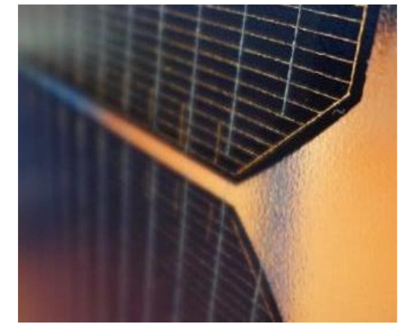

RELIABLE COPPER PLATING PROCESS FOR BIFACIAL HETEROJUNCTION CELLS

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Heterojunction cell

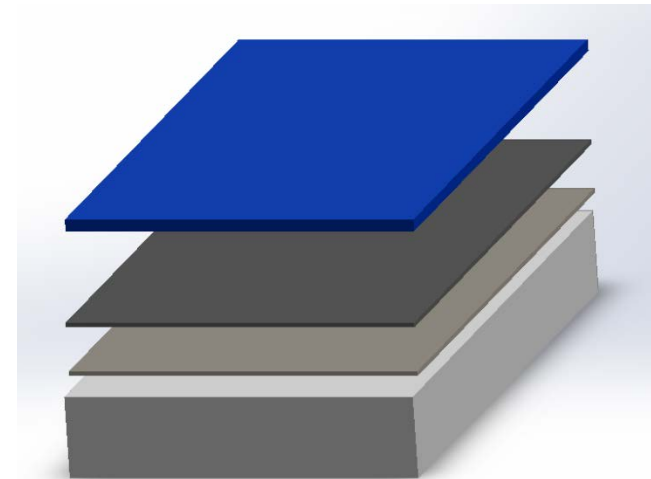
- Simple process sequence
- Excellent surface passivation
- Small temperature coefficient
- Full area contact (TCO)
- Low T metallisation required (low T Ag paste or plating)

PVD TCO

PECVD a-Si(n)

PECVD a-Si(i)

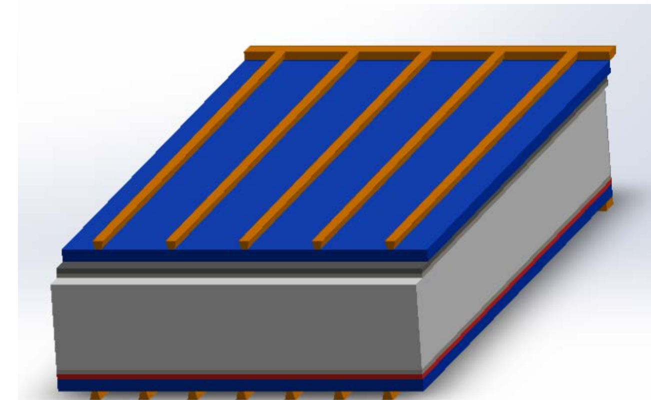
c-Si n-type, textured and cleaned



Important for plating:

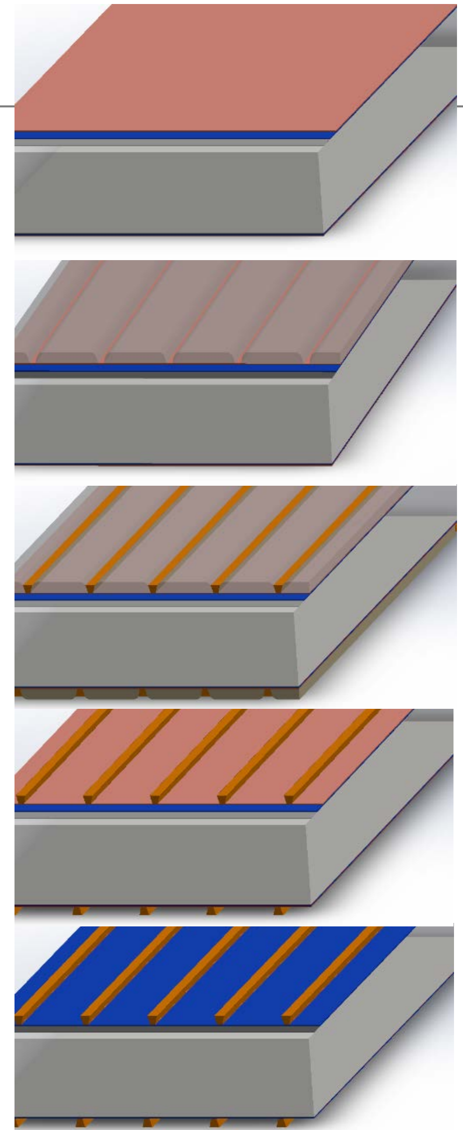
- Conductive TCO on the surface
  -> entire surface would be plated if not masked
- Lateral TCO conductivity not sufficient for uniform current distribution during plating

