Integrated OLED Substrates

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Topics

- Integrated substrate requirements
- Level of activity
- Technical approaches
- Outlook for commercial offerings

K. Yamae et al., “Highly Efficient White OLEDs with over 100 lm/W for General Lighting”, SID Symposium Digest of Technical Papers, July 1, 2013. Used with permission of John Wiley and Sons.
Integrated substrate requirements

• Substrate material
  – Transparent
  – Excellent oxygen and moisture barrier

• Light extraction technology
  – Initial target is 2.5x natural extraction (~50%)

• Transparent conductor + patterning
  – 10 ohms/sq is initial target
  – DoE roadmap would like <1 ohm/sq
  – Pattern of transparent conductor without introducing asperities

• Cost targets
  – DoE target is $60/m² by 2017
Requirements of internal light extraction technology

- Efficient extraction process to limit cathode absorption
  - Surface plasmon absorption
  - Cathode metal absorption
- Planarization
  - Surface roughness of <2 nm rms
  - No asperities
- Compatibility with downstream processes
  - Transparent conductor deposition
  - Patterning
  - Cleaning
  - OLED vacuum evaporation
  - Encapsulation and singulation
OLED light extraction issued patent families

- Eastman Kodak + Global OLED
- 3M
- Samsung Corning + Corning
- Samsung Display
- Thomson Licensing
- Asahi Glass
- Osram Opto

Approximately 138 issued patent families (US and International)
Top 9 represent 55% of issued patents
## Approaches to light extraction

<table>
<thead>
<tr>
<th>Approach</th>
<th>Mode</th>
<th>Examples</th>
<th>Net Light Extraction</th>
<th>Manufacturing Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>No modification</td>
<td>-</td>
<td>-</td>
<td>17-20%</td>
<td>-</td>
</tr>
<tr>
<td>Substrate modification</td>
<td>External</td>
<td>Surface texturing plastic foil or glass -</td>
<td>30-40%</td>
<td>High</td>
</tr>
<tr>
<td>Micro-lenses</td>
<td>External</td>
<td>PDMS 10 micron lenses</td>
<td>30-40%</td>
<td>Medium</td>
</tr>
<tr>
<td>Enhanced scattering</td>
<td>Internal</td>
<td>Micro-spheres, zirconia particles, high index substrates</td>
<td>-</td>
<td>Medium</td>
</tr>
<tr>
<td>Micro-cavity</td>
<td>Internal</td>
<td>SiO$_2$/Si$_x$N$_y$/metal</td>
<td>30-40% *</td>
<td>Low</td>
</tr>
<tr>
<td>Photonic crystals</td>
<td>Internal</td>
<td>300 nm period mesas in ITO</td>
<td>30-48% *</td>
<td>Low</td>
</tr>
<tr>
<td>Surface plasmons</td>
<td>Internal</td>
<td>Corrugated thin metal films</td>
<td>40% *</td>
<td>Low</td>
</tr>
<tr>
<td>Nano-structured interfaces</td>
<td>Internal</td>
<td>Gold nanoparticles in organic layers</td>
<td>50% *</td>
<td>Low</td>
</tr>
</tbody>
</table>

Review paper cites 130 papers on OLED light extraction

### Integrated substrate approaches to light extraction

<table>
<thead>
<tr>
<th>Approach</th>
<th>Pro’s</th>
<th>Con’s</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>High index glass or polymer substrate</td>
<td>No microstructure technology required</td>
<td>Processes for high quality substrate do not exist</td>
<td>NEG has reported 1.64 RI fusion drawn glass resulting in 10% improvement.</td>
</tr>
<tr>
<td>Scattering particles or voids in high index coating</td>
<td>Materials and processes are well known Potentially low cost</td>
<td>Planarization required</td>
<td>PPG has developed an all-glass light extraction substrate and reported a 1.3x enhancement.</td>
</tr>
<tr>
<td>Micro-lens</td>
<td>Potentially low cost</td>
<td>Compatibility with other process steps</td>
<td>Panasonic has reported 114 lm/watt using multi-layer laminate.</td>
</tr>
<tr>
<td>Waveguide extraction</td>
<td>Much stronger extraction than scattering</td>
<td>Planarization required</td>
<td>Corning has patents on structured resonant coupling.</td>
</tr>
</tbody>
</table>

3M has extensive patents for IEL and EEL films.
Panasonic is combining high refractive index and microlenses

K. Yamae et al., “Highly Efficient White OLEDs with over 100 lm/W for General Lighting”, SID Symposium Digest of Technical Papers, July 1, 2013. Used with permission of John Wiley and Sons.
Flexible glass is becoming available for OLED substrates

- Flexible glass can unlock the unique value of OLEDs for flexible and conformable luminaires
- Corning and others are now producing 100 micron, flexible glass sheets on a manufacturing scale.
- Technology requirements for flexible integrated substrates:
  - Carrier for processing
  - Encapsulation
  - Packaging
Conclusions

• No commercial integrated substrate is currently available
  – Limited demand
  – high cost of integrating
• Many options for light extraction
  – Cost/benefit will be key
  – Potential suppliers are focusing on manufacturable solutions
• New technologies may provide solutions
  – Nano-imprint
  – High refractive index coatings
  – Flexible substrates with roll to roll processing