OLED Lighting Material Development Status

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DOE SSL manufacturing R&D workshop

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Outline

1. Plextronics OLED lighting material development effort and status
2. OLED panel manufacture requirement for material suppliers-- HIL
3. OLED lighting material development focus post Solvay acquisition
Focus on Enabling Cost Reduction in Integrated Substrates

- More than 40% of estimated material cost is integrated substrates
- Plextronics has been developing conductive polymer based, solution processable HIL which can be a critical component of low cost Integrated substrates
Plexcore HIL—Optical Transmission

- High optical transmission >95% with film thickness up to 200nm

Transparency is important for planerization as well as optical cavity tuning. Plexcore HIL is significantly better than a competitive material that is often used in R&D studies.

Experimental note: to eliminate effect from substrate add approximately 7% to the measured values
Ink properties can be adjusted to achieve desired thickness
The increase in drive voltage measured for NPB based devices as a function of HIL thickness is negligible
Performance of Plexcore® AQ and NQ HIL in White OLED

<table>
<thead>
<tr>
<th>Plexcore® HIL</th>
<th>V</th>
<th>EQE</th>
<th>Lm/W</th>
<th>CIE (x, y)</th>
<th>LT50 (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ</td>
<td>4.0</td>
<td>18.4</td>
<td>38.2</td>
<td>(0.43, 0.46)</td>
<td>9,200</td>
</tr>
<tr>
<td>NQ</td>
<td>3.9</td>
<td>18.5</td>
<td>39.3</td>
<td>(0.44, 0.46)</td>
<td>27,400</td>
</tr>
</tbody>
</table>

Values measured at 1000 cd/m². LT50 extrapolated to L0 = 1000 cd/m² using AF≈ 1.8

- NQ HIL designed with no acidic components, no water or protic solvents
- No voltage trade-off up to 100 nm films
- Similar power efficiency and improved lifetime (x3)

Courtesy of Solvay presentation @ IMID 2013 – August 29th 2013 – Daegu, Korea
Plextronics HIL Enabling Low Cost Integrated Substrates for OLED Lighting

- **Plextronics together with PPG and UDC are recipients of 2013 U. S. DOE Solid State Lighting Manufacturing Award DE-FOA-0000792**

![Diagram of OLED Device with HIL layers](image)

- **Anode layer** is ITO replacement TC with high surface roughness
- **Thick solution processed HIL** can be used as both planarization film and Hole injection layer for the OLED device, enabling cost reduction in OLED lighting
Cost Reduction Demands All Solution Processed Anode Structure

Current Approach

Current OLED Lighting panel manufacture are using ITO, some do not use metal grids

ITO still requires patterning

All solution Processed Anode structure will eliminate the need for lithography and etch
Plextronics together with Electroninks successfully completed Phase I SBIR Contract from U.S. DOE to develop printed low cost electrodes for OLED lighting: DE-SC0010140

- Metal grids are necessary for large OLED lighting panel due to high sheet resistance of ITO (>5 Ω / sq) and other transparent conductors
- Both material and manufacturing process for metal grids are currently too expensive for OLED lighting panel manufacturing
Reactive silver inks summary

Key Advantages

• Excellent electrical performance
  - 3x higher conductive than nearest competitor
  - Greater than 10x more conductive than most

• Lower annealing temperatures (<200°C)
  - Compatible with a wide range of substrates

• Lower costs ($2.5/g vs. $10-20/g)

<table>
<thead>
<tr>
<th>Ink Suppliers</th>
<th>$ per gram</th>
<th>Anneal temp (°C)</th>
<th>Conductivity (% of bulk Ag)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive Ag</td>
<td>2.5</td>
<td>&lt;200</td>
<td>90</td>
</tr>
<tr>
<td>InkTec</td>
<td>10-15</td>
<td>150</td>
<td>10 - 30</td>
</tr>
<tr>
<td>SunTronic</td>
<td>10-15</td>
<td>150 - 300</td>
<td>4 - 15</td>
</tr>
<tr>
<td>Cabot</td>
<td>10-15</td>
<td>100 - 350</td>
<td>2 – 30</td>
</tr>
</tbody>
</table>