Intrinsically bifacial structure



Process sequence

- Sputtered seed layer
  - Wide choice for selection and combinations:
    - contact resistance
    - adhesion
    - barrier properties
  - Copper seed layer enables good conductivity
  - Enables plating of busbar-less cells
- Hotmelt inkjet printing
- Plating: copper and final finish layer simultaneously on both sides
- Hotmelt ink removal
- Seed layer etchback



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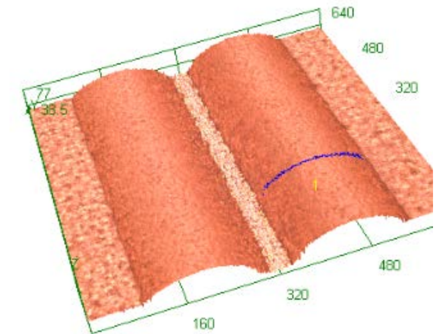
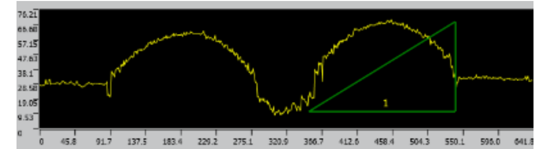
Hotmelt inkjet patterning

Courtesy: J. Hermans, Meyer Burger NL

- Low ink consumption
- Equipment for 2400 w/h available [1]
- Processing:
  - ink removal with alkaline solution
  - removed ink can be precipitated and filtered out

