Charge Balance in OLEDs: Optimization of Transport Materials

DOE SSL R&D Workshop
Tampa, FL
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All references to “Merck” refer to Merck KGaA, Darmstadt, Germany. In North America Merck operates under the name EMD.
Transport Materials are Critical Components in High-Performance OLED Devices

- Enable key performance characteristics
  - Low voltage
  - Long lifetime

- Voltage and lifetime typically trade-off in devices. Charge balance is key to maximize both properties.

- Reducing drive voltage to ~ 3V is a challenge. Can this be done with a single material or is p/n doping the best approach?
This behavior is well-established, particularly for fluorescent blue OLEDs
Mixed host systems

Two host components are used to adjust charge balance

- Lifetime improvement by a factor of two
- Low roll-off
- Low voltage

Emission Zone

- **e-type TMM** shifts luminance zone to the HTM layer
- **h-type TMM** shifts luminance zone to the ETM layer
- **Mixed or bipolar TMM** can lead to a luminance zone in the middle of the EML

Host materials (TMMs) are key to optimize & control charge balance in the device
Tuning Charge Balance with Mixed Host

Requirements

- Balance can be tuned by adjusting the host mixing ratio: e-type TMM + h-type TMM
- Customized for customer device
- Merck addresses triplet Green, Yellow & Red OLEDs

Balance Adjustment

Example: combination of
- h-type (material A and B) with e-type (material 1 and 2)
Charge Balance Optimization through the Introduction of an HBL

With a hole-rich EML mixture, we need to adjust the charge balance by introducing an HBL.

Lifetime and efficiency are further improved with the introduction of an HBL.
A Winning Strategy Leading to Impressive Results in Solution Processed Devices

Record efficiency & LT in phosphorescent green with more hole-injecting HTL. The gap between solution and vapor processing is closed?

<table>
<thead>
<tr>
<th>CIE x,y</th>
<th>Eff [cd/A] @1000cd/m²</th>
<th>Voltage [V] @1000cd/m²</th>
<th>EQE [%] @1000cd/m²</th>
<th>Est. LT50 [h] @1000cd/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.33, 0.63</td>
<td>81.3</td>
<td>4.7</td>
<td>21.8</td>
<td>320.000</td>
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</table>
Charge Balance Optimization

Adding more electron transport materials to EML mixtures results in lower voltage, but reduced lifetime.

→ Not enough holes to counterbalance the electrons!

For a given EML mixture, vary the hole injection properties of the HTL.

→ HTL with strong hole injection can improve voltage and lifetime simultaneously!

Introduction of more hole-injecting transport layers significantly improves lifetime
Huge performance improvement with new materials in optimized devices
Novel HTMs with Electron Blocking Capability

<table>
<thead>
<tr>
<th>Cathode</th>
<th>HTM</th>
<th>CIE x/y</th>
<th>Efficiency [cd/A] @ 1000 cd/m²</th>
<th>Voltage [V] @ 2000 cd/m²</th>
<th>EQE [%] @ 1000 cd/m²</th>
<th>LT₅₀ [h] @ 1000 cd/m² (based on n=2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETL</td>
<td>HTM-081</td>
<td>0.14/0.14</td>
<td>9.2</td>
<td>4.1</td>
<td>8.4</td>
<td>21 000</td>
</tr>
<tr>
<td>S-Blue EML</td>
<td>New HTM</td>
<td>0.13/0.14</td>
<td>13.2</td>
<td>4.1</td>
<td>11.6</td>
<td>44 000</td>
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<tr>
<td>HIL</td>
<td>HTM-081</td>
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<td>ITO</td>
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</table>

→ Further improvement compared to HTM-081 based device

- EMD / Merck have developed a variety of new HTMs, for use as hole transporting layers with high triplet level & electron blocking capability
- New stack configurations provide excellent lifetime, efficiency and voltage for fluorescent & phosphorescent devices
EMD: OLED Solution Provider

Commitment to OLED

- New investment of MRC Darmstadt (2009), extensions in 2013 and 2014
- Extension of OLED scale-up and production in DA in 2013
- Setup of OLED formulation in Germany and UK 2012/13
- Continuous Investment in laboratories in Korea, Taiwan and Japan

R&D experts

M&S experts

~1,400 patents
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Thank you for your kind attention.