Particle free ink

30 micron features
Anode Sheet Resistance Improvement

- Without metal grid, the ITO/glass has a sheet resistance of 13 $\Omega/\square$.
- Sheet resistance is reduced to 1.6 $\Omega/\square$ with IJP Ag grids using reactive Ag ink
- Optical transparency ~83%
- Further material and process development can reduce line width and improve optical transparency
Slot-die Coated Thick HIL Conformally Cover Metal Grids

Plexcore HIL: At 200 nm only 1.6% variance in thickness

SEM X-Section:
HIL coated metal grids
On ITO substrates
Brightness Uniformity and Efficiency Improvement

6”x6” Green PHOLED on ITO

6”x6” Green PHOLED on printed Ag grids with ITO. No insulation layer above Ag grids

<table>
<thead>
<tr>
<th></th>
<th>Current (mA)</th>
<th>Voltage (V)</th>
<th>Luminance (cd/m²)</th>
<th>Luminous Efficiency (cd/A)</th>
<th>Power Efficiency (lm/W)</th>
<th>Uniformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-grid Panel</td>
<td>500</td>
<td>5.29</td>
<td>55.4</td>
<td>1.67</td>
<td>1.0</td>
<td>35%</td>
</tr>
<tr>
<td>Grid Panel</td>
<td>500</td>
<td>4.96</td>
<td>98.8</td>
<td>2.98</td>
<td>1.9</td>
<td>71%</td>
</tr>
</tbody>
</table>
Requirement for HIL from OLED Panel Manufacture

- Overriding driver for solution processing is cost reduction, process simplification, and defect reduction

- Wish list for HIL properties from panel manufacture--Hybrid (solution HIL with VTE HTL and EML) to all-solution stacks
  - Thick HIL for passivation and planarization of defects
  - Tunable resistivity
  - High transparency with ultra low absorption
  - High index of refraction desirable for light out coupling

- Since there are no unique or standard panel and device architecture from panel manufactures. Requirement for HIL can vary widely
Solvay OLED – An Internal Start-up

- Solvay OLED is an incubator/internal startup. It is part of Corp R&I, Emerging business.
- It combines the best of both worlds:
  - **Big Corporate**
    - Stable financial investment
    - Process engineering capability
    - Strong corporate service
  - **Startup**
    - Risk taking culture, entrepreneurship
    - Innovative materials
    - Sharp business focus
- We operate in 2 sites, Pittsburgh and Seoul
  - customer support application lab and business development team in Seoul, Korea
  - fundamental materials development and validation in Pittsburgh
  - scale-up engineering capability in Europe
  - formulation capability in Europe and USA
- We are expected to transform into a business in 3~5 years, with tremendous growth opportunity.
Future Focus in OLED Lighting Material Development

• Continue developing solution Hole Injection Layer material to enable cost reduction in anode material and manufacturing process
• Continue working closely with substrates partners to enable low cost integrated substrates
• Continue develop material system and process to enable low cost printed electrodes for OLED lighting.
Who we are

Created by Ernest Solvay in 1863, Solvay is a Global company, headquartered in Brussels.

A major global player in Chemicals with compelling strengths

- 90% of sales in businesses among the top 3 global leaders
- 38% of sales in fast growing markets
- Balanced portfolio of activities
- A culture of sustainability, innovation and operational excellence

2012 figures

€12.4bn NET SALES
€2.1bn Adjusted REBITDA
111 MAJOR INDUSTRIAL SITES
13 MAJOR R&D CENTERS
29,100 EMPLOYEES 55 COUNTRIES
A 150 years old company with deep roots in USA

Solvay was the one of earliest multinational companies with operations in EU and US.

Solvay acquired several US based companies and successfully integrated/grown the business

- **2001**: BP Amoco Advanced Polymers, Atlanta GA
  - Now part of Solvay Specialty Polymers GBU
- **2002**: Ausimont Inc, West Deptford, NJ
  - Now part of Solvay Specialty Polymers GBU
- **2007**: Alumina Washcoat business from W.R. Grace & Co, Columbia, Maryland
  - Now part of Rare Earth GBU
- **2009**: Mc Intyre Group Ltd., Illinois, IL
  - Now part of Novecare GBU
- **2013**: Chemlogic Inc, Paso Robles, CA
  - To be integrated into Novecare GBU
Thank you!

We are Hiring

Please contact: careers@Plextronics.com if interested