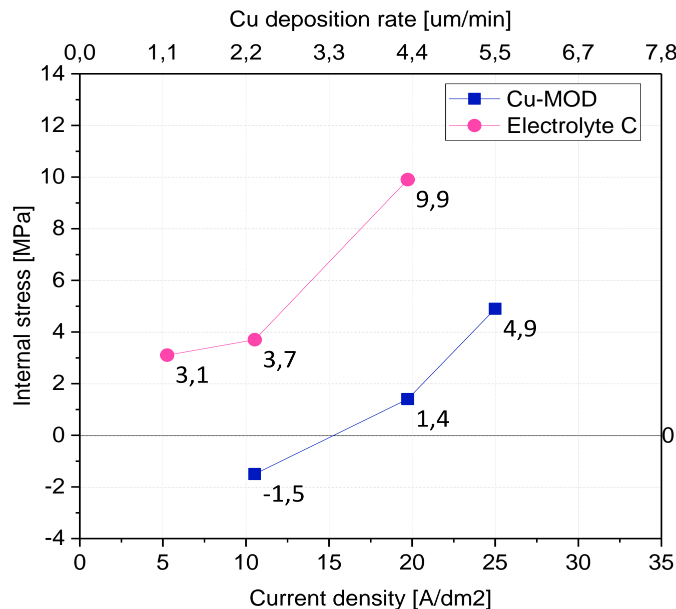


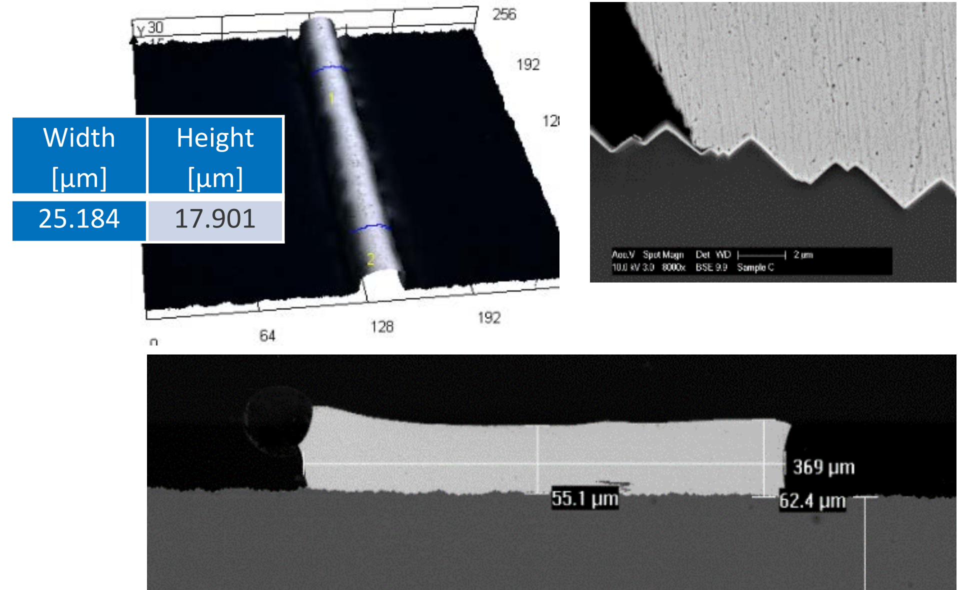


[1] J. Hermans et al., EUPVSEC, 2014

CSEM R&D plating line

- Vertical wafer processing with simultaneous plating of both sides for bifacial cells
- Contacting allows to control the e-plating rates on front and rear side independently
- CSEM electrolyte for copper layers with very low internal stress at high plating rates >3µm /min





Width [µm]	Height [µm]
25.184	17.901

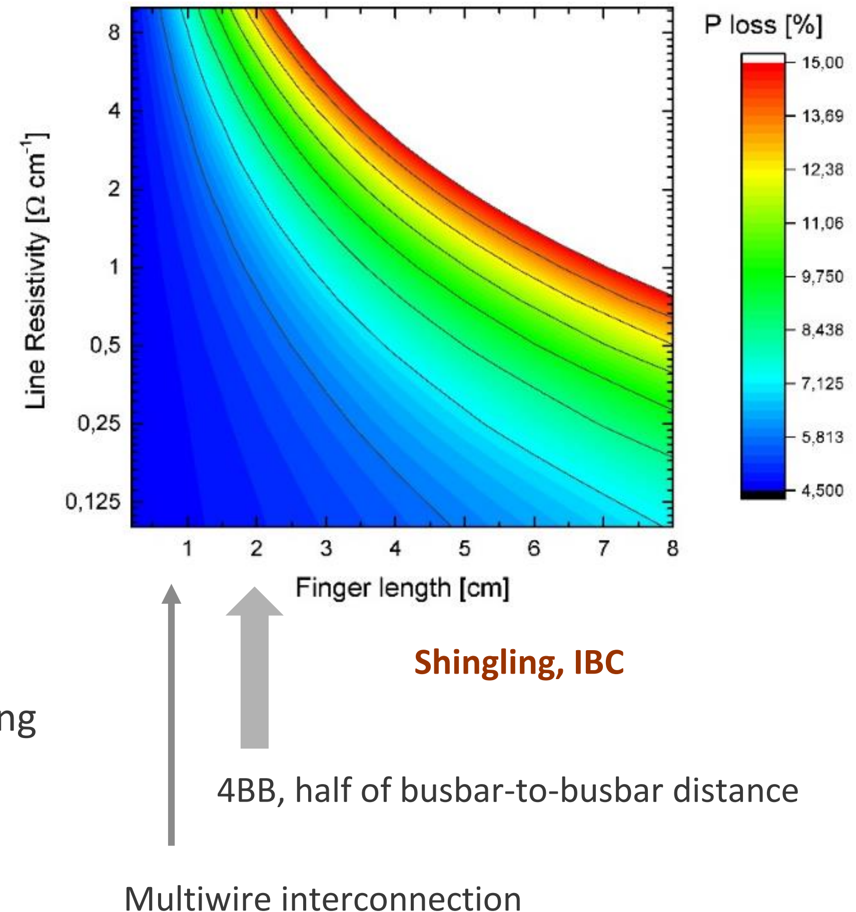
→ high throughput and thick layer build-up feasible

