Review on Plating Processes for Silicon Heterojunction Cells

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Heterojunction cell

- Simple process sequence
  - Cleaning and texturing
  - PECVD deposition of amorphous Si
  - PVD deposition of thin conductive oxide
  - Metallization
- All low temperature processes
- Symmetric cell structure

Heterojunction cell is intrinsically bifacial
⇒ Power gain in GG-modules 10 – 30%

Bifacial PV systems can sometimes see gains of more than 30% and, combined with tracking, the total electrical gain can be close to 50%, which will reduce LCOE to below 2ct/kWh.


1 A. Descoeudres et al., “Low-temperature processes for passivation and metallization of high-efficiency crystalline silicon solar cells”, Solar Energy, 2018
Plating directly on TCO

- Lateral conductivity of a standard TCO is not sufficient for contacting at the edges of the to-be-plated side

- Plating on patterned side with opposite-side-contact
  Light induced plating (rear emitter) or in forward diode direction (front emitter on n-type Si)

- Ni plating for improved adhesion\(^1\-\(^3\)

- ITO reduction for improved adhesion
  - Electrochemically (own experiments)
  - ITO reduction by plasma\(^4\)
  - To consider: ITO is consumed during reduction

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\(^1\) P. Papet et al., Proc. of the 28\(^{\text{th}}\) EUPVSEC, 2013
\(^2\) J. Geissbühler et al., Metallization Workshop, 2014
\(^3\) A. Dabirian et al., SOLMAT, 2017
\(^4\) US patent number 20160359058
Selective metal layer, contacting at busbars

- A selective seed layer in the openings of a mask would be very advantageous:
  - It would enable contacting at the busbar on the to-be-plated side and therefore also simultaneous plating on both sides of a bifacial cell.
  - The costly PVD deposition could be skipped, no seed layer etchback at the end.
- The process is challenging, mostly chemical and alkaline processes like electroless copper, adhesion an issue
- Development ongoing at several institutes and companies.
Standard process: PVD seed layer with an organic mask

- Seed layer deposition, PVD
  - High lateral conductivity allows for contacting at the edges of the to-be-plated side and simultaneous plating on both sides; good adhesion; low contact resistivity
- Organic mask, on both sides
  - Photolithography
  - Non-photosensitive resist: screen-printed \(^1\), patterned with an inkjet printed liquid \(^2\)
  - Hotmelt inkjet \(^3\)
- Plating simultaneously on both sides
- Mask removal and seed layer etchback
- Process applicable also for busbar-less cells

\(^1\) A. Khanna et al., Applied Surface Science, 2015
\(^2\) Z. Li et al., Energy Procedia, 2015
\(^3\) J. Hermans et al., Proc. of the 28\(^{\text{th}}\) EUPVSEC, 2013
Patterned seed layer and dielectric mask\textsuperscript{1,2}

- PVD seed layer deposition
- Patterning with an UV-curable ink
- Seed layer etchback / patterning
- PECVD dielectric layer like SiNx or SiOx
- Ink removal forms openings in dielectric
- Plating simultaneously on both sides
  - Contacting at the busbars
  - Dielectric layer serves as plating mask
- Dielectric forms an additional antireflective coating, TCO thickness can be reduced

\textsuperscript{1} O. Schultz-Wittmann, Proc. of the 27\textsuperscript{th} EUPVSEC, 2012 (TetraSun)

\textsuperscript{2} US patent number US000008236604B2, 2011 (TetraSun)
**Printed seed-grid and dielectric mask**

- Fine lines, inkjet or screen printing of metal paste
- PECVD deposition of a dielectric like SiNx or SiOx
- Surface of the printed seed is rough and the dielectric non-continuous on the grid, enhanced through annealing.
- Plating occurs only where seed grid is present underneath the dielectric layer
  - **Contacting at the busbars**
  - **Dielectric layer serves as plating mask**
- Process is used for production at Kaneka, JP
  - Improved module stability with SiOx

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1 European patent number EP000002489076B1, 2010 (EPFL)
2 Adachi et al., SOLMAT, 2017 (Kaneka)
Processes in development

- Laser induced transfer of a Ni seed layer from a foil
- PVD seed layer including AlOx-mask
- Selective plating: Dynamic Liquid Meniscus

- Direct plating of fingers on ITO: electrolyte meniscus on cell surface formed via micronozzles
  - patternning not necessary at all / cost saving potential
- High plating speed achievable through extremely high solution exchange at the surface
- Process in development
- High throughput and narrow finger lines challenging

1 Presentation Y. Franzl, this conference
2 Presentation T. Hatt, this conference
3 M. Balucani et al., Metallization Workshop, 2013

Courtesy: M. Balucani
Process cost calculation for bifacial HJT cells

- Considered cost: equipment depreciation and materials, consumables and waste treatment
- Calculation with different interconnection for screen printed cells and for two plating processes for interconnection with soldered ribbons

**SCREEN PRINTING**

- Cost highly dependent on silver paste consumption and price
- Paste consumption strongly depends on interconnection type:
  - Standard soldered ribbons
  - Ribbon gluing with ECA (electrically conductive adhesive)
  - Wire interconnection

