module integration for back contact back junction solar cells

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²: Eurotron BV
Introduction: IBC module

Advantages:
- highest power potential
- uniform optical appearance

Challenges:
- CTM losses
- interconnection method
Introduction: Zebra cell

- Low cost IBC cell
- Screen printed 3D metallization
- 6 inch n-type Cz wafer
- Bifacial IBC cell

- Front floating junction
- Industrial processes proven in PERC and PERT fabrication

» Current best efficiency: 22 %
Introduction: main CTM power losses

standard H-pattern cell

– electrical losses:
  • series resistance

– optical losses and gains:
  • absorption in glass and encapsulant layer
  • reflection at the interfaces
  • reflection from front metallization
  • reflection from backsheet

IBC cell

more liberty since all metal is on the rear side

thinner front encapsulation implementable

higher CTM loss in $I_{SC}$

increases $I_{SC}$ for bifacial IBC cells
Introduction: interconnection issues

Contacting of both polarities in one plane:

- 3D metallization of Zebra cell

- electrical isolation on cell or module level needed

- compensation of mechanical stress for single sided contacting needed

H. Wirth, Fraunhofer ISE, 2nd MWT Workshop 2010, Amsterdam
Introduction: possible interconnection concepts

Classical way: adapted tabber-stringer

Edge stringing (Sunpower)

Continous stringing (e.g. ISC)

NICE
multi busbar
smartwire

new approaches: dedicated equipment

weaving

Conductive backsheet

many other great concepts……
Introduction: possible interconnection concepts

Classical way: adapted tabber-stringer

Continuous stringing (e.g. ISC)

New approaches: dedicated equipment

Conductive backsheet
Outline

- ribbon based Zebra modules
  - contacting scheme
  - bifacial module measurements
  - reliability

- Zebra modules assembled with conductive backsheets
  - device optimization
  - results on 60 cell modules
  - cost structure

- outlook and summary
ribbon based interconnection

advantages and challenges:

+ easy built-up for cells with asymmetric BB structure
+ existing technology with long term experience
+ bifaciality implementable
+ 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) soldering of stress relieved ribbon

+ long term stability
- high mechanical stress

b) gluing of electrically conductive adhesive (ECA)

+ low mechanical stress
- reliability?
ribbon based interconnection: performance

Both techniques yield similar results!

- choice of ribbon main factor for series resistance losses

best results so far:

<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>bifi module front side</td>
<td>2.65</td>
<td>9.85</td>
<td>76.8</td>
<td>20.0</td>
<td>20.2*</td>
<td>1.5</td>
</tr>
<tr>
<td>bifi module rear side</td>
<td>2.62</td>
<td>7.03</td>
<td>78.0</td>
<td>14.3</td>
<td>14.4*</td>
<td></td>
</tr>
</tbody>
</table>

bifi factor: P rear / P front = 0.71

*measured with black frame in 1 mm distance to edge cells
ribbon based interconnection: bifacial measurements

both side illuminated IV measurements on a one-cell-module:

bifaciality factor: $\frac{P_{\text{REAR}}}{P_{\text{FRONT}}} = 0.77$
TC 200 testing of soldered one-cell-modules:

![Graph showing relative power drop vs. ribbon type](image-url)
ribbon based interconnection: reliability

temperature cycle testing up to TC 1000 for ECA glued one-cell modules:
conductive backsheet (CBS) approach

- Pick and place: low stress on cell
- Cu backsheet: low $R_{\text{series}}$
- Small cell spacing
- Flexible rear design
- Proven in mass production

» Good candidate for fast transfer to industry
CBS: contact optimization with ECA

Contact resistance measurements:

Measured quantity:

\[ R_{C\text{ system}} = R_{C1} + R_{C2} + R_{\text{Vol}}(h) \]

\( h \) : contact height
CBS: optimization of contact pattern

optimization on ECA layout: **points** versus **3mm lines**

-> quantity of contact points more significant than contact area
CBS: reliability

temperature cycle testing up to TC 1000:
## CBS: 60-cell Zebra modules

Cell preparation at ISC Konstanz during Hercules pilot line experiment:

<table>
<thead>
<tr>
<th>Group</th>
<th>$I_{\text{MPP}}$ (A)</th>
<th>$P_{\text{MPP}}$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Std. Dev.</td>
<td>Mean</td>
</tr>
<tr>
<td>A</td>
<td>9.18</td>
<td>0.016</td>
</tr>
<tr>
<td>B</td>
<td>9.13</td>
<td>0.016</td>
</tr>
<tr>
<td>C</td>
<td>9.07</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Module production at Eurotron’s competence center:

