3M and Minnesota

We could use “warm” OLED lighting!
OLED SSL Components

Manufacture barrier films
Validate performance
Provide low cost

Key to low cost: R2R processing

Flexible Barrier Substrate
- WVTR
- Optical
- Temperature stability
- Mechanical
- TCO? (Patterned?)
- Light extraction? (int vs ext?)

Barrier Adhesive
- WVTR
- Edge protection
- Optical
  - $T_{vis}$, haze, index
- PSA, UV, or thermal?
- Environmental durability

Barrier Film Encapsulation
- WVTR
- Optical
  - Bottom emitter – reflective
  - Top emitter - $T_{vis}$, haze
  - Transparent device
- Light extraction?

Encapsulating Barrier Film
Barrier Adhesive
Flexible Barrier Substrate
Issues Affecting Roll-to-Roll Manufacturing

• Process stability, control

• Cleanliness

• Web handling / roll formation

• Temperature stability / dimensional stability

• Static charge management

• Moisture management

• Product / material characterization

OLED dark spots
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3M Vacuum Processed Barrier Film

- Multi-layer construction
  - Substrate
  - Oxide layers
  - Polymer layers

- Flexible substrate
  - Roll-to-roll component manufacturing
  - Enables roll-to-sheet or roll-to-roll OLED fab

- Oxide provides barrier
  - High transparency & clarity
  - Low haze
  - Good flexibility

- Polymers planarize and protect

- Tortuous path from multi-dyads
  - Can increase barrier performance
3M Barrier Film Commercialization

Display Materials and Systems Division

- **3M™ Quantum Dot Enhancement Film**
- **3M™ Flexible Transparent Barrier Film (FTB)**
  - WVTR < $1 \times 10^{-3} \text{ g/m}^2/\text{day} @ 20^\circ\text{C}$
- **Barrier Adhesive, OLED Encapsulation**

Renewable Energy Division

- **3M™ Ultra Barrier Solar Film**
  - WVTR < $5 \times 10^{-4} \text{ g/m}^2/\text{day} @ 23^\circ\text{C} 85\%\text{RH}$
- **Ultra Barrier Solar Film for OPV & Perovskite PV**

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Barrier Films – Display Product Offerings and Development

**Commercialized**

- **FTB3-50**
  - Liner
  - Polymer
  - Barrier Oxide
  - Polymer
  - 2 or 5 mil PET
  - ~ 50 um
  - ~ 125 um
  - WVTR < 1x10^-3 g/m^2/day @ 20C
  - Mocon Permatran 700

- **FTB3-125**
  - Liner
  - Polymer
  - Barrier Oxide
  - Polymer
  - 2 or 5 mil PET
  - ~ 270 um
  - WVTR < 1x10^-3 g/m^2/day @ 20C
  - Mocon Permatran 700

- **BPS-270**
  - Liner
  - Polymer
  - Barrier Oxide
  - Polymer
  - Substrate
  - OCA
  - Substrate
  - Hardcoat
  - Liner
  - ~ 270 um
  - WVTR < 1x10^-3 g/m^2/day @ 20C
  - Mocon Permatran 700

**Developmental**

- **FTB3-50a**
  - Liner
  - Barrier Adhesive
  - Polymer
  - Barrier Oxide
  - Polymer
  - 2 or 5 mil PET
  - ~ 62 um
  - ~ 138 um

- **FTB3-125a**
  - Liner
  - Barrier Adhesive
  - Polymer
  - Barrier Oxide
  - Polymer
  - 2 or 5 mil PET
  - ~ 62 um
  - ~ 138 um
  - WVTR < 1x10^-3 g/m^2/day @ 20C
  - Mocon Permatran 700

- **FTB6-125L**
  - Liner
  - Barrier Adhesive
  - Polymer
  - Barrier Oxide
  - Polymer
  - Substrate
  - OCA
  - Substrate
  - Hardcoat
  - Liner
  - ~ 125 um