Requirements on line conductivity

Fine line printing possible 4 – 6 Ω/cm

Robust screen printing necessary <1 Ω/cm
➔ high Ag paste consumption

Copper plating



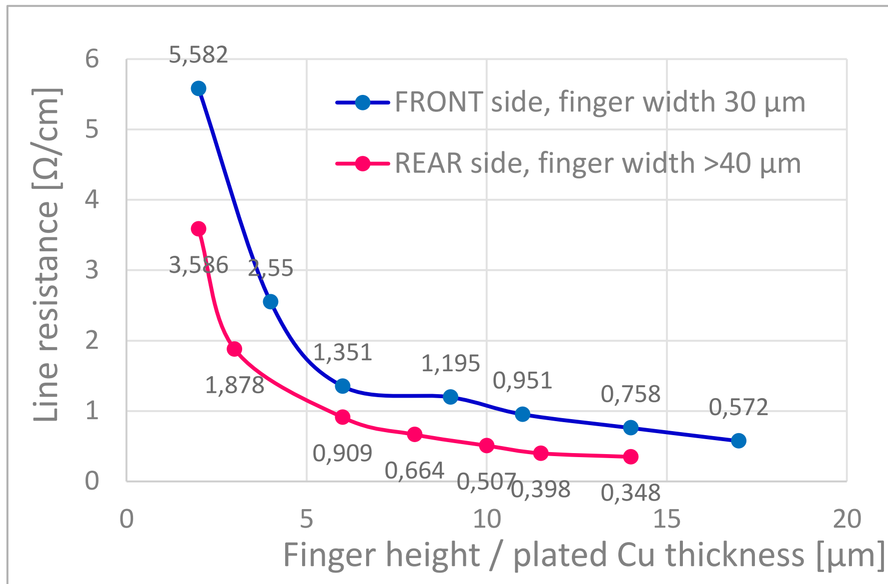
Shingling, IBC

4BB, half of busbar-to-busbar distance

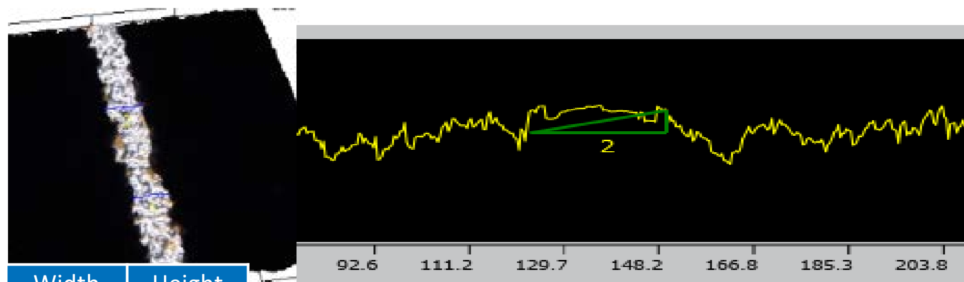
Multiwire interconnection

- High silver paste consumption for ribbon interconnection (bifacial cells)
- Multiwire interconnection allows for fine line printing and Ag paste reduction
- Copper plating: applicable for all

