**INTRODUCTION**

The object of this project has been working on developing new conductive ink formulas that use, on the one hand, epoxy resin glue and anhydrous solvents as vehicles and, on the other, conductive powders and flakes of different purities and sizes. The reason for using resin glues lies in that it allows to produce inks with high adhesion capabilities which can be cured at low temperatures. The use of anhydrous solvents enables the possibility of tweaking the ink in order to incorporate higher amounts of conductive materials, while ensuring the absence of water based components in the final mix.

The present poster summarizes the methodology and first results achieved in this ongoing project.

**METHODOLOGY**

Phase I: Mixing inks with conductive graphite powders, epoxy resin and different anhydrous solvents.

Phase II: Deposition by screen printing and doctor blade.

Phase III: Contact drying and curing at low temperatures.

Phase IV: Characterization
  - Visual appearance by digital microscope.
  - Resistance and resistivity by semiconductor characterization system.

**EXPERIMENTAL**

**RESULTS AND DISCUSSION**

<table>
<thead>
<tr>
<th>Mix code</th>
<th>Graphite (wt%)</th>
<th>Resin (wt%)</th>
<th>Solvent (wt%)</th>
<th>Resistance (Ωcm)</th>
<th>Residue (Ωcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M21</td>
<td>25.67%</td>
<td>76.03%</td>
<td>4.3%</td>
<td>3.5</td>
<td>N/C</td>
</tr>
<tr>
<td>M22</td>
<td>50.03%</td>
<td>46.97%</td>
<td>3.0%</td>
<td>217.92</td>
<td>N/A</td>
</tr>
<tr>
<td>M23</td>
<td>51.30%</td>
<td>58.13%</td>
<td>0.57%</td>
<td>57.62</td>
<td>N/A</td>
</tr>
<tr>
<td>M24</td>
<td>54.19%</td>
<td>53.37%</td>
<td>2.44%</td>
<td>44.25</td>
<td>N/A</td>
</tr>
<tr>
<td>M25</td>
<td>55.13%</td>
<td>49.16%</td>
<td>5.74%</td>
<td>38.24</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table II: Basic ink recipe trials.

- “N/C” stands for non conductive and “N/A” for non available.

**Basic ink recipe**

- Target of the basic recipe:
  - Suitable for screen printing.
  - Conductive.
- Different mixtures to determine an optimal ratio graphite/ resin/ toluene.
- 32% / 58% / 10% = Best candidate.

**Conductive Inks With Epoxy Resin Based Vehicles For Perovskite Screen Printing Metallization**

**Phase I: Mixing inks**

Figure 1: Fourth stages mixing procedure. Conducted with graphite powders, epoxy resin and different anhydrous solvents. Samples extracted at 5, 10, 20, 30 minutes after adding the hardener.

**Phase II: Screen Printing**

Figure 2: 10 μm thick contact example, deposited by screen printing (200 mesh, 0.040 D-Ø x 22.5 μm, Squeegee blade: 70 durometer) over glass substrate (25mm x 25mm x 2mm). Cured 10 minutes in a drying oven at 100 ºC.

**Phase III: Doctor Blade**

Figure 3: 6.35 μm thick contact example, deposited by doctor blade over glass substrate (25mm x 75mm) by extending the ink with a glass rod. Cured 10 minutes in a drying oven at 100 ºC.

**RESULTS**

- To achieve contacts with lowest resistance / resistivity.

**Ink trials with more graphite**

- N,N-dimethyl formamide (DMF).
- N-methyl-2-pyrrolidinone (NMP).
- Weight concentration: 35% / 58% / 7% (graphite / epoxy / solvent).
- Improvement reached but not significant.

**Solvents evaluated:**

- N,N-dimethyl formamide (DMF).
- N-methyl-2-pyrrolidinone (NMP).

**Table III: Resistance measured in the contacts deposited via screen printing.**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Toluene (Ω·cm)</th>
<th>Chlorobenzene (Ω·cm)</th>
<th>DMF (Ω·cm)</th>
<th>NMP (Ω·cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>172.9</td>
<td>267.9</td>
<td>169.1</td>
<td>123.1</td>
</tr>
<tr>
<td>10</td>
<td>359.8</td>
<td>499.6</td>
<td>168.9</td>
<td>158.7</td>
</tr>
<tr>
<td>20</td>
<td>629.9</td>
<td>360.8</td>
<td>266.4</td>
<td>304.4</td>
</tr>
<tr>
<td>30</td>
<td>821.8</td>
<td>667.3</td>
<td>272.5</td>
<td>342.8</td>
</tr>
</tbody>
</table>

Table IV: Resistivity measured in the contacts deposited via Doctor blade.

**Conclusions**

- A method for producing inks with epoxy resin/anhydrous solvents suitable for perovskite substrates has been developed.
- Graphite powders, as conducting material were used.
- Contacts were produced.
- Best screen printing contacts were achieved by recipes with DMF & NMP.
- Ways proposed for further improving the achieved results.

**Contact drying and curing at low temperatures.**

**Effect on curing process.**

**Vapor pressure @ °C (mN/m)**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Toluene</th>
<th>Chlorobenzene</th>
<th>DMF</th>
<th>NMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/mL)</td>
<td>0.944</td>
<td>0.39</td>
<td>0.944</td>
<td>0.39</td>
</tr>
<tr>
<td>Time (min)</td>
<td>5</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Resistance (kΩ)</td>
<td>119.49</td>
<td>119.49</td>
<td>119.49</td>
<td>119.49</td>
</tr>
</tbody>
</table>

Table V: Resistance and resistivity measured in the contacts deposited via Doctor blade, respectively.

**Figure 6: Resistance measured in the contacts deposited via screen printing.**

**Figure 7: Microscope images showing contacts deposited by screen printing.**

**Figure 8: Resistivity measured in the contacts deposited via Doctor blade.**

**Figure 9: Microscope images showing contacts deposited by doctor blade with Toluene (a), Chlorobenzene (b), DMF (c) and NMP (d). All the contacts were deposited 20 minutes after adding the hardener.**

**Figure 10: Resistance and resistivity measured in the contacts deposited via screen printing and doctor blade, respectively.**

**Figure 11: Microscope images showing contacts deposited by screen printing with DMF (a) and NMP (b) as well as doctor blade with DMF (c) and NMP (d). All the contacts were deposited 20 minutes after adding the hardener.**

**Table VI: Resistance and resistivity measured in the contacts deposited via screen printing and doctor blade, respectively.**

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>DMF Resistance (kΩ)</th>
<th>NMP Resistance (kΩ)</th>
<th>DMF Resistivity (Ω·cm)</th>
<th>NMP Resistivity (Ω·cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>172.9</td>
<td>123.1</td>
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<td>342.8</td>
<td>272.5</td>
<td>342.8</td>
</tr>
</tbody>
</table>

**Table VII: Resistance and resistivity measured in the contacts deposited via screen printing.**

**Figure 4: Microscope images showing contacts deposited via screen printing with inks M19 (a), M21 (b), M22 (c) and M23 (d).**

**Figure 5: Microscope images showing contacts deposited by doctor blade with inks M19 (a), M21 (b), M22 (c) and M23 (d).**

**Ways proposed for further improving the achieved results.**