High volume transfer of high viscosity silver pastes using Laser Direct-Write Processing for metallization of c-Si cells

M. Morales, Y. Chen, D. Munoz-Martin, S. Lauzurica, C. Molpeceres

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### Metallization of Solar Cells

Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing


- Ink-jet printing
Front-side Metallization: key process for enhancing efficiency in a cost effective way

- Screen-printing
- Ink-jet printing
- High-efficiency approaches: photolithography / evaporation / plating

LIFT: Laser-Induced Forward Transfer

- Some materials deposited using LIFT:
  - Metals, Oxides, Nanopowders
  - Organic polymers, Biomaterials & living cells
  - Conductive inks, Ag nanoparticles pastes

Experimental setup

- Low temperature screen-printing Ag pastes.
- Deposition onto donor substrate using a commercial paint coater.
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix).
- Diode Pumped Solid State Laser (Spectra Physics Explorer)
  - Nd:YVO4 emitting 532 nm
  - Pulse duration 14 ns
- Optical Scanner (ScanLab HurryScan)
  - F-Theta Lens, focal 250 mm
  - Focused beam diameter 22-25 µm
Dupont PV17F

**Silver paste**

- **Viscosity**: 28-40 kcps
- **Solid Content @750 ºC**: 91.0%
- **Non-newtonian, pseudoplastic, thixotropic fluids**

**Deposition onto donor substrate**

- Commercial paint coater (RK PrintCoat Instruments).
- Incorporates spreading blade adjustable using micrometers

Thickness, roughness (~2 um) and waviness (~5-8 um) are measured for every experiment by means of confocal microscopy.

**LIFT configuration**

- **Laser system**
  - Spectra Physics Explorer DPSS 532nm
  - Pulse duration: 14 ns
- **Paste thickness**
  - 30 um, 50 um, 80 um
- **GAP**
  - 50 um

**LIFT parameterization**

<table>
<thead>
<tr>
<th>Laser</th>
<th>Explorer@532nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Paste thickness: 60 um</td>
<td>GAP: 50 um</td>
</tr>
<tr>
<td>Laser position</td>
<td>Substrate distance</td>
</tr>
<tr>
<td>Paste thickness: 60 um</td>
<td>GAP: 50 um</td>
</tr>
</tbody>
</table>

**Matrix of spots**

- Many combinations of laser parameters are tested, including energy levels (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) and paste thicknesses (60, 50, 40, 30, 20, 10, 0 um).
- Transfer threshold
- Compact transfer is obtained
- All the paste is removed from the donor substrate

W: 88 um
H: 12 um

W: 85 um
H: 35 um

LIFT parameterization

- Explosive transfer
- All paste is removed from the donor substrate
- Transferred paste height is similar to silver powder size

W: 236 um
H: 13 um

W: 132 um
H: 57 um
LIFT parameterization

- Explosive transfer but with heights higher than particle size
- All the paste is removed from the donor substrate

<table>
<thead>
<tr>
<th>LIFT parameterization</th>
<th>Laser</th>
<th>Explorer@532nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptor substrate</td>
<td>Laser frequency</td>
<td>20 kHz, 50 kHz</td>
</tr>
<tr>
<td>Paste thickness</td>
<td>80 µm</td>
<td></td>
</tr>
<tr>
<td>GAP</td>
<td>50 µm</td>
<td></td>
</tr>
<tr>
<td>Pulse energy</td>
<td>14.5 µJ</td>
<td></td>
</tr>
<tr>
<td>Process speed</td>
<td>2 m/s</td>
<td></td>
</tr>
<tr>
<td>Laser frequency</td>
<td>20 kHz</td>
<td></td>
</tr>
</tbody>
</table>

W: 211 um  
H: 9 um

W: 136 um  
H: 56 um

LIFT printing of long lines

<table>
<thead>
<tr>
<th>LIFT printing of long lines</th>
<th>Laser</th>
<th>Explorer@532nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser frequency</td>
<td>20 kHz, 50 kHz</td>
<td></td>
</tr>
<tr>
<td>Pulse duration</td>
<td>14 ns</td>
<td></td>
</tr>
<tr>
<td>Pulse energy</td>
<td>0.1 – 35 µJ</td>
<td></td>
</tr>
<tr>
<td>Paste thickness</td>
<td>80 µm</td>
<td></td>
</tr>
<tr>
<td>GAP</td>
<td>50 µm</td>
<td></td>
</tr>
<tr>
<td>Receiving substrate</td>
<td>Monocrystalline Silicon wafer (520 µm)</td>
<td></td>
</tr>
<tr>
<td>Process speed</td>
<td>20 – 2000 m/s</td>
<td></td>
</tr>
</tbody>
</table>

Height: 55 µm  
Width: 90 µm – 150 µm  
Aspect Ratio: 0.36 – 0.61
• The LIFT process generates a column of paste that connects both substrates.

• When the glass substrate is removed the paste is stretched until the final shape is obtained.

• This could explain the high aspect ratio and high transferred volume.

• The paste thickness and the gap are key variables in the transfer of high viscosity pastes.

Large area metallization

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>Laser Explorer@532nm</td>
</tr>
<tr>
<td>Spot diameter</td>
<td>25 µm</td>
</tr>
<tr>
<td>Paste thickness</td>
<td>80 µm</td>
</tr>
<tr>
<td>GAP</td>
<td>50 µm</td>
</tr>
<tr>
<td>Pulse energy</td>
<td>14.5 µJ</td>
</tr>
<tr>
<td>Process speed</td>
<td>2 m/s</td>
</tr>
<tr>
<td>Line length</td>
<td>3 cm</td>
</tr>
</tbody>
</table>

Optical scanners allows fast processing and flexible design to print large areas.

Good predeposit conditions are needed.

Summary

1) The minimum energy required to transfer the paste increases with the thickness of the paste.

2) Viscosity of the paste plays a fundamental role. Thinner additives are needed for controlling the paste viscosity.

3) The paste thickness and the gap are identified as key variables in the transfer of high viscosity pastes.

4) Lines with higher height than the gap suggest that the paste forms a union with the acceptor substrate and the final shape is reached once the donor substrate is removed.

5) Lines deposited using best parameters have good shape and large aspect ratios (~0.3). The volume transferred per pulse (voxel) is quite large (~300 pL).

6) Optical scanners allows fast processing and flexible design to print large areas.

7) LIFT is a promising technique for the metallization of PV devices using commercial screen-printing pastes.
Acknowledgments

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Laser sintering

Metallization comprise different steps:
1. Pre-metallization processes
2. Metallization
3. Curing, sintering and firing

All-laser based process: Laser heating using a CW source.

Experimental setup:
• DPSS Laser (Spectra Physics Millenia)
  • Nd:YVO4 emitting 532 nm
  • CW, power up to 20W
• Optical Scanner (ScanLab HurryScan)
  • F-Theta Lens, focal 250 mm
  • Focused beam diameter 20 µm
Laser sintering

Lines deposited using screen-printing (Heraeus)

Lines deposited using LIFT (Heraeus)