Pilot Production of Bifacial Heterojunction Cells- and Modules

Heiko Mehlich, Andreas Wallinger, Jun Zhao, Yu Yao, Benedicte Bonnet-Eymard
Hercules Workshop, Berlin – 2016-10-11
the perfect combination

A
less material consumption

Diamond Wire sawing

Thinner wafer ➔ Lower costs

B
simple, efficient and low CoO cell technology

Si heterojunction cells

high efficiency
high energy yield
low CoO ➔ Lower costs

C
high yield, efficient and stable module technology

SmartWire Connection

less silver bifacial
microcrack resistant ➔ Lower costs
HJT Outdoor Performance

Example: Outdoor data from SUPSI (Switzerland) for March 2014 (max. module temp. 40°C)

HJT / SWCT
+ lower Temp. Coeff
+ Bi-facial module
= higher energy yield compared to std. c-Si

<table>
<thead>
<tr>
<th>kWh/kWp</th>
<th>HJT vs. Multi Module</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HJT Mono-facial</td>
</tr>
<tr>
<td>All days</td>
<td>+2.7%</td>
</tr>
<tr>
<td>Clear Days</td>
<td>+3.9%</td>
</tr>
<tr>
<td>Cloudy</td>
<td>+2.1%</td>
</tr>
</tbody>
</table>
Outline

- Heterojunction Cell Pilot Line
- Measurement of Busbarless and Bifacial Cells
- Bifacial SWCT Module Design
- Summary
Hercules Workshop, Berlin – 2016-10-11

- Heterojunction Cell Pilot Line
  - Measurement of Busbarless and Bifacial Cells
  - Bifacial SWCT Module Design
- Summary
Pilot line with 15MW capacity was installed in Q1 2015,
In 2016 line stability, tact time, handling and yield was improved, more than 500000 cells manufactured
Tool equipment is combined with Process Intelligence from Meyer Burger (Testing & MES)
only 6 process steps, up to 25% reduced line footprint
HJT Pilot Production Cell Line Performance

- Weekly production: ~25,000 cells, median efficiency 22 - 22.5%, full automation
- Roadmap 2017 >23% median in production
HJT key technology

HELiA PECVD
- Gross throughput: 2400 w/h
- 56 wafer/tray
- 84 s tact time
- Process pressure: 0.5…10 mbar

HELiA PVD
- Gross throughput: 2400 w/h
- 24 wafer/tray
- 36 s tact time
- Process pressure: 1E-2…5E-3 mbar
- **Heterojunction Cell Pilot Line**
- **Measurement of Busbarless and Bifacial Cells**
- **Bifacial SWCT Module Design**
- **Summary**
Certified Busbarless Cells

- GridTOUCH is now established at ISE Callab
- Shading-free $I_{sc}$ extrapolation by different wire configurations → 15, 25, 35 wire
- calibration report for busbarless cell

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4. Messergebnis
Measurement results

Mismatch-Faktor / Mismatch factor:
(Spektral-Korrektur / spectral correction)

Fläche / Area (l): $(244.25 \pm 0.24) \text{ cm}^2$

$V_{oc}$
$I_{oc}$ (Ed.2 - 2008)/3
$I_{sc}$
$I_{iso}$
$V_{oc}$ (nrel)
$P_{iso}$
$FF$
$\eta$

$= \begin{array}{c}
741.2 \pm 2.5 \text{ mV} \\
9.24 \pm 0.18 \text{ A}
37.82 \pm 0.72 \text{ mA/cm}^2
8.71 \text{ A}
641.8 \text{ mV}
5.59 \pm 0.11 \text{ W}
81.62 \pm 0.53 \text{ %}
22.88 \pm 0.46 \text{ %}
\end{array}$
Cell Performance

- Internal measurement shows 23.0% efficiency (22.9% confirmed independently)
- Excellent temperature coefficients

\[
\begin{align*}
TC \text{ Isc} & \approx +0.035 \%/K \\
TC \text{ Voc} & \approx -0.241 \%/K \\
TC \text{ Pmax} & \approx -0.239 \%/K
\end{align*}
\]

\[
\begin{align*}
P_{\text{max}} & = 5,625 \text{ W} \\
I_{\text{sc}} & = 9,234 \text{ A} \\
V_{\text{oc}} & = 0.741 \text{ V} \\
I_{p_{\text{max}}} & = 8,720 \text{ A} \\
V_{p_{\text{max}}} & = 0.645 \text{ V} \\
Eff & = 23.03 \%
\end{align*}
\]
Bifacial Behavior

- What happens in a backsheet module?

