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Data of the recombination loss mechanisms analysis on Al₂O₃ PERC cell using PC1D and PC2D simulations

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A B S T R A C T

This data article is related to our recently published article ('20.8% industrial PERC solar cell: ALD Al₂O₃ rear surface passivation, efficiency loss mechanisms analysis and roadmap to 24%', Huang et al., 2017 [1]) where we have presented a systematic evaluation of the overall cell processing and a cost-efficient industrial roadmap for PERC cells. Aside from the information already presented in Huang et al., 2017 [1], here we provide data related to Sectin 3 in Huang et al., 2017 [1] concerning the analysis of the recombination losses’ mechanisms by PC1D V5.9 and PC2D simulations (Clugston and Basore, 1997, Basore and Cabanas-Holmen, 2011, Cabanas-Holmen and Basore, 2012 and Cabanas-Holmen and Basore, 2012.) [2–5] on our current industrial Al₂O₃ PERC cell. The data include: i) PC2D simulations on J02, ii) the calculation of series resistance and back surface recombination velocity (BSRV) on the rear side metallization of PERC cell for the case of a point contact, and iii) the PC1D simulation on the cumulative photo-generation and recombination along the distance from the front surface. Finally, the roadmap of the solar cell efficiency for an industrial PERC...
The concurrent application of both PC1D Version 5.9 and PC2D simulations to industrial PERC cells provides a deeper insight into the optimization of the processing parameters.

The PC1D simulations on the cumulative photo-generation and recombination as a function of the distance from the front Si surface give an indication for the front surface passivation levels required for an optimized performance of the PERC cell.

The roadmap for cell efficiency to 24% is calculated from measured industrial performances and can therefore provide a valuable reference base for further development and optimization in the production processes.

The data presented is collected from an extensive database from industrial PERC cells, and can thus be used as a benchmark for industrial performances.

1. Data

The dataset of this article provides additional information to Ref. [1]. PERC cell performances are reported in Table 1, the recombination as a function of the distance from both front and rear side is reported in Figs. 1, 2. The roadmap to PERC technology to 24% at an industrial level is shown in Table 2.
2. Experimental design, materials and methods

PC2D simulations were performed to confirm the effect of $J_{02}$ on the current industrial PERC cell performance, and the results are reported in Table 1. The detailed parameters settings can be found in Table 8 and Fig. 21 in Ref. [1]. The data show that the cell efficiency will gain 0.04% with $J_{02}$ decreasing from $1 \times 10^{-9}$ to $1 \times 10^{-10}$ A cm$^{-2}$, which is mainly related to the gain in fill factor (0.13%).

The series resistance ($R_s$) and the back surface recombination velocity (BSRV) and their relation with rear side metallization geometry were calculated for a point contact array geometry for the rear local contacts, as a function of the rear contact fraction and pitch (Fig. 1). The calculations are based on Fisher’s and Plagwitz’s model [6–9]. The data show that rear point or segment local contact arrays give lower total series resistance and thus lower BSRV with lower contact fraction.

A representative example of the cumulative photo-generation and recombination as a function of the distance from the Si front surface is shown in Fig. 2. The data were simulated by PC1D Version 5.9 and it can be seen that the cumulative photo-generation profiles among different front n$^+$ emitters with different front surface recombination velocities (FSRV) coincide. Note that the data can also be used to calculate the collection efficiency along the depth from the front Si surface, as the collection efficiency is the ratio between the cumulative recombination and cumulative photo-generation.

A roadmap for industrial PERC cell technology to achieve efficiency up to 24% is shown in Table 2, which is based on the simulation data presented above and on the results on cell efficiency loss mechanisms presented in Ref. [1]. In particular, the recombination losses analysis was carried out with PC1D and PC2D simulations.

