Material Advances for Transparent OLEDs
What we do

Advanced Materials by Design
Developing New Materials is Really Hard

One set of properties can map to many different potential structures

**Structure**

- Materials Science
  (well understood with theory)
- Materials Discovery
  (hard to predict; one-to-many)

**Property**

- Melting Point
- Light Absorption
- Crystal Structure
- Etc.
Integrated Materials Discovery Platform
Quantum simulation + AI/ML + production validation

Properties
- Vapor pressure
- Optical constants
- Electronic structure
- Film forming
- Crystallinity
- Etc.

Structure

Quantum Simulation + AI/ML + Production Validation

Properties
- Quantum Simulations
- Machine Learning
- Production Testing

Resources:
- CPU
- GPU
- QPU (Quantum Computer)
Production Testing of Candidate Materials

Real World testing closes the loop on software platform

• 6,000 sqft facility in Toronto, Canada

Facility supported by:
Example: Aerelight for Print™
Flexible OLED module for print + packaging
New Market Opportunities for Transparent OLEDs
Enabling new product categories and applications for OLED displays

1. Large area transparent panel for advertising
2. Medium area transparent panel for AR + Auto
3. Mobile transparent panel for under display sensor
Market Demand for Transparent OLEDs

Major OEMs looking for solution with high transparency

Augmented Reality  Automotive  Smart Home  Smart Speaker

Leading consumer electronic brands seeking very high transparency OLED displays
Large Area Transparent Panel for Advertising

Transparent signage and windows display for retail

Global Transparent Digital Signage Market

Transparent OLED Signage production in 2019, but transparency is still poor (~45%)

Source: Technavio
Medium Area Transparent Panel for AR + Auto

Augmented reality display for automotive and knowledge worker

Automotive brands want transparent OLEDs for HUD, but transparency is too low (~45%)

Source: IHS
Mobile Transparent Panel for Under Display Sensor

Enable IR, camera and other sensors behind active area of display panel

Under display sensor requires high transparency (including in the NIR) to function
Transparent OLED Architectures

Transparent pixel vs transparent window

Both architectures require a highly transparent + conductive cathode solution
Cathode Transparency is a Significant Barrier
Worse for NIR to do strong absorption in metal thin films

<table>
<thead>
<tr>
<th>Optical Layers</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>~90%</td>
</tr>
<tr>
<td>OCA</td>
<td>~100%</td>
</tr>
<tr>
<td>Organic</td>
<td>~100%</td>
</tr>
<tr>
<td>Cathode</td>
<td>20 – 80%</td>
</tr>
<tr>
<td>TFE</td>
<td>95-100%</td>
</tr>
</tbody>
</table>

Transmission = Window Size × Window Transmission

Cathode layer transmittance is limiting factor for transparent OLED
Cathode Transparency is a Significant Barrier
Worse for NIR to do strong absorption in metal thin films

Transmission = Window Size × Window Transmission

Cathode layer transmittance is limiting factor for transparent OLED
Cathode Conductivity is a Significant Barrier

Worse for transparent display due to transparency trade-off

Cathode layer sheet resistance is limiting factor for transparent OLED
ConducTorr™ Electrode Technology

Micron-size patterning of top electrode

Self assembly yields low resistance electrode with micron resolution
ConducTorr™ Patterning Process
Multiple MP compatible process methods

- **Shadow Mask Deposition**
  - Substrate
  - Mask
  - Deposition

- **Light Exposure with Photomask**
  - Substrate
  - Mask
  - Light exposure

- **Direct Laser Writing (DLW)**
  - Substrate
  - Laser writing

- **Open-frame CEM Deposition**
  - Deposition

(Patterning Material)

(Electrode Material)
ConducTorr™ Enables Fine Features
Multiple MP compatible process methods

ConducTorr™ film with 6.5 µm circular mesh (mask patterning)

ConducTorr™ film with 25 µm lines (UV patterning)

High Resolution patterning demonstrated down to 6.5 µm features
ConducTorr™ Mask-free Patterning

Connection to auxiliary electrode in backplane
ConducTorr™ Mask-free Patterning
Connection to auxiliary electrode in backplane

Connection to auxiliary electrode in backplane

Top-emission PMOLED sample with ConducTorr™ Mask-free Patterning

3V, 6 mA
ConducTorr™ Demonstrated in 5.2” Mobile AMOLED

5.2” AMOLED display fabricated using ConducTorr™ Electrode

- 5.2” diagonal AMOLED panel
- Vacuum process using existing AMOLED tools and mask set
- No ConducTorr™ related defects
- 120 ppi (37” @ 4K equivalent)
- 10 µm auxiliary electrode width

Mass production ready ConducTorr™ materials now available in kg scale

- 15 nm cathode + 600 nm ConducTorr™ Electrode
ConducTorr™ Electrode for Transparent OLEDs

Transparent pixel vs transparent window

ConducTorr™ solution can be applied to both transparent OLED architectures
ConducTorr™ Demonstrated in 17” Transparent AMOLED

17” Transparent AMOLED display fabricated using ConducTorr™ Electrode
ConducTorr™ Demonstrated in 17” Transparent AMOLED

17” Transparent AMOLED display fabricated using ConducTorr™ Electrode

< 1 Ω/□ Sheet Resistance

Fill Factor ~ 15%

ConducTorr™ solution enables lowest resistance and highest transparency
Improved See-through Image Quality with ConducTorr™
Eliminates image blurring of see-through image for transparent AMOLED

Without ConducTorr™

With ConducTorr™

Image viewed through transparent panel

Image viewed through transparent panel
Improved See-through Image Quality with ConducTorr™
Eliminates image blurring of see-through image for transparent AMOLED

Without ConducTorr™

Transmitted Background
Internal TFT Reflection

Observer
Transparent display
Scene behind panel

With ConducTorr™

Transmitted Background

Transmissive window

Image Blur
ConducTorr™ Demonstrated in 17” Transparent AMOLED

17” Transparent OLED display fabricated using ConducTorr™ Electrode

- > 65% Transparency at Panel Level
- < 1 Ω/□ Sheet Resistance (15% fill factor)
- Eliminates see-through image blue

Live demo of 17” panel at SID 2019:

60.5 17-inch Transparent AMOLED Display With Self-Assembled Auxiliary Electrode

Email to schedule private demo at SID 2019
ConducTorr™ CEM as Cathode in Transparent OLED

Fabrication process using ConducTorr™ to pattern transparent window

OLED organic stack

ConducTorr™ CPM on the Open Window

ConducTorr™ CEM with open mask
ConducTorr™ CEM as Cathode in Transparent OLED

OLED device performance using ConducTorr™ CEM as cathode

Comparable voltage, efficiency, CIE and lifetime for ConducTorr™ CEM vs MgAg cathode
ConducTorr™ CEM as Cathode in Transparent OLED

Transparent OLED panels fabricated using ConducTorr™ CEM as cathode
Benefits of ConducTorr™ for Transparent OLEDs

Mass production ready solution to enable transparent OLED displays

- High Aperture Transparency of 99% (including NIR)
- High Electrode Transparency of > 85% (15% fill factor)
- High Panel Transparency of > 65% demonstrated
- High Conductivity of Rs < 1 Ω/□ (15% fill factor)
- Eliminates See-Through Image Blur from TFT
- Materials Ready for Mass Production in 2019
Thank you