Status of ZEBRA cell and module development

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Introduction: Zebra cell basic features

- **large area:**
  - industry-standard M2 n-type Cz wafers

- **screen printed metallization:**
  - open rear side grid » **bifacial IBC cell**

- **3-d metallization scheme:**
  - variable busbar configuration
  - no electrical shading due to busbars
Introduction: Zebra cell basic features

<table>
<thead>
<tr>
<th></th>
<th>$J_{SC}$ [mA/cm²]</th>
<th>$V_{OC}$ [mV]</th>
<th>FF [%]</th>
<th>Efficiency [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>black chuck</td>
<td>41.0</td>
<td>667</td>
<td>80.7</td>
<td>22.1</td>
</tr>
<tr>
<td>white chuck</td>
<td>41.3</td>
<td>668</td>
<td>80.7</td>
<td>22.3</td>
</tr>
</tbody>
</table>

Main challenges for industrial implementation:

- patterning technique to form $p^+$ and $n^+$ regions
- $p^+$ and $n^+$ metallization
- $p^+$ (Boron) emitter and passivation
- module integration
Outline

cell process:
  • passivation of the boron emitter

module integration:
  • conductive backsheet approach:
    - optimization of CTM loss
    - module results
  • ribbon based interconnection:
    - pre-bent soldering
    - module results
    - bifacial module measurements

• summary
Zebra cell process

process flow Al BSF

Texturing
Cleaning
Diffusion (POCl₃)
PECVD SiNₓ
Screen Printing
Contact Firing

ADDITIONAL STEPS to fabricate a ZEBRA cell

- BBr₃ diffusion (p⁺ emitter)
- Pre-diffusion cleaning
- PECVD SiNₓ
- PECVD masking step
- Laser patterning

» Industrial processes proven in mass production of PERC or PERT cells
passivation of boron emitter

Common $p^+$ passivation

1. BBr$_3$ diffusion ($\Rightarrow$ thick BSG)

2. BSG etching (e.g., 2% HF)

3. Passivating layer: (e.g., AlO$_x$, Al$_2$O$_3$, SiO$_2$)

4. PECVD SiN$_x$ ($\Rightarrow$ ARC)

ISC simplified process

1. BBr$_3$ diffusion ($\Rightarrow$ uneven BSG layer)

2. BSG etching/thinning ($\Rightarrow$ thin and even SiO$_2$)

3. PECVD SiN$_x$ ($\Rightarrow$ SiO$_2$/SiN$_x$, ARC)
passivation of boron emitter

Common $p^+$ passivation vs. ISC simplified process

» Comparable passivation quality with state-of-the-art Al$_2$O$_3$ based methods, but with no additional process steps

V.D. Mihaletchi et al. proceedings IEEE PVSC 44 2017
V.D. Mihaletchi et al. IEEE J. Photovolt. – to be published
module integration: interconnection scheme

Classical way: adapted tabber-stringer

Edge stringing

Continuous stringing

NICE

multi busbar

smartwire

new approaches: dedicated equipment

weaving

conductive backsheet

many other great concepts……
advantages and challenges:

+ dedicated back contact technology
+ Pick and place:
  low stress on cell
+ Small cell spacing
+ Cu backsheet: low $R_{\text{series}}$

- no EL inspection prior lamination
- invest

source: Eurotron
Module production at Eurotron´s competence center:

<table>
<thead>
<tr>
<th></th>
<th>Isc (A)</th>
<th>Voc (V)</th>
<th>FF (%)</th>
<th>P_{MPP} (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module A</td>
<td>9.97</td>
<td>39.3</td>
<td>77.1</td>
<td>303</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-0.6</td>
<td>0.00</td>
<td>1.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Module B</td>
<td>9.94</td>
<td>39.2</td>
<td>76.5</td>
<td>298 *</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-0.7</td>
<td>-0.05</td>
<td>2.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Module C</td>
<td>9.84</td>
<td>39.1</td>
<td>76.3</td>
<td>294</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-0.6</td>
<td>0.04</td>
<td>2.3</td>
<td>1.8</td>
</tr>
</tbody>
</table>

* confirmed by Fraunhofer Callab

» room for improvement:
• increased cell pitch for increasing Isc
• reduction of FF loss
CBS: optimization of contact pattern

optimization of ECA layout on one cell modules:
CBS: optimization of contact pattern

variation of contact points per busbar:

» 9 points is good compromise

ECA consumption with 9 points:
41 mg / cell
equals
2.5 g / module

» no drastic reduction of FF possible by increasing the amount of contact points

» transition to half cells for FF reduction and increasing white space in module
<table>
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<tr>
<th></th>
<th>Isc (A)</th>
<th>Voc (V)</th>
<th>FF (%)</th>
<th>Pmpp (W)</th>
<th>Eta (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>module 1</td>
<td>5.0</td>
<td>79.3</td>
<td>78.0</td>
<td>311.0</td>
<td>19.2 *</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-2.8</td>
<td>-0.3</td>
<td>-0.5</td>
<td>-3.6</td>
<td>8.3</td>
</tr>
<tr>
<td>module 2</td>
<td>5.0</td>
<td>79.3</td>
<td>77.8</td>
<td>310.6</td>
<td>19.1 *</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-3.7</td>
<td>-0.3</td>
<td>-0.2</td>
<td>-4.1</td>
<td>8.2</td>
</tr>
</tbody>
</table>

* full area efficiency
modules assembled with 20.9 % av. cells processed on M0 wafers

» potential power with 22 % av. cells on M2 wafers: 327 W
ribbon based interconnection

advantages and challenges:

+ easy built-up
+ existing technology
+ soldering or ECA gluing possible
+ bifaciality implementable by default
+ EL inspection of string possible

- special upgrade for stringer needed
- bowing problem
ribbon based interconnection: contacting scheme

assembly process at ISC to overcome excessive bowing

a) gluing of electrically conductive adhesive (ECA)

  + low mechanical stress
  - reliability not proven in field

  » avoiding bow by process sequence

b) soldering

  + long term stability
  - high mechanical stress

  » avoiding bow by pre-bending
soldering with pre-bending: process

assembly parameters:
• solder temperature: 325 °C
• manual fluxing and soldering
• curvature adjustable

experiment:
• single cell strings
• variation of ribbon cross section
• evaluation of structured ribbon
soldering with pre-bending: mechanical stability

temperature cycle tests on one cell minimodules:
(glass-backsheet)
soldering with pre-bending: process improvement

assembly parameters:

- chuck temperature: 50°C
- solder temperature: 325 °C
- manual fluxing and soldering
- fix radius of vacuum chuck
soldering with pre-bending: 4-cell module

best result:

bifacial glas-glas module (3.2 mm ARC) using 21.9 % cells

<table>
<thead>
<tr>
<th>module</th>
<th>Voc (V)</th>
<th>Isc (A)</th>
<th>FF (%)</th>
<th>Pmpp (W)</th>
<th>Eta (%)</th>
<th>CTM power (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>front side</td>
<td>2.68</td>
<td>9.95</td>
<td>78.0</td>
<td>20.8</td>
<td>20.7*</td>
<td>2.9</td>
</tr>
<tr>
<td>rear side</td>
<td>2.65</td>
<td>7.38</td>
<td>79.1</td>
<td>15.5</td>
<td>15.4*</td>
<td></td>
</tr>
</tbody>
</table>

bifi factor: P rear / P front = 0.74
*measured with black frame in 1 mm distance to edge cells

» potential power with same cells on 60 cell module: 312 W
soldering with pre-bending: 60 cell module proof of concept

bifacial glass-glass module assembled using low performing cells:

front glass:
0.8 mm non coated

rear glass:
0.8 mm non coated

weight:
11.5 kg

soldering:
by hand

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</thead>
<tbody>
<tr>
<td>IV front</td>
<td>9.5</td>
<td>38.2</td>
<td>73.2</td>
<td>266</td>
</tr>
<tr>
<td>IV rear</td>
<td>7.5</td>
<td>37.7</td>
<td>73.5</td>
<td>208</td>
</tr>
</tbody>
</table>

bifi factor: $\frac{P_{rear}}{P_{front}} = 0.78$
bifacial module measurement according to IEC norm 60904-1-2

1. separate measurement front and rear:

\[ \varphi_{Isc} = \frac{I_{sc\ rear}}{I_{sc\ front}} \]
\[ \varphi_{Voc} = \frac{V_{oc\ rear}}{V_{oc\ front}} \]
\[ \varphi_{P_{MPP}} = \frac{P_{MPP\ rear}}{P_{MPP\ front}} \]

2. determination of power gain:

\[ G_{E(i)} = 1000 \text{ W/m}^2 + \varphi \cdot G_{R(i)} \]
\[ \varphi_{\text{min}} = \text{Min}(\varphi_{Jsc}, \varphi_{MPP}) \]

\[ i = 0, 100, 200 \]
bifacial module measurement according to IEC norm 60904-1-2

\[\frac{P_{\text{gain}}}{P_{\text{module}}} = \frac{1}{2} \left( \frac{G_{E}}{G_{\text{Isc}}} \right)^{2}\]

<table>
<thead>
<tr>
<th>Module Type</th>
<th>(\phi_{\text{Isc}})</th>
<th>(\phi_{\text{Pmpp}})</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 cell module</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>60 cell module</td>
<td>79</td>
<td>78</td>
</tr>
</tbody>
</table>
bifacial module measurement according to IEC norm 60904-1-2

- Great potential for LCOE reduction!!

<table>
<thead>
<tr>
<th>albedo</th>
<th>effective efficiency (4 cell module)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20.7</td>
</tr>
<tr>
<td>0.1</td>
<td>22.2</td>
</tr>
<tr>
<td>0.2</td>
<td>23.7</td>
</tr>
</tbody>
</table>

Andreas Halm, 8th back contact workshop, November 22nd 2017
Summary

- simple method for p+ passivation
- conductive backsheet based half cell module with 310 W
- simple pre-bending method to counter cell bow
- bifacial 4-cell glass-glass module with 20.7 % front side aperture efficiency
- 60-cell bifacial glass-glass module as proof of concept
- bifacial measurements according to IEC std. as orientation for power gain
Acknowledgement

• Bart de Gier + Nico van Ommen from Eurotron

• my colleagues

• Rüdiger Farneda for soldering with patience

Thank you for your attention!
ribbon based interconnection: front sheet thickness reduction

temperature cycle tests on one cell minimodules:
(ECA glued glass-backsheet)
CoO calculation

- mc Al-BSF
- p-type PERC
- Zebra bifacial (soldered ribbons)

**Cell efficiency**
- 18.50%
- 21.50%
- 22.00%

**C2M-loss**
- 0%
- 2%
- 3%

**Module Pmpp (60 cells)**
- 271
- 309
- 312.9

**Wafer prize**
- p-type mc-Si wafer: 0.58 USD/wafer
- n-type Cz-Si wafer: 0.80 USD/wafer
- p-type Cz-Si wafer: 0.73 USD/wafer