Bifacial PERC+ solar cells: status of industrial implementation and future perspectives


Institute for Solar Energy Research Hamelin (ISFH)
PERC vs. bifacial: market share

~ 60% market share in 2027

~ 30% market share in 2027

Bifacial PERC cells = PERC+

Data from ITRPV roadmap, March 2017
ISFH PERC+ solar cell process

PERC

- Wafer cleaning
- Rear protection layer
- Texturing
- Phosphorus diffusion
- PSG + dielectric etch
- Rear: AlO$_x$/SiN$_y$
- Front: PECVD-SiN$_x$
- Rear: LCO
- Al screen-printing
- Ag screen-printing
- Co-firing

- 200 nm pitch
- Full area

PERC+

- 80 nm
- 1.5 x pitch
- 5 BB Grid

T. Dullweber et al., 31st EUPVSEC (2015), p. 341
Challenges with PERC+

Resistivity of Al paste (20 μΩcm$^1$) 6 times higher than Ag paste

Numerical modelling: high $\eta_{\text{front}}$

- $R_{s,L} < 0.05 \, \Omega \text{cm}^2$ required

\[ \text{Al finger series res. } R_{\text{SL}} \, [\Omega \text{cm}^2] \]

$[\text{Image}]$

\[ \text{Al finger width [μm]} \]

\[ \# \text{BB/wires} \]

Challenges with PERC+

Resistivity of Al paste (20 $\mu\Omega \text{cm}^1$) 6 times higher than Ag paste

Numerical modelling: high $\eta_{\text{front}}$

- $R_{s,L} < 0.05 \Omega \text{cm}^2$ required
- 5 BB design enabled PERC+
- Smart Wire enables narrow Al finger designs

Challenges with PERC+

Printing narrow Al fingers

- PERC Al pastes exhibit extreme spreading > 200 µm
- PERC+ Al pastes enable finger widths < 150 µm
Challenges with PERC+

Aligning Al fingers to LCO

- Al screen print to LCO align. tolerance $< \pm 30 \, \mu m$
- Requires cameras and high precision screens and lasers
ISFH PERC+ solar cells

5 busbar PERC+ cells

- $\eta_{\text{front}}$ up to 21.6%*
- $\eta_{\text{rear}}$ up to 16.7%
- Bifaciality up to 80%
- Al paste reduced by 90%

*independently confirmed by ISFH CalTeC

T. Dullweber et al., 31st EUPVSEC (2015), p. 341
PERC+ with deeper Al-BSF

- PERC+ with 7 µm deep Al-BSF
- New physical model to calculate Al-BSF depth:

\[
W_{p+} = \frac{m_{Al}}{A \rho_{Si}} \left( F \left( 1 - e^{-\frac{A \rho_{Si} v_{diss} t_{firing}}{m_{Al}}} \right) \right) \frac{1 - F}{1 - \left( 1 - e^{-\frac{A \rho_{Si} v_{diss} t_{firing}}{m_{Al}}} \right)} - \frac{E}{1 - E}
\]

\[
\frac{m_{Al}}{A} = \frac{A_{Al-finger} \rho_{Al}^*}{a}
\]

- Explains higher \( V_{oc} \) of PERC+ compared to PERC
- PERC+ has no voids

C. Kranz et al., IEEE Journal of Photovoltaics, 6 (2016), p. 830
22.1 % PERC+ cell at ISFH

Busbar less PERC+ cell

- $\eta_{\text{front}} = 22.1\%$
- Missing BB shadowing increases $\eta_{\text{front}}$ by 0.4%_{abs.}
- $\eta_{\text{rear}}$ not measured
- Rear Al grid optimized for high $\eta_{\text{front}}$
- 5 BB on rear not required