**I-V-curve MBG cell M2**

<table>
<thead>
<tr>
<th>Current [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pmax</td>
</tr>
<tr>
<td>Isc</td>
</tr>
<tr>
<td>Voc</td>
</tr>
<tr>
<td>Ipmax</td>
</tr>
<tr>
<td>Vpmax</td>
</tr>
<tr>
<td>Eff</td>
</tr>
</tbody>
</table>

**1000 W @ front**

<table>
<thead>
<tr>
<th>Power</th>
<th>5,666 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isc</td>
<td>9,383 A</td>
</tr>
<tr>
<td>Voc</td>
<td>0,741 V</td>
</tr>
<tr>
<td>Ipmax</td>
<td>8,870 A</td>
</tr>
<tr>
<td>Vpmax</td>
<td>0,639 V</td>
</tr>
<tr>
<td>Eff</td>
<td>23,20 %</td>
</tr>
</tbody>
</table>

*Is*<sup>c</sup>-gain ≈ 150mA

Eff-gain = 0,2%
Bifacial Behavior

- What’s the right bifaciality factor?

![I-V curve MBG cell M2 diagram]

<table>
<thead>
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<th>1000 W @ front</th>
<th>1000 W @ rear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pmax</strong></td>
<td>5,625 W</td>
</tr>
<tr>
<td><strong>Isc</strong></td>
<td>9,234 A</td>
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<tr>
<td><strong>Voc</strong></td>
<td>0,741 V</td>
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<tr>
<td><strong>Ipmax</strong></td>
<td>8,720 A</td>
</tr>
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<td><strong>Vpmax</strong></td>
<td>0,645 V</td>
</tr>
<tr>
<td><strong>Eff</strong></td>
<td>23,03 %</td>
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$I_{sc}$-Bifaciality = 93%
$P_{max}$-Bifaciality = 96%
Bifacial Behavior

- What`s the right bifaciality factor?
- $P_{\text{max}}$-bifaciality is a function of $I_{\text{pmax}}$-bifaciality and $R_{\text{ser}}$

\[ P_{\text{losses}} = I_{\text{pmax}}^2 \cdot R_{\text{ser}} \]
\[ \Delta P_{\text{losses}} = \Delta I_{\text{pmax}}^2 \cdot R_{\text{ser}} \]
\[ \Delta P_{\text{losses}} \approx -3\% \]
Bifacial Behavior

1. Bifaciality determination at STC:
   \[ \varphi_{isc} = \frac{I_{sc,\text{rear}}}{I_{sc,\text{front}}}; \]

2. I-V characterization vs. backside illumination:
   Equivalent 1-side irradiance levels
   \[ G_{\text{total}} = 1000\text{Wm}^{-2} + \varphi_{isc} \cdot G_{\text{rear}} \]

3. Specific Pmax reporting:
   \[ P_{\text{max, bif110}} = P_{\text{max}} \text{ with } G_{\text{rear}} = 100\text{Wm}^{-2} \]
   \[ G_{\text{total}} = 1000\text{Wm}^{-2} + \varphi_{isc} \cdot 100\text{Wm}^{-2} \]

<table>
<thead>
<tr>
<th>ground material</th>
<th>albedo</th>
</tr>
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<tbody>
<tr>
<td>snow</td>
<td>0,45-0,9</td>
</tr>
<tr>
<td>desert</td>
<td>0,3</td>
</tr>
<tr>
<td>greenfield</td>
<td>0,18-0,23</td>
</tr>
<tr>
<td>asphalt</td>
<td>0,15</td>
</tr>
</tbody>
</table>
Bifacial properties

- Equivalent Irradiance method according Pasan for Albedo factors of 10% and 20%

### I-V-curve MBG cell M2

**1000 W @ front**
- Pmax: 5,625 W
- Isc: 9,234 A
- Voc: 0,741 V
- Ipmax: 8,720 A
- Vpmax: 0,645 V
- Eff: 23,03%

**1000W + 10% Albedo**
- Pmax: 6,136 W
- Isc: 10,072 A
- Voc: 0,742 V
- Ipmax: 9,508 A
- Vpmax: 0,645 V
- Eff: 25,12%

Isc-gain ≈ 0,5 A
Eff-gain ≈ 2,1%
Bifacial properties

- Equivalent Irradiance method according Pasan for Albedo factors of 10% and 20%
- \( P_{\text{max,Bifi10}} = 6,136 \text{W} (@1093 \text{W/m}^2) \) and \( P_{\text{max,Bifi20}} = 6,646 \text{W} (@1186 \text{W/m}^2) \)
- Heterojunction Cell Pilot Line
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Busbarless Cell Connection

- compatible with very thin wafers
- compatible with all wafer technologies
- up to 7%* more module output power
- over 80%* savings in silver.

