A novel interconnection scheme for thin-film silicon solar modules with highly conductive intermediate reflector layer

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A novel interconnection scheme for thin-film silicon solar modules with highly conductive ZnO:Al intermediate reflector layer (ZIR) was introduced.

In contrast to designs from literature neither extra scribing steps are needed nor extra active area is lost compared to the standard interconnection scheme.

Implementation into tandem modules with 70nm ZIR layer has proven applicability.

New problems which arise from debris redeposition on the surface were discussed.

Possible solutions to the shunting problem

- Known designs from literature to cut current path between P2 interconnect and IR
  - Four scribes [1]
  - Four scribes/shift [2]

- Four scribes: Introduce a fourth scribe P1' before bottom-cell deposition
  - Drawbacks: additional scribing step and additional active area lost!

- Four scribes/shifted: Move P1' closer to P1
  - Active area loss reduced, but additional scribing step

A new interconnection scheme is proposed

This work: P1' scribe is “delayed” after top-cell
- Intermediate reflector deposition
- Bottom-cell is used to cut short-circuit between P2 scribe and intermediate reflector
- Advantages: NO additional scribing steps and NO additional area losses

New problems

- Effects on cell properties caused by scribing processes before bottom-cell deposition
- Dark spots due to redeposition on surface, effect amplified when TCO is ablated
- Possible shunting paths created by delayed P1’ need to be characterized

Proposed design applicable

- Shunting with standard interconnection
- High Fill-Factors for the other design schemes

Table: Interconnection scheme

<table>
<thead>
<tr>
<th>Interconnection scheme</th>
<th>Standard scribes</th>
<th>Four scribes</th>
<th>Four scribes/shifted</th>
<th>This work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency η [%]</td>
<td>6.21</td>
<td>7.96</td>
<td>8.18</td>
<td>8.4</td>
</tr>
<tr>
<td>Fill-Factor FF [%]</td>
<td>49.8</td>
<td>69.2</td>
<td>73.16</td>
<td>73.4</td>
</tr>
<tr>
<td>Short-circuit curr. dens. Jsc [mA/cm²]</td>
<td>10.86</td>
<td>8.8</td>
<td>8.58</td>
<td>8.77</td>
</tr>
<tr>
<td>Open-circuit voltage Voc [V]</td>
<td>9.18</td>
<td>10.46</td>
<td>10.42</td>
<td>10.44</td>
</tr>
</tbody>
</table>

Results

- Shunt with four scribes from literature.
- Shunting problem effect amplified when TCO is ablated.
- No shunting with three scribes.
- Effects amplified when TCO is ablated.

Motivation

Tandem thin-film solar cells with intermediate reflector (IR) layer

- Shift sub-cell current generation from bottom- to top-cell
- Thinner top-cell increased stability against light-induced degradation
- Aim: higher stabilized overall cell efficiency

Realization for thin-film silicon solar technology

- Introduction of thin 50nm-100nm layer with suitable refractive index
- Used materials are usually ZnO:Al TCO and/or µc-SiOx:H
- Demands: Highly conductive, and spectral selective reflectivity

Problems and limitations

- Demand of high electrical conductivity on solar cell level is at the same time problematic on solar module level

<table>
<thead>
<tr>
<th>P3</th>
<th>P2</th>
<th>P1</th>
</tr>
</thead>
<tbody>
<tr>
<td>µc-Si:H</td>
<td>µc-Si:H</td>
<td>µc-Si:H</td>
</tr>
<tr>
<td>ZnO:Al IR</td>
<td>a-Si:H</td>
<td>a-Si:H</td>
</tr>
</tbody>
</table>

- After interconnection process P2, back-contact deposition will short-circuit the bottom-cell between intermediate reflector and back-contact

Module characteristics

- J–V plot of a tandem module on SnO2:F with 70nm sputtered ZnO:Al intermediate reflector
- 8 sub-cells series connected with 1cm cell stripe width and 1cm cell length
- Total area: 8.8cm²
- 4 Modules processed on one 10x10cm² glass substrate

Conclusions

- Novel interconnection scheme for thin-film silicon solar modules with highly conductive ZnO:Al intermediate reflector layer (ZIR) was introduced.
- In contrast to designs from literature neither extra scribing steps are needed nor extra active area is lost compared to the standard interconnection scheme.
- Implementation into tandem modules with 70nm ZIR layer has proven applicability.
- New problems which arise from debris redeposition on the surface were discussed.

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