An Integrated OLED Substrate for Low-Cost and Enhanced Light Extraction

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ITO/glass vs Integrated Plastic Substrate

ITO and Organic Mode (~50%)

Glass Mode (~30%)

Escape Cone

Air Mode (~20-25%)

AgNW network
Nanoparticles
Polymer Substrate

Air Mode (up to 60%)
ITO/glass Replacements

- ITO/PET
- Conducting polymers (PEDOT)
- Single-wall carbon nanotubes (SWCNT)
- Graphene
- Ultrathin metal
- Metal grid
- Silver nanowires

L. Hu, H. Kim, J. Lee, P. Peumans, Yi Cui, ACS Nano, 4, 2955, 2010
Fabricating an Integrated Plastic Substrate

- Composite materials are deposited via a solution based, low temperature process
- Conventional coaters may be used.
- Process can potentially be scaled up on a roll-to-roll production line.
# Integrated Plastic Substrate vs Competing Substrates

<table>
<thead>
<tr>
<th>Property</th>
<th>ITO/Glass</th>
<th>AgNW/PET</th>
<th>Integrated Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ohm/sq</td>
<td>~10</td>
<td>~10</td>
<td>5~10</td>
</tr>
<tr>
<td>Substrate bonding</td>
<td>Strong</td>
<td>Weak (requires a binder)</td>
<td>Strong</td>
</tr>
<tr>
<td>Roughness</td>
<td>&lt;2 nm</td>
<td>High</td>
<td>&lt;2 nm</td>
</tr>
<tr>
<td>EQE</td>
<td>20-25%</td>
<td>Comparable to ITO/glass</td>
<td>~40%</td>
</tr>
<tr>
<td>Mechanical flexibility</td>
<td>Thick and brittle</td>
<td>Thin and flexible</td>
<td>Thin and flexible</td>
</tr>
</tbody>
</table>
2D FDTD Simulation of Light Extraction Efficiency
**OLED Performance**

- **Al / CsF**
- **White Polymer**
- **PEDOT:PSS**
- **Composite Substrate**

EQE ~30.5%

![Graphs showing OLED performance metrics](image-url)
**Light Extraction Enhancement: 2.0-2.5X**

<table>
<thead>
<tr>
<th>Al / CsF</th>
<th>Yellow + Blue</th>
<th>PEDOT:PSS</th>
<th>Integrated Substrate</th>
</tr>
</thead>
</table>

The efficiencies of white OLEDs at 1000 cd/m² luminance are 120 cd/A, 40% EQE, and 110 lm/W the devices (CRI~55).
Wider Viewing Angle

OLEDs viewed from the Al cathode side

ITO/Glass

Integrated Substrate
Preliminary Results under the OLED Testing Program

- Most devices were shorted
- One sample showed 2.7X enhancement
Challenges and solutions for integrated plastic substrate

- Mechanical flexibility does not fit well in the current fabrication line designed for rigid glass substrate
Challenges and solutions for integrated plastic substrate

- Thermal stability of the polymer substrate may not be high enough (softening, warping, etc.)
- Silver nanowire network needs protection for high T process and for high current operation

Untreated AgNW Network at specified temperature for 30 min.

Treated AgNW Network: @ 300 °C for 30 min.
Challenges and solutions for integrated plastic substrate

- Thermal stability of the polymer for the substrate may not be high enough
- Silver nanowire network needs protection for high T process and for high current operation

Untreated AgNW Network: 155 mA/cm² for 1 hour

Treated AgNW Network: 155 mA/cm² for 1 hour
Lifetime is longer than on ITO/glass

Initial luminance: 5000 cd/m²
Integrated substrates incorporating barrier film or glass

3M Barrier Film or Glass

Willow® glass  Sheet glass
## Integrated Plastic Substrate or Glass Substrate?

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Sheet Glass</th>
<th>Flexible Glass</th>
<th>Plastic</th>
<th>Plastic w/ Barrier Coatings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensional stability</td>
<td>Best</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Barrier property</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost</td>
<td>Low</td>
<td>?</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Compatibility with R2R OLED manufacture</td>
<td>No</td>
<td>Work in progress</td>
<td>Yes</td>
<td>Yes?</td>
</tr>
</tbody>
</table>

**UCLA Soft Materials Research Lab**
Conclusion and Perspective

- An integrated plastic substrate has to tailor made to fit with the OLED fabrication process.
- Our integrate plastic substrate is designed to replace ITO/glass, internal and external light extraction structures,
- can be produced at dramatically lower cost,
- is compatible with solution-based process, vacuum thermal deposition, and 250 °C annealing,
- could enable R2R OLED panel manufacturing.