Light Extraction Technologies in Organic Light Emitting Devices for Lighting Applications

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Light Extraction Technologies

Outline

- Energy Losses in OLED
- External Outcoupling Technologies
- Internal Outcoupling Technologies
- Cathode Outcoupling Technologies
Energy Losses in OLED
Energy Losses in OLED

Optical Waveguides

- light is being transported in a medium with high index of refraction due to total reflection at the interface
- optical fiber
Energy Losses in OLED

- wave guiding is also present in OLED
  - wave-guided mode in organic/ITO
  - wave-guided mode in glass substrate

- losses on cathode
  - near-field interaction between the dipole and cathode (strong function of exciton-cathode distance)
  - charge density oscillations (surface plasmon polaritons, SPP)

Index of refraction:
- n = 1.7 ... 1.85 for organic/ITO
- n = 1.8 ... 2.0 for glass substrate
- n = 1.5 for metal cathode

“bottom emitting structure”
Energy Losses in OLED

- only 20 ... 30% of light is actually coupled out
- work on extraction from
  - substrate → external
  - OLED stack → internal
External Outcoupling Technologies
External Outcoupling Technologies

- use of high-index substrate → high cost
- no impact on organic/ITO mode
- increase in outcoupling by 2x

External Outcoupling Technologies

- outer surface of substrate modified to decrease substrate mode
- microlens array: 50% increase in outcoupled light

External Outcoupling Technologies

- brightness enhancement films (eg. 3M BEF 90/50)

Internal Outcoupling Technologies

incorporating patterned grids
Internal Outcoupling Technologies

- low-index-grid on top of ITO layer
  - grid material: SiO$_2$ (n=1.5)
  - grid patterned by photolith
  - power efficiency was improved by 2.3x

Internal Outcoupling Technologies

- patterned ITO, use of conductive polymer
  - grid patterned by photolith, neg impact on sheet resistance
  - power efficiency was improved by 74%

Internal Outcoupling Technologies

incorporating randomly distributed scattering centers
Internal Outcoupling Technologies

- simulated light propagation with scattering center
- Poynting vector shows energy direction, color shows intensity

Internal Outcoupling Technologies

- ETL material induced scattering from cathode
  - evaporated material underneath the cathode
  - power efficiency was improved by 71%

source: Canzler (Novaled) et al., SID Digest, p975 (2011)

Remark: SPP reduction due to cathode morphology?
Internal Outcoupling Technologies

- “buckles” underneath ITO and organic stack
  - PDMS stamp with “buckles” used to transfer features to UV-curable resin before ITO was sputtered onto this layer
  - power efficiency was improved by 80% ... 400%

source: Koo et al., Nature Photonics 4, p222 (2010)

Remark: SPP reduction due to cathode morphology?
**Internal Outcoupling Technologies**

- scattering layer between ITO and glass substrate
  - TiO$_2$ particles (size 400nm)
  - more than 100% improvement in efficiency
  - better color stability vs. angle

Source: Chang et al., Journal SID 19/2, p196, (2011)
Internal Outcoupling Technologies

- use of ITO alternatives: metallic nanowires
- elimination of the high-index ITO layer
- no significant efficiency increase, but freedom to develop new structures
  - process temperature to form effective network 140 °C
  - option of depositing conductive layer on top of other material

- index of refraction
  - $n = 1.7 \ldots 1.85$
  - $n = 1.5$

“bottom emitting structure”
Cathode Outcoupling Technologies
Cathode Outcoupling Technologies

- surface plasmon polaritons
  - loss mechanism: coupling of exciton radiative energy in non-radiative surface plasmon
  - application of patterned surface to recover energy
  - resonant coupling with lumophore

source: An et al., Optics Express 8 (5), p 4041 (2010)
Cathode Outcoupling Technologies

- Oji Paper
  - use of microstructures on metal cathode
  - no further details on device structure available
  - reported gains of 100%

## Pros & Cons

<table>
<thead>
<tr>
<th>Technology</th>
<th>Pros</th>
<th>Cons</th>
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<tbody>
<tr>
<td><strong>External Outcoupling</strong></td>
<td>simple technology compared to internal light extraction layers</td>
<td>only substrate modes are being extracted</td>
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<tr>
<td>high-index glass</td>
<td>easy solution</td>
<td>high cost</td>
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<tr>
<td>microlens array</td>
<td></td>
<td>expensive patterning process</td>
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<tr>
<td><strong>Brightness Enhancement Film</strong></td>
<td>established technology, easy processing</td>
<td>quite costly</td>
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<tr>
<td><strong>Internal Outcoupling</strong></td>
<td>organic / ito mode is being extracted</td>
<td>more complicated due to impact on device structure</td>
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<td>low-index grid</td>
<td>high impact on efficiency</td>
<td>SiO2 deposition and patterning layer</td>
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<tr>
<td>patterned ITO</td>
<td>no additional layers</td>
<td>requires ITO patterning, increases ITO sheet resistance</td>
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<td>evaporated scattering layer</td>
<td></td>
<td>possible impact on device performance due to material system</td>
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<tr>
<td>buckles</td>
<td>high impact on efficiency</td>
<td>PDMS imprinting technology not scalable</td>
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<tr>
<td>scattering layer underneath ITO</td>
<td>high impact on efficiency</td>
<td>ITO deposition on top of scattering layer difficult</td>
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<td>SSP harvesting</td>
<td></td>
<td>not mature technology yet, but very interesting</td>
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