Novel Developments of PIN OLEDs for Lighting & Display Applications

Sven Murano, Plastic Electronics Conference 2012
Novaled AG
Outline

› Novaled PIN-OLED® Technology

› Material Portfolio for Display Applications
   › ETL development for long lifetime and high Efficiency blue pixel

› Efficiency enhancement with NET-61
   › Surface plasmons outcoupling at corrugated cathode
Novaled offers a unique combination of skills

STACKS & OLED ARCHITECTURE

ORGANIC MATERIALS

PRODUCT KNOW HOW

ENGINEERING
Novaled PIN OLED® Technology

- Low operating voltage due to
  - Good injection
  - Good charge transport
- Results in high power efficiencies
- Manufacturing benefits, as well, e.g.
  - No injection layer between electrodes and HTL/ETL required
  - No ITO treatment necessary due to doping technology
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New Novaled Materials for Blue Pixel of AMOLED Displays

- New fully air-stable ETL: dopant/additive systems specifically for display use under development:

- Goal of stack development:
  - Optimize 3 main parameter (Voltage, Current Efficiency, Lifetime) to match product-specific target parameters

  ➔ portfolio of materials and device structures
Lifetime and Efficiency of Novaled ETL Host Materials

Data of different Novaled ETLs
- Extremely long lifetime with NET-142 and NET-164, but also reduced efficiency
Improved Efficiency with Long Lifetime

- New NDN-87 dopant increases the efficiency compared to older n-dopant. Lifetime remains increased.
- Air-stable ETLs with good thermal stability and evaporation properties

<table>
<thead>
<tr>
<th>N-ETL</th>
<th>Voltage / V</th>
<th>Cd/A</th>
<th>CIE-y 1931</th>
<th>LT95% / h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard ETL</td>
<td>4.4</td>
<td>4.4</td>
<td>0.046</td>
<td>85</td>
</tr>
<tr>
<td>NET-164:NDN-87</td>
<td>4.8</td>
<td>4.7</td>
<td>0.040</td>
<td>140</td>
</tr>
<tr>
<td>NET-142:NDN-87</td>
<td>5.3</td>
<td>4.3</td>
<td>0.048</td>
<td>125</td>
</tr>
</tbody>
</table>
Performance Optimization

Many ETLs and EILs were developed at Novaled to optimize all performance parameters of blue OLEDs:

- Lifetime
- Efficiency
- Voltage

Material screening showed that it is easy to optimize one or two parameters, but the third parameter usually gets worse:

- Very long lifetime → lower efficiency, high voltage
- Extended lifetime, slightly higher efficiency → higher voltage
- Low voltage, high efficiency → short lifetime

Some applications might tolerate a slightly lower efficiency or a increased voltage, but especially mobile applications need an improvement of all parameters.
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“You cannot have your cake and eat it, too.” (English idiom)
Reduced Voltage with New Novaled EILs

- Optimization of the n-dopant can lead to -10% in voltage, +10% efficiency and similar lifetime at constant current density compared to the standard ETL.

- No big improvements, but an improvement of all three main OLED parameters.

- Bottom-emission OLEDs
Low Voltage with Strong n-Dopants

- Lowest voltages can be achieved with ETLs such as NET-164:NDN-77 or NET-18:NDN-26.
- With low voltage typically comes very high efficiency, but also very very short lifetime.
- The quantum efficiency was calculated from forward emission assuming Lambertian emission (top-emission OLEDs).
**Issue: Electron-Transporting EML**

- Most fluorescent blue EMLs are electron-transporting.
- With good electron injection the recombination will only take place right at the interface EBL/EML:
  - Very high exciton density $\rightarrow$ Triplet-triplet annihilation with high efficiency, but also faster decomposition of the materials at the interface, which leads to very short lifetime.
- More ambipolar blue EMLs are needed for low-voltage OLEDs!
Low Voltage with Ambipolar Blue EML

