Evolution of Cell Technology and its Impact on Metallization Paste Development

PV CellTech
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DuPont Photovoltaic and Advanced Materials

For over 40 years our material innovations have led the photovoltaics industry forward, and helped our clients transform the power of the Sun into power for us all. Today we offer a portfolio of solutions that deliver proven power and lasting value over the long term. Whatever your material needs, you can count on quality DuPont Photovoltaic Solutions to deliver the performance, efficiency and value you require, day after day after day...
Solar Cell Efficiency Evolution

- LDE & PERC is still the majority with PERC gaining share.
- Adoption of N type, IBC, HJT is still uncertain due to the high technology content and investment threshold.
DuPont™ Solamet® Product Generation Roadmap

--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---

**P-type**
- PV17x for LDE: Pioneer in LDE
- PV18x for Enhanced LDE
- PV18J with improved fine line and high adhesion
- PV76x for PERC
- PV19x for Extreme LDE
- PV19B market benchmark with superior aspect ratio and fine line printability
- PV19L, PV19H with superior adhesion
- PV20x: Improving cell performance for LDE and PERC
- PV3Nx Improved fine line, conductivity and P-contact capability
- PV51x, PV52x: Low cost tabbing interconnects
- PV5x non-fire through tabbing interconnect for PERC
- PV36x Al for PERC (Laser Contact Openings)

**N-type**
- PV3N1, PV3N2 for P-contact
- PV3Nx Improved fine line, conductivity and P-contact capability
- Back Contact Metallization Pastes (p and n contacts)
- HJT Metallization Pastes (Finger with excellent conductivity and Solderable Busbar)

**Front Side Silver**
- Single Print
- PVD2A, PVD2B: Pioneer in floating busbars
- PVD1x / PVD2x for Double Print driving higher aspect ratios
- PVM1x with excellent fine line printability and aspect ratio on MCF screens

**Rear Side Tab**
- Multi Print
- PV5x for LDE
- PV18J with improved fine line and high adhesion
- PV76x for PERC
- PV19x for Extreme LDE
- PV19B market benchmark with superior aspect ratio and fine line printability
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DuPont™ Solamet® Next Gen Front Side Silver Achieving Higher Cell Performance for P-Type Solar Cells
DuPont™ Solamet® Enabled Significant Improvement in P-Type Cell Efficiency

First to introduce LDE with Solamet® PV17x achieving a step change in efficiency

First to offer an integrated solution for PERC unlocking further efficiency entitlements for p-type cells

Solamet® Next Gen. FS silver enabling adoption of fine line screen with excellent aspect ratio

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Metallization Paste Development for Fine Line Printing

- Excellent paste transfer property enables moving to finer line screens

Note: Screen opening is narrow side.
Enabling Finer Line Contact

Wafer: 6" M2 Mono 90 ohm/sq

Significant contact resistance improvement to further boost efficiency through diffusion optimization
Enabling Fine Line Screen

<table>
<thead>
<tr>
<th>360.16-31um</th>
<th>380.14-27um</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV19x</td>
<td>Next Gen FS</td>
</tr>
</tbody>
</table>

EL defect count (50pcs/group inspection)
Efficiency Optimization by Finer Line Screen

>0.1% Efficiency gain demonstrated. Higher Isc without FF drop while moving to finer line

<table>
<thead>
<tr>
<th>Paste</th>
<th>Screen</th>
<th>Eff</th>
<th>Voc</th>
<th>Isc</th>
<th>FF</th>
<th>Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next Gen</td>
<td>380.14.27um-110F</td>
<td>+0.12</td>
<td>0.639</td>
<td>9.311</td>
<td>80.50</td>
<td>1.59</td>
</tr>
<tr>
<td>Next Gen</td>
<td>380.14.29um-105F</td>
<td>+0.06</td>
<td>0.640</td>
<td>9.299</td>
<td>80.25</td>
<td>1.72</td>
</tr>
<tr>
<td>Next Gen</td>
<td>360.16.31um-105F</td>
<td>+0.04</td>
<td>0.639</td>
<td>9.290</td>
<td>80.43</td>
<td>1.62</td>
</tr>
<tr>
<td>Next Gen</td>
<td>360.16.31um-105F</td>
<td>Ref</td>
<td>0.639</td>
<td>9.299</td>
<td>80.16</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Note: Screen opening is narrow side.
Maintain Good Adhesion Performance

Comparable Adhesion Performance as Solamet® PV19L
DuPont™ Solamet® Next Generation Front Side Silver – Enabling Fine Line Screen

• Excellent gridline resistance and printability, which enables < 27μm opening screen printing with 0.1% efficiency gain

• Wide screen selection allows fine line printing performance without high cost

• Quality and consistent materials are critical to ensure long term printability for stable mass production
DuPont™ Solamet®
Front Side Silver Development Direction
Focus on PERC

