Advanced Materials Help Make Solar Panels More Powerful

DuPont™ Solamet® PV19x
New Front Side Silver Metallizations

DuPont Microcircuit Materials
DuPont™ Solamet® Driving Cell Performance Evolution

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

New Gen. Solamet® PV19x enabling extreme LDE with excellent fine line capability

Looking to the future:

Fine line aspect ratio will be key focus in metallization development to improve p-type cell efficiency
DuPont™ Solamet® Driving Cell Performance Evolution

Fine line aspect ratio is key to efficiency improvement with pattern optimization

Advance fine line innovations achieved by synergy from screen technology, paste and pattern design
Lower Cost of Ownership, Greater Profitability

DuPont™ Solamet® PV19x delivers higher cell performance through:

- Fine Line Capability
- Processing Latitude
- Reliability
Lower Cost of Ownership, Greater Profitability

DuPont™ Solamet® PV19x delivers higher cell performance through:

- Fine Line Capability
- Processing Latitude
- Reliability
DuPont™ Solamet® PV19A Demonstrates Superior Fine Line Control

**Superior line control for narrower line width**

**Higher aspect ratio**

Excellent fine line aspect ratio to sustain fill factor and gridline conductivity
DuPont™ Solamet® PV19A
Demonstrates Superior Fine Line Paste Transfer

Excellent printability down to 30µm screen opening:
- Reduced line spreading
- Better line definition
- Smoother morphology
- No printing EL defect
DuPont™ Solamet® PV19A Achieves Higher Cell Efficiency

- >0.1% Efficiency improvement on multi cells

- Improved line width control with significant Isc benefit on 35µm screen opening

- Excellent aspect ratio to boost fill factor and gridline conductivity
Lower Cost of Ownership, Greater Profitability

**DuPont™ Solamet® PV19x** delivers higher cell performance through:

- **Fine Line Capability**
- **Processing Latitude**
- **Reliability**
DuPont™ Solamet® PV19x Enabling Extreme LDE by Reducing Contact Resistance by an order of Magnitude

Diffusion insights to advance cell performance through innovative chemistry
Excellent contact capability allowing robust processing latitude
DuPont™ Solamet® PV19x Industry Collaboration 1: Superior Performance and Yield Demonstrated on Multi Cells

Cell Efficiency Distribution

- **>0.15%** Efficiency gain on multi proven in pilot run
- **Robust processing** latitude allowing tighter cell distribution to reduce low efficiency binning <17.8%
- **Production yield** increased from 93% to 98.5% for >260W power output
### Solamet® PV19x Industry Collaboration 2: Multi Cell with High Rsheet Emitters

<table>
<thead>
<tr>
<th>Paste</th>
<th>Screen</th>
<th>Rsheet</th>
<th>Eff (%)</th>
<th>Eff gain (rel. %)</th>
<th>Voc</th>
<th>Isc</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV19x</td>
<td>3BB 35umx 100F</td>
<td>90ohm/sq</td>
<td>17.91%</td>
<td>-</td>
<td>0.635</td>
<td>8.652</td>
<td>79.3</td>
</tr>
<tr>
<td></td>
<td>3BB 31umx 110F</td>
<td>100ohm/sq</td>
<td>18.02%</td>
<td>0.11%</td>
<td>0.637</td>
<td>8.677</td>
<td>79.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110ohm/sq</td>
<td>18.04%</td>
<td>0.13%</td>
<td>0.637</td>
<td>8.684</td>
<td>79.4</td>
</tr>
</tbody>
</table>

Customer B
N=200pc

Maximize efficiency through high Rsheet and fine line pattern optimization
## DuPont™ Solamet® PV19x Industry Collaboration 3: Mono Cell with Extreme LDE

<table>
<thead>
<tr>
<th>Paste</th>
<th>Rsheet</th>
<th>$\Delta$Eff (rel. %)</th>
<th>Voc</th>
<th>Isc</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref-2</td>
<td>70ohm/sq (LDE)</td>
<td>-</td>
<td>0.632</td>
<td>9.285</td>
<td>77.47</td>
</tr>
<tr>
<td><strong>PV19x</strong></td>
<td></td>
<td>+0.23%</td>
<td>0.631</td>
<td>9.311</td>
<td>78.29</td>
</tr>
<tr>
<td>Ref-2</td>
<td>70ohm/sq (extreme-LDE)</td>
<td>-0.03%</td>
<td>0.634</td>
<td>9.309</td>
<td>76.87</td>
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<tr>
<td><strong>PV19x</strong></td>
<td></td>
<td>+0.3%</td>
<td>0.634</td>
<td>9.322</td>
<td>78.09</td>
</tr>
</tbody>
</table>

N=40pc

Significant Voc/Isc benefit while maintaining fill factor through diffusion optimization and innovative paste technology
Lower Cost of Ownership, Greater Profitability

DuPont™ Solamet® PV19x delivers higher cell performance through:

- Fine Line Capability
- Processing Latitude
- Reliability
Field Studies Reveal Quality Issues

Subcomponent degradation mode pareto based on visual inspection

41% of inspected modules exhibited some visual defect
Findings consistent with BP and SunPower data

DuPont Field Module Program

• Inspected >60 global installations (>200 MW & 1.5 million modules) in NA, EU, & AP ranging from 0-30 years installed

• Data includes c-Si modules from > 45 module manufacturers

Accepted for presentation at IEEE PVSC (New Orleans, 2015, A. Bradley et al)
DuPont Holistic Cell and Module Durability Program

- Evaluate durability for PV materials and their interactions and synergies in module
- Develop products with highest durability to deliver more power output
Aged Bonding Strength and Corrosion Resistance are Common Accelerated Testing Protocols for Metallization Related Durability

**Aged Bonding Strength**
(for Busbar)

- Cu
- Sn/Pb
- Ag
- Si

Weak solder bond connection after acceleration test

**Corrosion Resistance**
(for Finger Line)

Loss of finger grid contact after accelerated test

Contact resistance

![Graph showing contact resistance over finger distance](image)

- EL dark
- EL bright

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New Generation Solamet® Designed to Improve Aged Bonding Strength

Successful differentiation of pastes allows development of superior products

*Relevance to fielded modules is under investigation
DuPont™ Solamet® PV19x
Lower Cost of Ownership, Greater Profitability and Reliability

✓ Proprietary technology delivering >0.15% efficiency improvement on multi cell with proven module reliability

✓ Excellent fine line printability down to 30µm screen opening with improved aspect ratio to maintain FF and gridline conductivity

✓ Robust processing latitude to reduce low efficiency binning and improve production yield

✓ Enabling extreme LDE by reducing contact resistance by an order of magnitude to further boost Efficiency

✓ New, advanced materials such as Solamet® PV series metallization pastes can enable 20% cost of ownership reduction by 2020 through increased cell efficiency and lower materials consumption.....without compromising solar panel reliability and durability