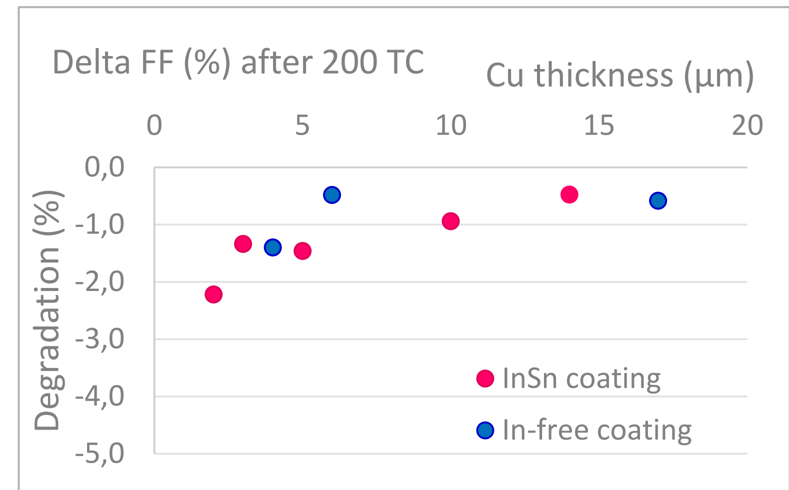
Line resistance per unit length of plated fingers



- 4-probe resistance measurement on BB-less cells with finger thickness 2 – 17 µm
- Lower FF measured only for 2 µm copper thickness on cell level (GridTouch, 78.8%), no impact on module level (1-cell modules)
- Good stability after 200 TC



Width [µm]	Height [µm]
26.536	2.128



Copper thickness 2 µm ➔ **plating time < 1 min**

Solar cell results

Busbar-less bifacial solar cells on different 6" HJT precursors: identical metallisation pattern;

all co-processed in the same batch

Cell	Tcorr. J_{SC} [$mA.cm^{-2}$]	Tcorr. V_{OC} [mV]	Tcorr. FF [%]	Tcorr. Eff [%]	Rserie [$\Omega.cm^2$]	n	FF_0 [%]	PL mean after annealing [counts]
Type1_002	38.24	731.38	78.45	21.94	0.83	1.29	82.26	25683
Type1_003	38.38	731.55	78.86	22.15	0.88	1.21	83.04	24888
Type1_004	38.19	730.13	77.83	21.71	0.74	1.40	81.18	25332
Type2_100	38.36	735.84	81.30	22.95	0.50	1.12	84.07	28825
Type2_101	38.29	737.52	82.21	23.21	0.52	1.03	85.08	28703
Type2_102	38.27	736.33	82.24	23.17	0.46	1.06	84.73	29171
Type2_103	38.29	736.56	81.77	23.07	0.55	1.07	84.59	29153
Type2_104	38.38	736.73	82.40	23.30	0.47	1.03	85.03	29813

Measured wtih PCBTouch

Substrate	Pc (mΩ.cm2)
Type 1	0.093
Type 2	0.047

- Specific contact resistivity (TCO-metal) in the same very low range for both substrate types.

  ➔ Plating does not limit the FF (> 82%)

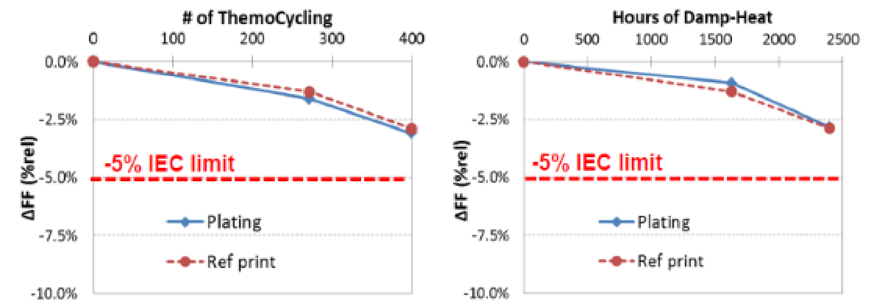
Certified efficiency >24%

Cell	Area [cm^2]	Jsc [mA/cm^2]	Voc [mV]	FF [%]	Eff [%]
M2, 4BB, bifacial	224.8	40.0	731	82.5	24.14

