Catastrophic OLED failure and pathways to address it

Chris Giebink
Electrical Engineering Department, Penn State University
Killer shorts

OLED panels that short catastrophically:

- Decrease manufacturing yield
- Increase warranty expenses
- Decrease customer satisfaction

Highly localized current flow $\rightarrow$ heating & irreversible damage

Origin of shorts presently unknown

To solve this problem:

- Identify incipient shorts early & determine physical origin
- Model their evolution/growth toward catastrophe
- Predict failure & develop mitigation strategies
Hot Spots & Bright Spots

Typical images:
Bright spot microscopy

- Bright spots associated with visible inhomogeneities
- Hot spots not easily visible in microscopy

<table>
<thead>
<tr>
<th>Bright field</th>
<th>Dark field</th>
<th>DIC</th>
<th>EL @ 14V</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Bright field image" /></td>
<td><img src="image2" alt="Dark field image" /></td>
<td><img src="image3" alt="DIC image" /></td>
<td><img src="image4" alt="EL at 14V image" /></td>
</tr>
</tbody>
</table>

1. Bright field image with a scale bar of 10 µm
2. Dark field image with a note: Length 2
3. DIC image with a note: Length 2
Bright spot origin: ITO agglomerations

- Improved panel deconstruction
  → delamination

SEM image of bright spot

Bright spots are consistently ITO-rich

EDS elemental mapping
Hot Spot Fine Structure

- Characteristic ‘volcano’ structure of hot spots
- Hot spots exhibit more Ohmic EL vs. voltage → local shunts
- Hot spots often cluster
Hot spot link to shorts

- Dark spots emerge from original hot spots
Connecting to catastrophic failure

- Early connection to catastrophic short failure (fractal-like growth of shorts)
- Volcano analog of short growth
Emerging model of short growth

Cathode

Organics

ITO

Eruption

‘Nanoshort’

‘Microshort’

Growth toward ‘Macroshort’

After first aging test

Biased @ -20V

After second aging test

Biased @ -15 V

After driving the panel with 100mA
Almost catastrophically failed
The need for OLED thermal stability

• Automotive applications
  ◦ Hot cars --> 85°C +

• Solid-state lighting
  ◦ Panels operate at elevated temperature
  ◦ Thermal stability closely connected to catastrophic failure
  ◦ Intrinsic OLED lifetime ~ exp(-E_A/kT)
Current status for small molecule OLEDs

- Elevated temperature causes:
  - Crystallization/morphological changes
  - Expansion
  - Melting and/or vaporization

- Existing strategies to improve thermal stability:
  - New molecules with increased $T_g$:
    - TPD
      - $T_g \approx 60^\circ C$
    - NPD
      - $T_g \approx 90^\circ C$
  - Additives:
    - Co-deposition of high $T_g$ small molecules
    - Co-deposition of inorganics (e.g. LiF)

The additive route: Teflon AF

- Co-evaporate Teflon AF w/ small molecules

1. Evaporation
2. Deposition
3. Re-polymerization

[Diagram showing the process of evaporation, deposition, and re-polymerization of Teflon AF with OLED molecules and Teflon AF chain fragments.]
Evidence for polymer network

- Ellipsometry of Teflon/NPD films → Dissolve out NPD

Nanoporous Teflon network must exist
Dilute organic semiconductors

- Dilution in insulating matrix can improve trap-limited transport
  - $J \sim \left( \frac{N}{N_t} \right)^m$
  - Example: hole-only MEH-PPV / PVK

NPD + Teflon AF

- Hole-only devices: ITO/NPD (60 nm)/Al
  - $T_g \approx 95^\circ$C
- Measured **on and post**-hot plate

![Graphs showing current density vs. applied bias](image)

**T = 25°C**

- Neat NPD
- 25% Teflon
- 50% Teflon
- 80% Teflon

**T = 110°C**

- Neat NPD
- 25% Teflon
- 50% Teflon
- 80% Teflon

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(Baseline drawing of molecule structure)

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(Chemical structure of molecules)
NPD + Teflon AF

- Hole-only devices: ITO/NPD (60 nm)/Al
  - $T_g \sim 95^\circ$C
- Measured on and post-hot plate

![Diagram of NPD + Teflon AF](image-url)

![Current Density vs. Applied Bias graphs](image-url)

- $T = 170^\circ$C
- $T = 210^\circ$C
NPD + Teflon AF

- Hole-only devices: ITO/NPD (60 nm)/Al
  - Tg ~ 95°C
- Measured on and post-hot plate

**Summary**

<table>
<thead>
<tr>
<th>Hole-only device (50 nm)</th>
<th>Voltage at 10 mA/cm² (25°C)</th>
<th>“Shorted” Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat NPD</td>
<td>3.4 V</td>
<td>110°C</td>
</tr>
<tr>
<td>25% NPD/Teflon</td>
<td>2.2 V</td>
<td>250°C</td>
</tr>
<tr>
<td>50% NPD/Teflon</td>
<td>2.7 V</td>
<td>&gt;260°C</td>
</tr>
<tr>
<td>80% NPD/Teflon</td>
<td>4.0 V</td>
<td>&gt;260°C</td>
</tr>
</tbody>
</table>
Conclusions

OLED panel failure

• Bright spots & Hot spots
• Temp. selective EL imaging
• Hot spots >> short precursors
• Nano >> Micro >> Macroshort

Thermal stability via Teflon

• Co-evap w/ HTLs
• Repolym to nanoscale Teflon network
• Improves injection & bulk transport
• >100°C thermal stability increase
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PennState

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