Flexible OLEDs on Corning® Willow® Glass

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Outline

- OLED lighting value proposition
- Challenges in building flexible OLED panels
  - Review of state of technology
  - OLEDWorks/Corning approach
- OLEDWorks Panel
  - Status
  - Flexible integrated substrate value
- Summary
OLED Lighting Value Proposition
Technology adoption is driven by efficiency and operating cost in lighting; white LED is the forerunner today.
OLED Lighting Value Proposition
Next generation lighting will be driven by integration, light quality, and function

<table>
<thead>
<tr>
<th><strong>Value Drivers</strong></th>
<th><strong>Today</strong></th>
<th><strong>Future</strong></th>
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<tbody>
<tr>
<td></td>
<td><strong>Bulb/luminaire replacement</strong></td>
<td><strong>Lighting integrated with other functionalities</strong></td>
</tr>
</tbody>
</table>
|                   | ✓ Cost & performance  
• $/klm  
• lm/W  
• Color temperature (K) | ✓ Added aesthetics & functionalities  
• Lighting without light bulbs  
• Overall operating expense  
• New user productivity/experience |
| **Light Sources** | ✓ Replace existing bulb  
✓ Maintain form factors | ✓ Light quality: CRI>90  
✓ Low glare  
✓ Integration with fixture  
✓ Integration into walls, furniture, shelving |
| **Quality** | ✓ Simple controls  
• On/off  
• Dimmability | ✓ Building controls integration  
✓ Sensor-based control  
✓ Wireless controls using Zigbee and Bluetooth |
| **Integration** | ✓ Lumens only | ✓ Health benefits  
✓ Location services  
✓ Data communication |
| **Controls** | | |
| **Function** | | |
OLED Lighting Value Proposition

LEDs are expected to prevail in the lighting market; With cost reduction, OLEDs will also become popular
Challenges in building flexible OLED panels
Review of state of technology

- Multiple options for flexible OLEDs
- Which problems to solve?
- Balance cost and performance

FUTURE OLED LIGHTING WILL BE FLEXIBLE

<table>
<thead>
<tr>
<th>Thin glass</th>
<th>Plastic foil</th>
<th>Metal foil</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Image of thin glass OLEDs" /></td>
<td><img src="image2" alt="Image of plastic foil OLEDs" /></td>
<td><img src="image3" alt="Image of metal foil OLEDs" /></td>
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</tbody>
</table>

What means „FLEXIBLE OLED“?

--folded? wrapped? rolled?
- twisted? „crumpled/creased“?
- curvable? bendable? conformable?
- with negligible effect on its electronic function

Consensus: use of flexible substrate

Different applications ask for different types of „Flexibility“:

1-dimensional, 1.5-dimensional, 2-dimensional curvature

Flexible Substrate for OLED

<table>
<thead>
<tr>
<th>Plastic</th>
<th>Metal Foil</th>
<th>Thin Glass</th>
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<tbody>
<tr>
<td><img src="image4" alt="Image of flexible substrate" /></td>
<td><img src="image5" alt="Image of metal foil substrate" /></td>
<td><img src="image6" alt="Image of thin glass substrate" /></td>
</tr>
</tbody>
</table>

- Suitability for R2R process
- Surface smoothness
- Flexibility
- Heat resistance
- Barrier property

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<th>Thin Glass</th>
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<tbody>
<tr>
<td><img src="image7" alt="Table of properties" /></td>
<td><img src="image8" alt="Table of properties" /></td>
<td><img src="image9" alt="Table of properties" /></td>
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</tbody>
</table>

Remark (Key Points):

- good property for R2R process and flexibility
- high performance barrier film is required
- poor property for high temperature process
- possibility of bent and broken in R2R process
- flattening layer is required
- transparent OLED can not be made
- good property for barrier
- possibility of broken in R2R process
- OLED panel can be easily broken
Challenges in building flexible OLED panels

Review of state of technology

- Barrier-coated plastic substrates, under development by several organizations (Fraunhofer, Holst, Konica-Minolta, Sumitomo, Vitriflex, etc.)
- Konica-Minolta: R2R mass production plant has started
- LG Chem: Plastic-based OLED light panel samples are available at very high price
Challenges in building flexible OLED panels