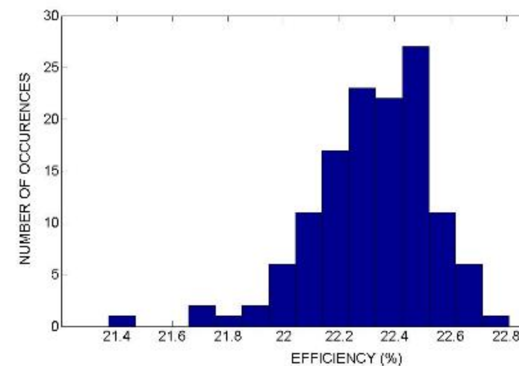
- Bifacial cell with 4 busbars on 6" CZ-Si HJT solar cell precursor from Choshu Industry
- With double antireflective coating.
- Aperture measurement on a reflective chuck

Module results with plated HJT solar cells

- Damp-heat and TC tests of 4-cell-modules: passed two times the IEC 61215 norm



- BB-less bifacial cells for 60-cells SmartWire module plated in our R&D with narrow efficiency distribution.
  Mean 22.3%, best cell 22.8% (GridTouch)



- 60-cells-glass-glass modules assembled with InSn and In-free wires

Wire type	Voc [V]	FF [%]	Pmax[W]
InSn coated wires	43.59	78.74	307.89
In-free coated wires	43.50	78.01	303.40

Glass-glass-module, measurement with white backsheet.

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Process cost: screen printing, BB-less

Assumed values:		
Cell area	244.4	cm^2
Silver price = Ag paste price	500	US$/kg
Cost of hotmelt ink	50	US$/kg

- Qualitative cost assessment based on information from our partners and values from literature.
- Separate numbers for equipment and facilities and for paste consumption

Screen printing			Equipment amortization / facilities / labor / consumables		Cost of Ag paste			Total cost	
	Cell eff.	Pmpp	Cost per cell	Cost per Wp	Consum-ption per cell	Cost per cell	Cost per Wp	Cost per cell	**Cost per Wp**
Cell type	[%]	[W]	[US$cent]	[US$cent/ Wp]	[mg]	[US$cent]	[US$cent/ Wp]	[US$cent]	**[US$cent/ Wp]**
BB-less, bifacial, SWCT	22.9	5.6	5.0	0.89	**100**	5	0.89	10.0	**1.79**

- **Conservative values** for equipment and paste consumption
- Strong reduction in paste consumption to <60 mg (bifacial cell) already demonstrated. [1]

[1] A. Faes et al., EUPVSEC, 2017

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Process cost: screen printing, 4BBs

Assumed values:		
Cell area	244.4	cm^2
Silver price = Ag paste price	500	US$/kg
Cost of hotmelt ink	50	US$/kg

Screen printing			Equipment amortization / facilities / labor / consumables		Cost of Ag paste			Total cost	
	Cell eff.	Pmpp	Cost per cell	Cost per Wp	Consum-ption per cell	Cost per cell	Cost per Wp	Cost per cell	**Cost per Wp**
Cell type	[%]	[W]	[US$cent]	[US$cent/ Wp]	[mg]	[US$cent]	[US$cent/ Wp]	[US$cent]	**[US$cent/ Wp]**
BB-less, bifacial, SWCT	22.9	5.6	5.0	0.89	**100**	5	0.89	10.0	**1.79**
4BBs, bifacial	22.5	5.5	5.0	0.91	350	15	2.73	20.0	**3.64**

