LIFT of high viscosity silver paste for new metallization methods in photovoltaic and flexible electronics industry

1. Introduction: metallization for solar cells
2. Metallization using LIFT
3. Application to flexible photovoltaic devices
4. Summary & Acknowledgements
Front-side Metallization: key process for enhancing efficiency in a cost effective way

Metallization comprises different steps:

1. Pre-metallization processes
   - Patterning of dielectric layer
   - Developing metal seed layers
Front-side Metallization: key process for enhancing efficiency in a cost effective way

Metallization comprises different steps:

1. Pre-metallization processes
2. Metallization
   • Transference of the conductive material
Front-side Metallization: key process for enhancing efficiency in a cost effective way

Metallization comprises different steps:

1. Pre-metallization processes
2. Metallization
3. Curing, sintering and firing

Metallization using Laser Induced Forward Transfer (LIFT)
Metallization using LIFT

- Commercial screen printing Ag paste (DuPont PV17F)
- Basic LIFT configuration (no intermediate absorbing layer or assisting liquid matrix). Gap distance: 25 – 50 µm.
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser source</td>
<td>ns-pulsed Spectra Physics Explorer</td>
</tr>
<tr>
<td>(λ = 532 nm)</td>
<td>ps-pulsed EKSPLA Atlantic</td>
</tr>
<tr>
<td>Beam focusing &amp; sample scanning</td>
<td>Optical galvo scanner with f-theta lens (ω₀ = 15µm)</td>
</tr>
<tr>
<td></td>
<td>Motorized XY stage with fix focal lens (ω₀ = 5µm)</td>
</tr>
</tbody>
</table>

**Metallization using LIFT**
DuPont PV17F

- Commercial screen printing Ag paste
- Provides excellent efficiency
- Reliable soldered adhesion
- Low lay down
- Rapid dry
- Very fast firing

Non-newtonian, pseudoplastic, thixotropic fluids
Viscosity 250 ± 30 Pa·s

Ag particles size: 1-5 µm
Solid Content @750°C: 91.0 %
High viscosity paste transfer mechanisms

- Morphology of the transferred voxel depends on laser fluence ($F$), donor film thickness ($h$) and gap distance ($d$)

- Voxels transferred using large $F$ consist of non-continuous clusters of paste (cluster-dot transfer)

- $F$ just larger than the transfer threshold allows printing single dots of paste with large aspect ratio (concrete-dot transfer)

- **Effect of the substrate:** formation of a continuous pillar between donor and acceptor

## Printing of lines

<table>
<thead>
<tr>
<th>Substrate</th>
<th>polished c-Si</th>
<th>textured c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>ns-laser</td>
<td></td>
</tr>
</tbody>
</table>

- $E_p = 13 \, \mu J$
- $\omega_0 = 15 \, \mu m$
- Rep Rate = 20 kHz
- $v = 1800 \, \text{mm/s}$
- $h = 50 \, \mu m$
- $d = 50 \, \mu m$
### Printing of lines

<table>
<thead>
<tr>
<th>Substrate</th>
<th>polished c-Si</th>
<th>textured c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>ns-laser</td>
<td></td>
</tr>
</tbody>
</table>

**Image Description:**
- Left image: Photomicrograph of a polished c-Si substrate with a laser mark.
- Middle image: Photomicrograph of a textured c-Si substrate with a laser mark.
- Right image: Graph showing profile and depth measurements for laser treatment.

**Technical Details:**
- **Centro Láser UPM**
- **Metallization using LIFT**
- **Printing of lines**
- **Substrate options:**
  - polished c-Si
  - textured c-Si
- **Laser type:** ns-laser
Metallization using LIFT

Printing of lines

<table>
<thead>
<tr>
<th>Substrate</th>
<th>polished c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>ns-laser</td>
</tr>
</tbody>
</table>

- **Ep** = 13 µJ  
  - \( \omega_0 \) = 15 µm  
  - Rep Rate = 20 kHz  
  - \( v \) = 1800 mm/s  
  - \( h \) = 50 µm  
  - \( d \) = 50 µm

- **Ep** = 11 µJ  
  - \( \omega_0 \) = 5 µm  
  - Rep Rate = 0.6 kHz  
  - \( v \) = 60 mm/s  
  - \( h \) = 40 µm  
  - \( d \) = 50 µm
Metallization using LIFT

Printing of lines: design flexibility

- Optical scanners allow fast processing and flexible design to print large areas.
- Very versatile, allowing any freeform design for the solar cells personalization.
- Application in Building integrated PV.
Proof of concept: full metallization of a CIGS solar cell on steel flex substrate
Electrical properties

**Fingers**

**Busbars**

**TLM test**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity</td>
<td>40 µΩ·cm</td>
</tr>
<tr>
<td>Specific contact resistance</td>
<td>50 mΩ·cm²</td>
</tr>
</tbody>
</table>
Mechanical properties

Good adherence after bending with radius down to 12 mm
Solar cell performance

![Diagram of solar cell with measurements](image)

![Graph showing current density (J) vs. voltage (V) for different cells](image)

With LIFT metallization:
- Cell #1
- Cell #2
- Cell #3

![Image of solar cell with LIFT metallization](image)
1) LIFT is a promising technique for the metallization of PV devices using commercial screen-printing Ag pastes.

2) The transfer mechanisms are strongly determined by the high viscosity of the paste.

3) Lines can be printed using both ns- and ps-lasers by simple overlapping single voxels. Optimum lines have aspect ratios of 0.2 – 0.5.

4) There is a strong influence of the roughness of the acceptor substrate on the morphology of the lines.

5) Lines can be printed onto flexible PV devices (CIGS on flex steel). Lines are continuous, have low electrical resistance and show good mechanical adherence.

6) Flexible CIGS solar cells have been metallized showing appropriate functionality.
This work has been supported by the EUROPEAN COMISSION – APPOLO FP7-2013-NMP-ICT-FOF. 609355 and the Spanish MINECO projects SIMLASPV-MET (ENE2014-58454), HELLO (ENE2013-48629-C4-3-R).
Thank You
CIGS cell layer structure