Review of state of technology

- Thin Glass OLEDs
- LG Chem introduced in 2013, but apparently no longer selling
- Fraunhofer demonstrated in 2015, but identified challenges with reliable low resistance electrical contacting

LG Chem OLEDs – Bendable W-OLEDs

- Bendable OLED lighting panel will be available in the 2nd half of this year
  - 200mm x 50mm, thin glass
  - 4,000K, 45lm/W

Flexible & Transparent Panels

R2R OLEDs on Flexible Glass - Results

R2R TCO electrode and OLED process on 50 µm UTG, PET laminated
Challenging. Reliable electrical contact with low contact resistance for large area illumination

J Moon et al., 2013 Society for Information Displays

Christian May, OLEDs World Summit, 10/28/2015
Challenges in building flexible OLED panels
OLEDWorks/Corning approach

• Glass is established low cost substrate for OLED lighting

• Cost is the major inhibitor to OLED lighting adoption

• “Bendable” is significant and sufficient improvement over no curvature

• Sheet processing is sufficient for initial OLED lighting volumes. R2R processing capability will help drive down cost at high volume.

• Flexible glass OLEDs require improvements in glass properties and in flexible encapsulation and electrical contacting
Challenges in building flexible OLED panels

OLEDWorks/Corning approach

• Joint development program between OLEDWorks and Corning
  • Develop process and equipment technology needed to manufacture flexible OLED lighting panels on Willow glass

• Corning responsible for
  • Willow to Carrier bond/de-bond process and equipment
  • Integrated substrate materials, processes and equipment
  • Singulation process and equipment

• OLEDWorks responsible for
  • OLED fabrication
  • Encapsulation materials, processes and equipment
  • Panel finishing (EEL, electrical contacting, packaging and testing)
Challenges in building flexible OLED panels

Initial issues

- 2-up 43mm x 102mm panel design, 102mm x 102mm substrate
- 0.1mm Willow bonded to 0.7mm carrier substrate by Corning
- OLED coating and encapsulation by OLEDWorks
- Poor and variable bonding quality with low debonding yield
- Able to demonstrate first working samples
- Poor overall yield – breakage when flexed
OLEDWorks Panel

Current status

- Corning developed improved bonding process for Gen2/2.5 samples
- Corning developed improved singulation process
- OLEDWorks coated OLEDs onto Gen2 Willow on Carrier (65mm x 175mm panels)
- OLEDWorks developed improved processes and materials for flexible encapsulation, electrical connection, and packaging
OLEDWorks Panel

Current structure

- Flexible Encapsulation
- Flexible Electrical Contacts
- Anode
- Willow Glass
- External Light Extraction Film
- Backside Protection Film
- OLED
- Cathode
Flexible Integrated Substrate Value

Three key value propositions for Corning Willow Glass based Integrated substrate

1. **Integrated substrate**
   - Internal light extraction layer (ILEL) provides 40% (2x) light extraction leading to higher efficiency
   - Reduces cost and complexity for panel makers by providing a deposition-ready substrate

2. **R2R process capability → >30% cost reduction**
   - Drives faster market adoption by lowering cost
   - Provides substrate with highest barrier property in a R2R format

3. **Unlocks the conformability value element**
   - Conformable products are important to applications such as hospitality and transportation
Flexible Integrated Substrate Value

Flexible glass unlocks the conformability value element for OLED lighting

“If you need a thin design with a curve, instead of a gap and diffusing media, OLED is inherently better”
- Leslie North, Aurora Lighting

“Luminaire design is important. Future applications depend on how creative luminaires get”
- Amy Laughead-Riese, President and Principal Lighting Designer, 37 Volts Studio
Solid State Lighting is the Future

Thinness, Lightness and Flexibility of OLED will be a Key Differentiator to LED

Glass, Plastic and Metal Substrates each have Pros and Cons

Willow Glass Enables Cost Effective Conformability

OLEDWorks/Corning JDA is Developing the Processes and Equipment Needed to Manufacture Cost Effective Flexible OLEDs on Willow Glass