Efficiency Entitlements from FS silver

• 0.1% by 10μm narrower lines
• 0.3% by reduced recombination
• 0.1% by better contact

Enable extreme Lightly Doped Emitter (LDE) by reducing contact resistance and optimizing overall cell performance through fill factor (FF) and open circuits voltage (Voc) improvement.
Metallization Paste Development for “Mesh Cross Free” Screens

<table>
<thead>
<tr>
<th>Concept</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Standard mesh with low mesh count</td>
<td>Special mesh (2~3 wires removed at finger location)</td>
</tr>
<tr>
<td>Requirement</td>
<td>Precise alignment in screen MFG process</td>
<td>Work with upstream mesh supplier</td>
</tr>
</tbody>
</table>

Solamet® PVM1A

- With 25µm design > 0.1% Efficiency improvement demonstrated over incumbent 38µm screen.
- Adoption of this novel screen technology is still at early stage
### Metallization Paste Considerations for Black Si

<table>
<thead>
<tr>
<th>Process (multi)</th>
<th>STD acidic etching</th>
<th>Reactive ion etching (RIE)</th>
<th>Metal catalysis chemical etching (MCCE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Etch rate</td>
<td>Slow</td>
<td>Fast</td>
<td>Relative Low</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Relative Low</td>
<td></td>
</tr>
</tbody>
</table>

- **SEM photo**

- **The current challenge of Black silicon is lower adhesion than on standard texture.**

- **Need to continue to monitor contact and printability performance.**
DuPont™ Solamet®
Metallization Paste Development for N-cell
Opportunities for Further Improvement on N-cell

• Screen printing paste improvement
  • Reduce contact resistivity and gridline resistivity
  • Improve recombination parameter ($J_0$) for higher Voc
    • Floating busbar (PVD2x, PV61B) to reduce $J_{o,m}$ under busbars
    • Improve PV3Nx to further reduce $J_{o,m}$ under fingers
  • $<40\mu m$ fine-line printing

Ag/Al contact still has much higher rho-c and rho-gl compared to P-type standard

<table>
<thead>
<tr>
<th>Rho-c</th>
<th>Rho'-gl</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ref] PV18X on standard P-type</td>
<td>[~2x] PV3N2 on N-type</td>
</tr>
<tr>
<td>[ref] PV18X on standard P-type</td>
<td>[~+60%] PV3N2 on N-type</td>
</tr>
</tbody>
</table>

Voc improvement

$$V_{oc} = \frac{kT}{q} \ln \left( \frac{J_{sc}}{J_0} + 1 \right)$$

Need to reduce $J_0$ under metal ($J_{o,m}$)

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Double Print Package for N-cell: Solamet® PV3N2+PVD2A

2nd print: Finger lines & busbar: PVD2A
1st print: Finger lines only: PV3N2

- Double Print process enables a Decoupling of the functions of each layer to maximize overall performance.
- 1st layer paste can focus more on improving the contact resistance on the B-doped emitter.
- 2nd layer paste focusing on conductivity and soldered adhesion. Also, the “Non-contacting” nature of PVD2A (floating busbar) provides an additional benefit in improving Voc of the cell (less recombination under the busbar).
Improved Fine Line Performance

- Better aspect ratio with 10% laydown saving
- 0.05% efficiency increase demonstrated
Next Gen Paste Development Progress for N-cell

- Significant contact resistance improvement to further boost efficiency through diffusion optimization
- Candidate pastes identified with improved conductivity, contact resistance, & Voc.
DuPont™ Solamet®
Metallization Pastes for HJT Finger Line and Busbar
L9281: Polymer thick film paste for fine line electrode

【Features】
- Process temperature 150 - 200degC
- Air curable
- Screen printable
- Low resistivity
- Store in room temperature (Thermoplastic)

Table.1 Typical physical properties

<table>
<thead>
<tr>
<th>Test</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity (uohm cm) @ 200degC-30min</td>
<td>13</td>
</tr>
<tr>
<td>Printing properties (#325 W:80um Emulsion:25um)</td>
<td></td>
</tr>
<tr>
<td>Line width (um)</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Thickness (um)</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Cross section (um²)</td>
<td>&gt;1500</td>
</tr>
<tr>
<td>Solderable</td>
<td>Not recommend</td>
</tr>
</tbody>
</table>

Table.2 Composition properties

| Viscosity (Pa.s) @ 10rpm       | 190-230    |
| Solid content (wt%) @ 750degC | 83.0-86.0  |

L9180: Solderable PTF paste

【Features】
- Process temperature 150 - 250degC
  - Air curable
  - Screen printable
- Good solder-ability and adhesion (>3N)
- OK with Pb-free solder
- Store in room temperature (Thermoplastic)