### Table 1

<table>
<thead>
<tr>
<th>$J_{02}$ (A cm$^{-2}$)</th>
<th>$V_{oc}$ (mV)</th>
<th>$J_{sc}$ (A cm$^{-2}$)</th>
<th>FF (%)</th>
<th>$\eta_{cell}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0E-09</td>
<td>661.5</td>
<td>38.62</td>
<td>80.98%</td>
<td>20.69%</td>
</tr>
<tr>
<td>1.0E-10</td>
<td>661.7</td>
<td>38.62</td>
<td>81.11%</td>
<td>20.73%</td>
</tr>
<tr>
<td>1.0E-11</td>
<td>661.8</td>
<td>38.62</td>
<td>81.12%</td>
<td>20.73%</td>
</tr>
</tbody>
</table>

Fig. 1. $R_s$ and BSRV (point contact array) as a function of rear contact fraction and pitch.
Table 2
Roadmap for industrial PERC technology up to 24%.

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Topic</th>
<th>Key factor</th>
<th>New cell process or design</th>
<th>Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Current</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2</td>
<td>Front emitter and passivation</td>
<td>To decrease $J_{01 \text{, front } \nu \text{ emitter region}}$ down to $\leq 5 \cdot 10^{-14}$ A cm$^{-2}$</td>
<td>More advanced emitter process to tailor emitter profile such as ion implantation</td>
<td>★★★☆</td>
</tr>
<tr>
<td>3</td>
<td>Front metallization engineering</td>
<td>To decrease $J_{01 \text{, front contact region}}$ down to $\leq 2.5 \cdot 10^{-13}$ A cm$^{-2}$</td>
<td>Screen printing Ag paste development, metallization pattern optimization (multi-busbar or free busbar schemes)</td>
<td>★★☆</td>
</tr>
<tr>
<td>4</td>
<td>LBSF + Rear local metal contact recombination</td>
<td>$J_{01 \text{, rear local metallization down}}$ to $\leq 3 \cdot 10^{-12}$ A cm$^{-2}$</td>
<td>To continue R&amp;D on screen-printed local BSF Al paste</td>
<td>★★</td>
</tr>
<tr>
<td>5</td>
<td>Rear side metallization pattern optimization</td>
<td>Metallization array dimension unchanged, keeping fraction unchanged or a suitable value</td>
<td>Laser ablation and Al paste development</td>
<td>★★☆</td>
</tr>
<tr>
<td>6</td>
<td>Light trapping</td>
<td>Front and rear optical structure optimization</td>
<td>Texture process, ARC process</td>
<td>★★★☆</td>
</tr>
<tr>
<td>7</td>
<td>Bulk diffusion length improvement</td>
<td>To increase bulk lifetime to $\geq 400$ μs (diffusion length $\geq 1100$ μm)</td>
<td>To improve Si ingot technique</td>
<td>★★★</td>
</tr>
<tr>
<td>8</td>
<td>Rear side passivation</td>
<td>$J_{01 \text{, rear passivation region}}$ down to $\leq 5 \cdot 10^{-15}$ A cm$^{-2}$</td>
<td>Al$_2$O$_3$ process optimization</td>
<td>★★★☆</td>
</tr>
<tr>
<td>9</td>
<td>Cell structure update from PERC to PERL</td>
<td>$J_{01 \text{, rear local metallization}}$ &lt; $1 \times 10^{-13}$ A cm$^{-2}$, rear side p$^+$ local BSF</td>
<td>PVD Al process, local p$^+$ heavy boron doping process (laser doping/ inkjet print doping/selective ion implantation doping)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Fig. 2. The cumulative photo-generation and recombination as a function of the distance along the Si from the front surface (Erfc (error function complement) profile “2”: surface n$^+$ concentration = $1.0 \cdot 10^{20}$ at cm$^{-3}$, $X_c$: ~0.4 μm, $R_i$: 90 Ω/□, FSRV = 5000 cm s$^{-1}$, BSRV = 25 cm s$^{-1}$).
Acknowledgements

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Transparency document. Supporting material

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