* compared to a 3BB cell design
SmartWire Module Line

Line Performance:
Tact time: 90 sec/module
Uptime: 92%
Yield: 98%
Operating time: 24 x 330
→ 85MW throughput

*Cell efficiency: 22% (MB HJT Gridtouch measured)
** Indicative value
Module Design in Pilot Produktion

- 2,5mm glass-glass with FS-ARC
- PO based encapsulent
- 60 x M2 size bifacial HJT cells
- SWCT interconnecting (18 x 300µm dia.)
- decentralized jbox
Module Production in Thun

- On-going production of about 2200 glass-glass modules with heterojunction cells from MB until week 45
- About 200 produced, including ~30 modules produced with cell efficiency class from 22.2%-22.4%

<table>
<thead>
<tr>
<th>Pmax</th>
<th>Voc</th>
<th>Isc</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>309.1</td>
<td>43.8</td>
<td>9.1</td>
<td>77.5%</td>
</tr>
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Average power with very low reflective backsheet

- When measured with a white backsheet, this is equivalent to a 318.5W module (+3.0%)
Golden Module in Pilot Production
(standard bill of material)

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</tr>
</thead>
<tbody>
<tr>
<td>front_white BS</td>
<td>330,29</td>
<td>36,90</td>
<td>8,95</td>
<td>44,49</td>
<td>9,46</td>
<td>78,45%</td>
</tr>
<tr>
<td>back_white BS</td>
<td>302,24</td>
<td>36,48</td>
<td>8,28</td>
<td>44,40</td>
<td>8,74</td>
<td>77,91%</td>
</tr>
<tr>
<td>front_black BS</td>
<td>320,42</td>
<td>36,92</td>
<td>8,68</td>
<td>44,42</td>
<td>9,07</td>
<td>79,52%</td>
</tr>
<tr>
<td>back_black BS</td>
<td>296,09</td>
<td>36,88</td>
<td>8,03</td>
<td>44,35</td>
<td>8,45</td>
<td>78,98%</td>
</tr>
</tbody>
</table>

330,3 W<br>white BS, 99% CtlM<br><br>320,4 W<br>Bif, black ground, STC<br><br>&gt; 93%<br>Isc-Bifaciality
Measurement conditions

DUT's temperature: 25.47 °C

Average Irradiance: 1.175.03 [W/m²]

Electrical performance at STC summary

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</tr>
</thead>
<tbody>
<tr>
<td>379.85</td>
<td>36.59</td>
<td>10.38</td>
<td>44.61</td>
<td>10.85</td>
<td>78.47%</td>
<td>0.23</td>
</tr>
</tbody>
</table>

P_{eq. BiF 20} = 379.85 \, \text{W}_p

60 x 6inch cell module
Summary

- Meyer Burger has successfully combined high efficient cells with a novel interconnection technology
- Since 2015 more than 500,000 HJT busbarless cells were produced (Eta_{med} >22%)
- HJT & SWCT is preferred for bifacial module design
- J_{sc}-bifacaility of 93% has been achieved

Move in to the 1^{st} european cell line customer in Jan. 2017
«Your task is not to foresee the future, but to enable it!»
Antoine de Saint-Exupéry

This work is partly supported by the EU project HERCULES

Meyer Burger Germany
An der Baumschule 6-8
09337 Hohenstein-Ernstthal
Germany

Thank you!
Competitive Production costs

Cost per WP

Cell line Opex*

- Current cell conversion cost below 7$Cent/Wp
- 5$Cent/Wp in 2017
- Opex cost down applicable to current equipment

*95% yield, Opex only

Roadmap until end of 2016

Beyond 2017

Note:
- CoO depending on region and assumptions
- Capex not included
- M2 wafer size 22.5% cell efficiency

$/Wp
Assumptions

- **1600 kWh/m²** yearly irradiation
- **55°C** average module working temperature
- **25 years** system lifetime
- **1-2% LID for PERC**
- **10% albedo effect for HJT bifacial**
- **6% albedo for PERC/PERT/L bifacial**