Influence of metallization and firing processes on solar cell ‘Voc’ – A simulation

Lejo. J. Koduvelikulathu \textsuperscript{1}, V. D. Mihailetchi, A. Edler, G. Galbiati, A. Halm, R. Roescu, R. Kopecek, K. Peter

International Solar Energy Research Center Konstanz e.V. (ISC Konstanz)
Rudolf-Diesel Str.15, D-78467 Konstanz, Germany
\textsuperscript{1}lejo.joseph@isc-konstanz.de

The paper analyses, using SILVACO ATLAS device simulation study, for the observed drop in the $V_{OC}$ between the measured implied $V_{OC}$ and final $V_{OC}$ after the screen printing of silver paste and the subsequent firing processes.

I. Motivation

An experimental observation on the behaviour of $V_{OC}$, Table 1, on a standard n-type cell structure, with emitter profiles of different sheet resistances. It could be seen that there is a considerable drop in the final obtained Voc, when compared to the implied $V_{OC}$ value. Also, shown are the obtained Voc values at different firing temperature.

<table>
<thead>
<tr>
<th>Emitter Profiles</th>
<th>Implied $V_{OC}$ (mV)</th>
<th>$V_{OC}$ at 750$^\circ$C firing (mV)</th>
<th>$V_{OC}$ at 780$^\circ$C firing (mV)</th>
<th>$V_{OC}$ at 900$^\circ$C firing (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet resistance 67 $\Omega/\square$</td>
<td>665</td>
<td>635</td>
<td>638</td>
<td>574</td>
</tr>
<tr>
<td>Sheet resistance 110 $\Omega/\square$</td>
<td>662</td>
<td>634</td>
<td>632</td>
<td>550</td>
</tr>
</tbody>
</table>

Table 1: Experimental observation on Voc behavior before and after metallization process for different firing temperatures

II. Simulation Analysis, Results

In view of the above observed experimental results, [1] details experimental evidence of direct contact formation of Ag pastes onto Silver substrate and [2] shows through SIMS analysis diffusion of Ag particles into Si (111) substrate at moderate temperatures. These studies, however, investigated and analyzed pastes for optimum contact formation but, results were only limited to obtain an optimum fill factor. At the same time, the metal penetration phenomenon in the silicon substrate could also have deteriorating effect on the Voc of the cell, which could be a possible explanation to the experimentally seen trend.

The performed simulation analysis, attempts to capture the metal penetration phenomena into the silicon substrate, with varying metal penetration depth, correlating it to the different firing temperature process, and studying its effect on the solar cell parameters. As an initial assumption to the simulation study, the entire metal structure has been introduced into the substrate. The unit n-type structure, shown in Fig.1, simulates for the effect of metal penetration considering deep emitter profile ($67 \Omega/\square$) and also shallow emitter ($110 \Omega/\square$). Metal penetration depth variations, from 0 nm until the metal block
is completely through the emitter of the cell structure (~ 400nm/ 600nm, depending on the emitter doping profile) and also metal penetrations into the BSF layer is considered for the simulation.

![Figure 1: Unit cell for simulation of standard n-type structure](image)

From the simulated IQE, Fig. 2, for different metal penetration depths, it is seen that there is no change in the spectral behavior of the cell, and hence have a constant Jsc, until the metal is completely through the emitter resulting in a complete shunted cell structure. This behaviour is also seen experimentally, with the different firing temperatures, the obtained Jsc of the cell remains the same.

![Figure 2: Simulated spectral response for different metal penetration depths](image)

From the simulated IV, Fig. 3 & Fig.4, the Voc behaviour for the various metal penetrations is analyzed. The Voc values are relative to the 0nm metal penetration. The simulation is also performed in terms to separate the contributions front and the rear side metal penetration and its effect on Voc (Figure 3).
Figure 3: Simulated Voc drop, considering individual effects from the Front and Rear side for different doping profiles.

Figure 4 details the final obtained drop in Voc, which is the cumulative drop, considering the individual front and rear effects, for the different doping profiles.

Figure 4: Net drop in Voc due to the total metal penetration contributions (Front and Rear side contributions)
III. Conclusion and Future work

The above simulation analysis moves in the direction for a possible explanation to the experimentally observed Voc drop. As a first step in this direction, introduction of a metal block into the substrate emulates for the effect of the metal penetration of the crystallites into the silicon substrate under different firing temperatures, as observed experimentally [1] [2].

From the simulation results, these metal contaminants would act as recombination centers and thus resulting into a drop in Voc. Also observed, shallow emitters resulted into higher Voc drop when compared with the deep emitter. Thus the shape of the doping profile and the dopant concentrations at a particular depth in the substrate governs the recombination activities and thus the drop in Voc. In another way, controlling the aggressiveness of the metal penetration and at the same time a better contact would be a driving force to obtain higher Voc, close to the observed implied Voc of the cell.

The above simulation analysis is considered based on an introduction of a metal block into the silicon substrate. To further verify the above discussed conclusion, future simulation analysis is planned considering localized Ag metal concentrations, with localized recombination velocities. Also at the same time, experimental runs have been planned to study the metal contamination effects on Voc.

Further results based on the new the simulation and experimental analysis shall be updated at a later stage.

IV. References