Improving OLED performance via semiconductor dilution

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‘Intrinsic’ properties of OLED materials

- Refractive index $n \sim 1.7$
  - Limits optical outcoupling efficiency
- Glass transition temperature $T_g \sim 100-120^\circ C$
  - OLED panels operate at elevated temperature
  - Thermal stability closely connected to catastrophic failure
  - Intrinsic OLED lifetime $\sim \exp(-E_A/kT)$

What if we could change properties like these without re-engineering OLED molecules?
Most of the molecules aren’t necessary

Transport is percolative, involves <5% of all molecules
Changing blend properties with Teflon AF

- Co-evaporate Teflon AF w/ small molecules

Refractive Index

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Refractive index (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>2.0</td>
</tr>
<tr>
<td>600</td>
<td>1.8</td>
</tr>
<tr>
<td>700</td>
<td>1.6</td>
</tr>
<tr>
<td>800</td>
<td>1.4</td>
</tr>
<tr>
<td>900</td>
<td>1.2</td>
</tr>
<tr>
<td>1000</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Morphological stability

- 50% TAF:NPD
- 25% TAF:NPD
- neat NPD
- Pure NPD
- Pure Teflon
- 80% Tef.
- 50% Tef.
- 20% Tef.
What happens to electrical transport?

- Hole-only devices:

<table>
<thead>
<tr>
<th>ITO</th>
<th>TAF:NPD (60 nm)</th>
<th>Al (100 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat NPD</td>
<td>3.5±0.1</td>
<td></td>
</tr>
<tr>
<td>25% TAF:NPD</td>
<td>2.3±0.1</td>
<td></td>
</tr>
<tr>
<td>50% TAF:NPD</td>
<td>2.9±0.1</td>
<td></td>
</tr>
<tr>
<td>80% TAF:NPD</td>
<td>4.0±0.1</td>
<td></td>
</tr>
</tbody>
</table>

\[ T_g \approx 95^\circ C \]

Decreases drive voltage for up to 50% Teflon:NPD
High temperature performance

- Teflon-blended devices don’t short
- Maintain rectification above 250ºC

Increases thermal stability of diodes to >250ºC

<table>
<thead>
<tr>
<th>Neat NPD</th>
<th>Catastrophic failure temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>110 ºC</td>
<td>110 ºC</td>
</tr>
<tr>
<td>25% TAF:NPD</td>
<td>260 ºC</td>
</tr>
<tr>
<td>50% TAF:NPD</td>
<td>&gt;260 ºC</td>
</tr>
<tr>
<td>80% TAF:NPD</td>
<td>&gt;260 ºC</td>
</tr>
</tbody>
</table>
How we think it works

- Analogy to fiberglass:

1. Evaporation
2. Deposition
3. Re-polymerization

OLED molecules
teflon AF chain fragments
vapor

network of teflon chains

substrate

折射率（n）

波长 (nm)

(d)
What’s happening electrically?

- NPD hole-only diodes:
  - Suggests improved injection but degraded bulk transport

- Injection improves:
  - Interface dipole reduces hole injection barrier
  - Reduces $V_{bi}$

- Bulk mobility decreases
  - Reduced disorder
  - Reduced percolation
Prospects for improvement?

- Genuine dilution is non-trivial

- Reduced site connectivity
- Improved energetic disorder

- Percolation
- Blend morphology

- Relative dipole moments
- Relative polarizabilities

- Optical properties (lower n)
- Thermal properties (higher $T_g$ blends) ... 
- Spont. orient. polarization

Graph showing current (a.u.) vs. time (µs) for Neat NPD and 25% UGH2:NPD with note on same TOF mobility.
Questions for the community

- What if we could tailor $\mu$ and $n$ in every transport layer of a WOLED stack?
  - What does the grand electrical & optical optimization look like?
  - What does the magic dilution molecule look like? (We don’t want Teflon AF)
  - Is there economic value in displacing the cost of ‘expensive’ organic semiconductors?

Should dilution molecules become another standard ingredient for OLEDs? (like emitters, HTMs, ETMs, HBLs, EBLs, etc)
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