*measured at ISFH with IV tester from PASAN
**Industrial introduction of PERC+**

<table>
<thead>
<tr>
<th>Year</th>
<th>$\eta$ [%] front / rear</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>21.5 / 16.7</td>
<td>ISFH</td>
</tr>
<tr>
<td>2016</td>
<td>20.7 / 13.9</td>
<td>Big Sun Energy Technology</td>
</tr>
<tr>
<td>2017</td>
<td>21.5 / 16.1</td>
<td>JinkoSolar</td>
</tr>
<tr>
<td>2017</td>
<td>21.6 / 17.3</td>
<td>LONGi Solar</td>
</tr>
<tr>
<td>2017</td>
<td>21.6* / n.p.</td>
<td>ISFH (5 BB)</td>
</tr>
<tr>
<td>2017</td>
<td>22.1 / n.p.</td>
<td>ISFH (BB less)</td>
</tr>
</tbody>
</table>

*Independently confirmed; n.p. = not published

- PERC+ in (pilot) production at SolarWorld, LONGi, Trina Solar, Neo Solar Power, …

- 5 largest solar cell companies are producing PERC and evaluating PERC+
### Commercial PERC+ Modules

<table>
<thead>
<tr>
<th>Company</th>
<th>Product</th>
<th>Max. power rating [Wp]</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SolarWorld</td>
<td>Bisun</td>
<td>290</td>
<td>5 BB, 60 cells, Cz</td>
</tr>
<tr>
<td>Neo Solar Pow.</td>
<td>Glory Bifi</td>
<td>300</td>
<td>4 BB, 60 cells, Cz</td>
</tr>
<tr>
<td>Trina Solar</td>
<td>Duomax</td>
<td>300</td>
<td>5 BB, 60 cells, Cz</td>
</tr>
<tr>
<td>LONGi Solar</td>
<td>LR6-60P</td>
<td>305</td>
<td>4 BB, 60 cells, Cz</td>
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- ~ 300 Wp power rating stated for front side illumination, only
- Additional rear side illumination (e.g. 10%) will increase $P_{\text{max}}$ (e.g. to ~ 320 Wp)
PERC+ outdoor test sites

SolarWorld installations, Germany:
- 3.2 kWp Bisun modules
- 74% albedo (white), 0.28 m mou. height
- 13.0% increased energy yield of PERC+ vs. PERC (13.3% predicted)

- 13 kWp Bisun modules on 1 axis tracker
- 17% albedo (sand), 0.9 m mou. Height
- 21.6% increased energy yield of PERC+ vs. PERC

Novel PERC+ SWCT modules

Conventional Ag pads

Smart Wire Connection Technology (SWCT)

T. Dullweber et al., 33rd EUPVSEC (2017), in press
PERC+ module processing

- 18 PERC+ cells without busbars => 55 mg Ag paste per full-size PERC+ cell
- Half cell design
- Smart Wire Connection Technology
  - 18 wires coated with InSn
  - 200 μm wire diameter
  - Foil with glue on one side
- 1.5 mm Light Reflective Film (LRF) from 3M in-between PERC+ cells
- Glass-glass module with AR coating

T. Dullweber et al., 33rd EUPVSEC (2017), in press
**PERC+ module results**

<table>
<thead>
<tr>
<th></th>
<th>$V_{oc}$</th>
<th>$I_{sc}$</th>
<th>$FF$</th>
<th>$\eta$</th>
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<tr>
<td></td>
<td>[V]</td>
<td>[A]</td>
<td>[%]</td>
<td>[%]</td>
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<td>18 PERC+ cells, front</td>
<td>$11.9^\Sigma$</td>
<td>$4.91^\sigma$</td>
<td>$77.3^\sigma$</td>
<td>$20.5^\sigma$</td>
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<tr>
<td>Module front</td>
<td>11.8</td>
<td>4.80</td>
<td>78.7</td>
<td>19.8*</td>
</tr>
<tr>
<td>Module back</td>
<td>11.8</td>
<td>3.94</td>
<td>78.8</td>
<td>16.4*</td>
</tr>
</tbody>
</table>

*Independently confirmed by TÜV Rheinland®

T. Dullweber et al., 33rd EUPVSEC (2017), in press
## PERC+ module results

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<tr>
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*Independently confirmed by T. Dullweber et al., 33rd EUPVSEC (2017), in press

\[
\eta_{eq,0.1} \equiv \eta_{front} + 0.1 \times \eta_{rear} = 21.4\
\]

