONS

This paper studied the loss analysis of inline processed multi crystalline silicon solar cells. Systematic analysis was carried out and Griddler Finite - Element model was also studied on fabricated multi crystalline silicon solar cells. This study revealed that the range of FF values and the metal contact resistance in fabricated cells are good and typical, however there is a scope for improving V_{oc} and J_{sc} by doing further process optimizations. Detailed results will be presented during the conference.

ACKNOWLEDGEMENTS

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