**COPPER PLATING**

- Cost independent of metal consumption and of interconnection
- Several processing steps and equipment types required:
  - PVD for seed layer deposition
  - Patterning
  - Plating
## Cost comparison: metallization and interconnection / SP

- Screen printing: very high silver paste consumption 350mg for bifacial HJT cells (low temperature paste) for standard interconnection with soldered ribbons
- Reduced silver paste consumption for screen printing for interconnection with electrically conductive adhesive (ECA) but additional cost for the interconnection / adhesive
- Lowest silver paste consumption for bifacial busbar-less cells for Smart Wire interconnection (SWCT)

### Ag paste price used for calculation: 550 EUR/kg

<table>
<thead>
<tr>
<th>Interconnection:</th>
<th>SP 5BBs Soldering</th>
<th>SP 5BBs ECA/LCR</th>
<th>SP BB0 SWCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mat./consum./waste</td>
<td>350 mg</td>
<td>210 mg</td>
<td>90 mg</td>
</tr>
</tbody>
</table>

Only small cost share for equipment for screen-printing: basic version considered

LCR: light capturing ribbons
Cost comparison: metallization and interconnection

- **Plating**: high cost share for equipment because of several process steps
- **PVD + HMI**: process with sputtered seed layer and hotmelt inkjet patterning
- **Slightly lower cost** for process with patterned seed layer and a dielectric layer as plating mask

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Ag paste used for calculation: 550 EUR/kg

- **SP 5BBs Soldering**: 350 mg
- **SP 5BBs ECA/LCR**: 210 mg
- **SP BB0 SWCT**: 90 mg
- **Cu 5BBs PVD + HMI Soldering**: 
- **Cu 5BBs PVD + SiNx Soldering**: 

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**Interconnection: Mat./consum./waste**

**Equipment depreciation (7a)**

**Metallization: Mat./consum./waste**

**Equipment depreciation (7a)**
Cost comparison: metallization and interconnection / Ag price

- Because of the high consumption of the low temperature Ag paste its price is decisive for the cost relation between plating and screen printing.
- The price for a medium production volume customer is 700 - 850 EUR/kg.
- Plating processes are cost competitive for metallization of HJT cells at the current prices for Ag paste.

![Bar chart showing Ag paste price used for calculation: 750 EUR/kg](image)
**Plating in production**

<table>
<thead>
<tr>
<th>Company</th>
<th>Technology</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunpower</td>
<td>IBC cells</td>
<td>&gt; 2 GW (just for comparison)</td>
</tr>
<tr>
<td>Kaneka</td>
<td>HJT</td>
<td>small production with copper plating</td>
</tr>
<tr>
<td>Sunpreme</td>
<td>HJT</td>
<td>Pilot line in 2018, 24% reached with copper plating</td>
</tr>
<tr>
<td>Tongwei</td>
<td>HJT</td>
<td>100 MW production line with copper plating in construction</td>
</tr>
<tr>
<td>GS – Solar</td>
<td>HJT</td>
<td>500 MW production line with copper plating in construction. Start with 100 MW, 22.8% average efficiency achieved</td>
</tr>
</tbody>
</table>

Taiyang Report, Heterojunction Solar Technology, 2019
Processes and results at CSEM

- Baseline process at CSEM
  - Sputtered seed layer and hotmelt inkjet patterning
  - Seed layer consisting of an adhesion layer and a copper conductive layer
  - Peel force measurement: 4 – 5 N/mm (180° peel test on soldered ribbons)
- Contact resistivity: < 1 mΩ·cm²
- High line conductivity, spec. resistivity close to bulk copper: 2 µΩ·cm
- Finger dimensions for 4-BB-cells: 25 µm width/height reliably feasible with hotmelt-inkjet patterning

Cross section of a copper line defined by hotmelt inkjet mask and with immersion silver as solderable capping layer.
Stability of modules with copper plated cells

- SmartWire modules (1-cell): stability exceeding 3x IEC norm, for standard InSn-coated wires as well as for In-free wires
- Modules with soldered ribbons with standard SnPbAg-coating, glass-glass 1-cell modules: >500 TC and >3000 h DH
Highest achieved efficiency: > 24.7%, FF 83.3%

- Monofacial cell with 4 busbars on an industrial precursor (M2)
- Double ARC, measurement with aperture
Plating on aluminum zinc oxide AZO

- Replacement of indium tin oxide for cost reduction
- AZO is chemically very sensitive and not stable in commonly used plating and etching solutions
  
  ⇒ Plating process must not attack the AZO layer

- With a modified process sequence:
  - Cells with AZO on POLO carrier selective contacts have been successfully plated and good fill factor achieved: FF 79.8%
  - Good adhesion on textured as well on polished surface with AZO.
  - Good adhesion and low contact resistivity 1.2 mΩ·cm² also on CIGS cells
Summary

- Several proven and reliable processing routes for plating on HJT cells are already available and are cost competitive to screen printing.
- New processes with alternative patterning techniques in development
- Implementation of plating in production has started with IBC and HJT cells
- Further cost reduction for equipment and consumables are expected once production volumes with plating increase.

Plating processes at CSEM:
- Excellent reliability and high efficiency achieved
- Process for copper plating on AZO developed
- Research for alternative patterning techniques ongoing
Thank you for your attention!

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