Bifaciality = 83%
PERC efficiency potential

Selection criteria

- large area > 148 cm$^2$
- p-type, monocrystalline
- screen-printed contacts

K.A. Münzer et al., 25th EUPVSEC (2010), 2314
Bosch Solar Energy AG, press release April 2011
Schott Solar AG, press release August 2011
P. Engelhart et al., 26th EUPVSEC (2011), 821
A. Lachowicz et al., 27th EUPVSEC (2012), 1846
B. Tjahjono et al., 28th EUPVSEC (2013), 775
P. Verlinden et al., 6th WCPEC (2014), in press
Trina Solar, press release Dec. 2015

T. Dullweber and J. Schmidt, IEEE JPV, 6, 1366 (2016)
PERC+ efficiency potential

\[ \eta_{\text{front}} > 23\% \]
- selective emitter
- narrow Ag fingers
- improved surface passivation

\[ \eta_{\text{rear}} > 20\% \ (85\% \text{ bifaciality}) \]
- narrow Al fingers
- improved AR properties

T. Dullweber and J. Schmidt, IEEE JPV, 6, 1366 (2016)
Conclusions

Data from ITRPV roadmap, March 2017
Conclusions

with PERC+

Data from ITRPV roadmap, March 2017
Conclusions

- PERC+ cells are attractive for monofacial and bifacial applications with $\eta_{\text{front}}$ up to 22.1% and $\eta_{\text{rear}}$ up to 17.2%

- Leading solar cell manufacturers are evaluating / producing PERC+ cells. Commercial PERC+ modules available from 4 companies

- PERC+ module with Smart Wire Connection Technology reduces Ag paste to 55 mg and increases bifaciality to 83%

- Evolutionary PERC improvements will increase PERC+ $\eta_{\text{front}} > 23\%$ and $\eta_{\text{rear}} > 20\%$ in next few years
Acknowledgements

• Funding was partly provided by the German Federal Ministry for Economic Affairs and Energy under contract number 032577C (HELENE).

• Toyal for providing the Al paste

• Meyer Burger for supporting SWCT set up
Challenges with PERC+

Aligning Al fingers to laser contact openings (LCO)

- Misalignment forms open Si surface -> high recombination
- Al screen print to LCO align. tolerance < ± 30 µm
- Requires cameras in screen printer for aligned printing
- Requires high precision screens and lasers
### Industrial introduction of PERC+

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Company</th>
<th>PERC status</th>
<th>PERC+ status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>JinkoSolar</td>
<td>production</td>
<td>in evaluation</td>
</tr>
<tr>
<td>2</td>
<td>Trina Solar</td>
<td>production</td>
<td>pilot production</td>
</tr>
<tr>
<td>3</td>
<td>Canadian Solar</td>
<td>production</td>
<td>not published</td>
</tr>
<tr>
<td>4</td>
<td>Hanwha Q-Cells</td>
<td>production</td>
<td>in evaluation</td>
</tr>
<tr>
<td>5</td>
<td>JA Solar</td>
<td>production</td>
<td>in evaluation</td>
</tr>
</tbody>
</table>

- 4 of 5 largest solar cell producers are evaluating / producing PERC+ cells based on their PERC mass production.
- 5 largest solar cell manufacturers account for approx. 25 GWp production capacity / 30% market share.

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Commercial PERC+ modules

Bifacial PERC+ modules with conventional stringing technology

Ag pads
Al busbars

Bisun module from SolarWorld
Improvements in Ag screen print, rear design, IV tester calibration:

- 5BB $\eta_{\text{front}}$ up to 21.5%
- noBB $\eta_{\text{front}}$ up to 22.1%
- 0.6% increase due to missing BB shadowing and improved rear passivation
- Measured with PASAN IV tester at ISFH
PERC+ large scale installations

Neo Solar Power, Taiwan¹
- 2 MWp Glory Bifi roof installation
- Currently under construction

Trina Solar, China²
- 20 MWp Duomax power plant
- Under construction on sandy ground with high albedo

PERC+ solar cell process

- “No BB“ PERC+ cells without busbars for smart wire module
- “5 BB“ PERC+ cells with 5 busbar design as reference

T. Dullweber et al., 33rd EUPVSEC (2017), in press

55 mg Ag paste per BB-less PERC+ cell