Recommended Process Conditions
Dry: 180deg.C for 60mins
Thickness: 30μm (A)
Ribbon: Sn/Pb solder coated Cu
Flux: Kester 955 (B)
Pre-heat Temp: 90deg.C
Iron Temp: 230 deg.C

(A) >25um electrode thickness required for good adhesion
(B) Only apply flux on Ribbon. Not on PTF.
DuPont™ Solamet®
Metallization Paste Options for IBC
## Metallization Options for IBC

<table>
<thead>
<tr>
<th></th>
<th>Two Pastes System</th>
<th>One Paste System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Print/Dry</strong></td>
<td>2 times</td>
<td>1 time</td>
</tr>
<tr>
<td><strong>Contact via opening</strong></td>
<td>No need (Fire-through)</td>
<td>Need (Laser, Etching)</td>
</tr>
<tr>
<td><strong>Firing temperature</strong></td>
<td>700-800°C</td>
<td>550-600°C</td>
</tr>
<tr>
<td><strong>Electrode width</strong></td>
<td>As narrow as possible</td>
<td>&lt; 600µm less than p-n pitch</td>
</tr>
<tr>
<td><strong>Electrode thickness</strong></td>
<td>As thick as possible</td>
<td>&lt; 10µm</td>
</tr>
<tr>
<td><strong>Passivation area loss</strong></td>
<td>(electrode width)</td>
<td>No limitation with electrode width</td>
</tr>
<tr>
<td></td>
<td>(p-n pitch)</td>
<td></td>
</tr>
</tbody>
</table>

Further progress on IBC paste development will require close collaboration with cell / module customers.
DuPont™ Solamet®
Interconnect Paste for Advanced Cell Assembly
**Introduction**

• In parallel to innovation on new cells structures (PERC, n-PERT), there is a move towards advanced module structures, for example shingled cell modules.

• DuPont has developed innovative interconnect paste to replace materials like SnPb Alloy used for advanced cell assembly.

**DuPont Interconnect Paste**

**Stable at room temperature**

**Shingled cells assembly in DuPont facility**

**Ag**, **Si**, **Laser cutting**, **Interconnect**
**Technical Features**

- Innovative paste chemistry enables performance differentiation from alternatives
- Module reliability
  - Low elastic modulus helps modules release stress
  - High temperature durability from new binder matrix
- Processing flexibility
  - Equipment and application developers enjoy flexibility with DuPont offerings as they are stable at room temperature

<table>
<thead>
<tr>
<th>Key Features of DuPont</th>
<th>Value Delivered</th>
<th>Comparison with other interconnect materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DuPont pastes</td>
</tr>
<tr>
<td>Elastic modulus(^1) (MPa)</td>
<td>Lower mechanical stress</td>
<td>20</td>
</tr>
<tr>
<td>Resistivity (ohm · cm)</td>
<td>Effective electrical connection</td>
<td>0.5-3 x 10(^{-4})</td>
</tr>
<tr>
<td>High adhesion to multiple substrates</td>
<td>Meeting process standard</td>
<td></td>
</tr>
<tr>
<td>High temperature durability</td>
<td>Use in high temperature applications</td>
<td></td>
</tr>
<tr>
<td>bleeding out control</td>
<td>Avoids shading, waste and short-circuit</td>
<td></td>
</tr>
<tr>
<td>Product stability at room temperature</td>
<td>Lower cost of shipping and storage; Flexibility for processing;</td>
<td></td>
</tr>
<tr>
<td>Intermediate state available for processing, inspection and re-working</td>
<td>Flexibility for processing; New application like coated ribbons</td>
<td></td>
</tr>
<tr>
<td>Environment-friendly</td>
<td>Lead free</td>
<td></td>
</tr>
</tbody>
</table>

1. **Measured value for binder materials w/o metallic fillers**
“Easy-to-Use” for Both Dispensing and Screen Printing

Dispensing

Module Maker
“Attachment”

Screen Printing
Potential Applications

• Shingled cell design
• Floating electrode design
  – Less recombination
    • passivation layer preserved at busbar area bringing significant Uoc contribution.
  – More light absorption
    • combined together with textured ribbons

• Other applications (IBC, HJT etc.) where a flexible & low process temperature cell interconnection solution is required
Solamet® Metallization Technology
Lower Cost of Ownership and Greater Profitability

• Moving to finer lines with excellent contact performance is the key for P-type metallization development to further boost cell efficiencies
• Next generation Solamet® front side silver maximizes cell efficiency on P-type solar cell (LDE & PERC) more than 0.1%
• DuPont continues to set the pace of innovation in the solar industry by introducing leading performance pastes that work to deliver greater solar panel efficiency and power.