<table>
<thead>
<tr>
<th>Group</th>
<th>Isc (A)</th>
<th>Voc (V)</th>
<th>FF (%)</th>
<th>$P_{\text{MPP}}$ (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>
CBS: certified module measurement

ISE Callab measurement:

<table>
<thead>
<tr>
<th>Module</th>
<th>$I_{SC}$ (A)</th>
<th>$V_{OC}$ (V)</th>
<th>FF (%)</th>
<th>$P_{MPP}$ (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IV @ Callab</td>
<td>B</td>
<td>9.94</td>
<td>39.24</td>
<td>76.5</td>
</tr>
</tbody>
</table>

Full area efficiency: 18.4%
Total aperture efficiency: 19.1%
CBS: Short term improvements

*Calculated power increase with identical cell and module process:*

<table>
<thead>
<tr>
<th>Module configuration</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current status</td>
<td>303</td>
</tr>
<tr>
<td>Use 22% cell efficiency instead of 21.4%</td>
<td>311</td>
</tr>
<tr>
<td>Introduce M2 wafers (now M0)</td>
<td>319</td>
</tr>
<tr>
<td>Increase cell spacing from 1.25 to 4 mm</td>
<td>322</td>
</tr>
</tbody>
</table>

Comparison to example high end c-Si modules on the market:

<table>
<thead>
<tr>
<th>Module</th>
<th>Technology</th>
<th>Area (m²)</th>
<th>Cells / Size</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunPower</td>
<td>N IBC</td>
<td>1.66</td>
<td>96 / 5 inch</td>
<td>345</td>
</tr>
<tr>
<td>Zebra</td>
<td>N IBC</td>
<td>1.68</td>
<td>60 / 6 inch</td>
<td>322</td>
</tr>
<tr>
<td>Zebra</td>
<td>N IBC</td>
<td>1.62</td>
<td>60 / 6 inch</td>
<td>303</td>
</tr>
<tr>
<td>Yingli</td>
<td>N PERT</td>
<td>1.63</td>
<td>60 / 6 inch</td>
<td>300</td>
</tr>
<tr>
<td>Solarworld</td>
<td>P PERC</td>
<td>1.68</td>
<td>60 / 6 inch</td>
<td>295</td>
</tr>
<tr>
<td>Trina</td>
<td>P PERC</td>
<td>1.63</td>
<td>60 / 6 inch</td>
<td>290</td>
</tr>
</tbody>
</table>
CBS: CoO calculation

Cell efficiency: 20.5% 22%
Module power: 300 W 322 W

Δ = 4.5 ct /W

$0.46 $/W $0.55 $/W

Labor (cell)
Yield loss (cell)
Waste disposal (cell)
Utilities (cell)
Material/Consumables (cell)
Depreciation (cell)

module transformation cost (USD/Wp)

A. Halm, 2nd HERCULES workshop, Berlin, October 2016
Outlook: Zebra half cell module

<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*</td>
<td>5.0</td>
<td>79.0</td>
<td>77.3</td>
<td>308</td>
</tr>
<tr>
<td>CTM (%)</td>
<td>-2.8</td>
<td>0.05</td>
<td>0.4</td>
<td>-3.2</td>
</tr>
</tbody>
</table>

* measured at EDF
Outlook: new concept

Bifacial conductive backsheets - proof of concept:

Transparent rear backsheets with copper tracks:

Bifacial Zebra module:

First prototype $P_{\text{front}} = 18.1 \text{ W}$, bifaciality factor $= 0.7$

(designed by ISC Konstanz produced by Coveme)
Outlook: outdoor performance 4 cell modules

Outdoor performance Zebra modules measured between 12-2015 and 05-2016

- bifi CBS: +11%
- std. CBS: 100%
- bifi ribbon: +21%
Summary

- ribbon interconnection possible for Zebra cells soldered or ECA glued
- bifacial 4-cell module with 20.2 % front efficiency and 71 % bifi factor
- Assembly of Zebra cell in conductive backsheet module possible
- 60-cell module with 303 W power output based on industrial cell and module processes and 308 W module with 120 half cells
- Short term improvements up to 322 W feasible with competitive cost structure
Acknowledgement

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Thank you for your attention!