- Ag concumption for 4-BB-cells under assumption of good (low T) Ag paste conductivity
- A way to reduce paste consumption is to increase the number of busbars. [1, 2]

[1] A. Leuwen et al. , SOLMAT, 2016
[1] J. Geissbühler et al. , Photovoltaics Intern., 2017

Process cost: Patterning for Cu plating

Assumed values:		
Cell area	244.4	cm^2
Silver price = Ag paste price	500	US$/kg
Cost of hotmelt ink	50	US$/kg

Screen printing			Equipment amortization / facilities / labor / consumables		**Cost of hotmelt ink**			Total cost	
	Cell eff.	Pmpp	Cost per cell	Cost per Wp	Consum-ption per cell	Cost per cell	Cost per Wp	Cost per cell	**Cost per Wp**
Cell type	[%]	[W]	[US$cent]	[US$cent/ Wp]	[mg]	[US$cent]	[US$cent/ Wp]	[US$cent]	**[US$cent/ Wp]**
4BBs, bifacial	22.5	5.5	5.5	1.00	1000	5	0.91	10.5	**1.91**

- Considered is the ink amount for substrates with larger pyramids; reduction possible for substrates with smaller pyramids, with different ink and optimized recipes
- The price for the ink is expected to fall with increasing production volumes
- Best case for low ink consumption: IBC cell (one side to pattern and low coverage area).

Screen printing vs. plating cost comparison for 4BB layout

- Total cost for plating of 6" HJT cells (20 µm Cu, bifacial): **1.55 US$cent/Wp**
  (courtesy M. Zwegers, MECO, the number includes equipment amortization, facilities (electricity, DI water, water treatment, CDA), labor, factory space, chemicals & anodes, consumable parts)

Screen printing			Equipment amortization / facilities / labor / consumables		Cost of Ag paste or hotmelt ink			Total cost	
	Cell eff.	Pmpp	Cost per cell	Cost per Wp	Consum-ption per cell	Cost per cell	Cost per Wp	Cost per cell	**Cost per Wp**
Cell type	[%]	[W]	[US$cent]	[US$cent/ Wp]	[mg]	[US$cent]	[US$cent/ Wp]	[US$cent]	**[US$cent/ Wp]**
4BBs, bifacial **screen printing**	22.5	5.5	5.0	0.91	Ag: 350	15	2.73	20.0	**3.64**
4BBs, bifacial **patterning and plating**	22.5	5.5			ink: 1000				**3.46**

- Cost of PVD seed layer to include (low cost metals; cost probably in the range <1 US$cent per wafer)

Conclusions

- Process stability demonstrated with pilot production for 60-cell-modules
- Efficiency >24% and FF > 82% confirmed on high performance substrates
- Plated metallization is not limiting the fill factor (to a level up to 83%)
- High plating rates and low internal stress demonstrated for Cu plating
- Cost for plating process for 4BB-cells in the same range as screen printing.
  Cost reduction for hotmelt ink expected through increasing production volumes.

Acknowledgements

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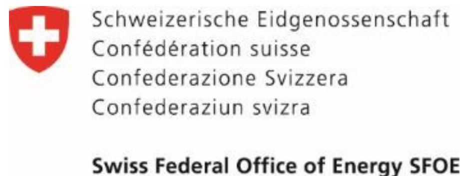

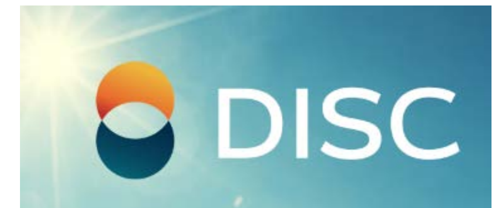

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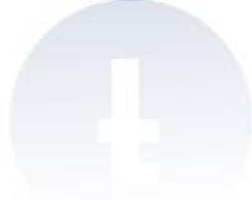

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