Tests with a more ambipolar blue host were done (same dopant).
The voltage was similar to previous low-voltage devices, but with a similar efficiency as the typical display OLEDs.
The lifetime is not only better compared to the low-voltage ETL with an electron-transporting blue EML, but also better compared to the reference blue OLED.
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OLED Efficacy: main parameters

\[ \eta_{external} = b_I \times \frac{h \nu}{eU} \times \eta_{recomb} \times \eta_{optical} \]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Current Status</th>
</tr>
</thead>
</table>
| 1/U: inverse operating voltage (doping) | - close to thermodynamic limit (1.5-2.5V depending on colour)  
- Optimizations for higher brightness still possible |
| \( \eta_{optical} \): optical outcoupling | - w/o enhancement methods around 20-25%  
- With OC: approx. x1.5 demonstrated  
- Must meet large area and cost/area requirements |
| \( \eta_{recomb} \): recombination efficiency (singlet-triplet, PL efficiency) | - Phosphorescent emitters enable 50-75%  
- blue not stable yet |
| \( b_I \): electron-hole balance | - 100% can be reached, more complicated for phosphorescent devices, injection dependent |
Outcoupling Problem in OLEDs

- Light is trapped in organic/ITO layers and glass substrate because of total internal reflection at ITO/glass and glass/air interface.
- Only 20-30% of the generated light is coupled out (air mode) in standard devices.

Questions:
- How can internal modes be addressed?
- Can losses by surface plasmons be avoided?
Outcoupling Requirements

In order to meet the demanding price and performance targets of the lighting market, a suitable light extraction method for OLEDs needs to be:

- Cheap (i.e. no costly substrates or pre-treatments)
- Efficient (internal light modes need to be addressed, losses need to be minimized)
- Compatible to industrial processes (e.g. scalable to large area manufacturing)
- Delivering high quality light (e.g. low angular color variation)

Novaled evaporation processable material NET61 may deliver all of this
60 lm/W White OLED

- With a three unit stacked white OLED an efficiency improvement from 50 to 60 lm/W could be reached
  - Phosphorescent green (Ir(ppy)₃ and orange emitter (Ir(MDQ)₂(acac))
  - Fluorescent blue emitter (SFC ABH036:NUBD369)
  - Low driving current needed → long lifetime
  - Use of external flat outcoupling (MLA)

- NET61 allows for extraction of internal light modes
  - 60 lm/W and LT50=90.000 hours (see Canzler et al. SID 2011, Pavicic et al. IDW 2011)

- Evaporation based material, fully compatible to existing manufacturing processes
- Process requires Ag cathode
Morphology with NET-61

- NET-61 grows in crystallites
- Surface corrugation is replicated in the cathode layer
- Use of doped transport layers allows for operation at low driving voltages
Color Stability Investigations

- In lighting applications both a small angular color variation for a given tile as well as a small tile to tile color variation are desirable.

- A single unit fluorescent white OLED with an ETL thickness variation from 13 – 73 nm was processed.

- Color variation was measured for blank devices and devices with microlens array and scattering outcoupling films.
Color Stability Investigations – Outcoupling Films

- Similar reduction in color shift with ETL thickness variation and angle is visible for a pure MLA and a pure scattering film
- NET61 results in efficiency enhancement and reduces color variation for ETL thickness variations
- Use of NET61 may result in production stability enhancement
Conclusion

Novaled offering is OLED Technology and Materials

Display: newly developed n-doped ETL systems with air-stable n-dopants have been introduced for long lifetime

Lighting: self-crystallizing NET-61 offers a simple outcoupling enhancement method that is compatible to existing manufacturing

60 lm/W with white OLED using fluorescent blue emitters could be achieved while losses through the absorption of SPMs can be avoided with a corrugated Ag-cathode
Acknowledgements

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- Novaled OLED Team

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Creating the OLED Revolution