- **FTBA-12**
  - Liner
  - Barrier Adhesive
  - Polymer
  - Substrate
  - ~ 62 um
  - ~ 138 um
  - WVTR < 2 g/m^2/day @ 20C
OLED Barrier Characterization

- Develop technology/product
- Test technology/product
  - WVTR
  - Optical
  - Mechanical
  - Chemical
  - Electrical

- Do these tests validate device performance?
- Lifetime
- Brightness
- Uniformity
- Form Factor
Characterizing Barrier Performance - WVTR

Water Vapor Transmission Rate
(g/m²/day)

\[ WVTR = \frac{m_p}{A \times t} \rightarrow 10^{-6} \frac{g}{m^2/\text{day}} \]

Direct WVTR Measurement
Mocon Aquatran 2, SEMPA HiBarSens2

Indirect WVTR Correlation
Mass Spectroscopy, i.e. Vinci QHV-4

Indirect WVTR Prediction
Optical or electrical Ca test

Measure \( H_2O \) (or \( O_2 \)) TR

Measure test gas (He, etc.), correlate to \( H_2O \)

Measure OD vs time, model WVTR – oCa

Measure \( \sigma \) vs time, model WVTR – eCa (NREL)
3M Optical Calcium Test

1) Deposit Ca (1000Å thick) on glass slides

2) Encapsulate with barrier film and barrier adhesive

3) Measure optical density at t = 0 hr

4) Place in 60°C / 90%RH and periodically remove for scanning

5) Use image analysis software to measure
   • Optical density $\rightarrow$ WVTR
   • Moisture edge ingress
   • Defects
   • Barrier uniformity
Barrier Film Characterization by Optical Ca test

- **OD Loss (%)**
- **Time at 60C/90%RH (hrs)**

**OD Loss (%)**
- 5%
- 10%
- 15%
- 20%
- 25%
- 30%
- 35%
- 40%
- 45%
- 50%

**Time at 60C/90%RH (hrs)**
- 0
- 200
- 400
- 600
- 800
- 1000
- 1200
- 1400

**10^-5 g/m^2-day**
**10^-6 g/m^2-day**

**Pictures of samples after 136 hours at 60C/90%RH**
- 2 mil PET
- 1 mil Barrier PSA
- Glass
- 2-Ply Laminate

**2 mil PET**
**1 mil Barrier PSA**
**Glass**

**3M**

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OLED Barrier Characterization

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  - Brightness
  - Uniformity
  - Form Factor
In-device characterization

Manufacturing success
• Product performance
• End-use performance
• Reliability
• Reproducibility
• Customer acceptance

Beyond steady state WVTR
• Handle-ability
• Form factor (rolls vs sheets)
• Mechanical durability
• In-device flexibility
• Optical interactions
• Permeation dynamics
• Defect distribution
• Device lifetime

• Sustainable Development Technology Canada
  • OTI Lumionics Inc. — OLED Lighting Pilot Production Line
  • SDTC Investment: $5,700,000
    Total Project Value: $17 million
  • Consortium Members: OTI Lumionics, 3M, Dr. Reddy’s Laboratories, NSG-Pilkington, TE Connectivity, Teknion, Lumentra

• Fraunhofer FEP
• DOE SSL Proposal

How could barrier films be used?

- Direct encapsulation
  - Glass
  - OLED
  - Adhesive

- Barrier substrate
  - Glass
  - OLED
  - Adhesive
  - Barrier

- Encapsulating foil
  - Adhesive
  - OLED
  - Barrier
  - Barrier substrate

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OLED Barrier Characterization

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  - WVTR
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  - Chemical
  - Electrical

- Do these tests validate device performance?
  - Lifetime
  - Brightness
  - Uniformity
  - Form Factor
Suggested Areas for Research

- WVTR measurement techniques
  - Faster methods with lower detection limits
  - Commercially available systems and standards

- In-line characterization techniques
  - Faster methods for validating control, performance

- Flexibility characterization techniques
  - Commercially available systems and standards

- Edge ingress & edge sealing
- Defects
  - Elimination, reduction, rapid detection
- Substrates
  - Low cost
  - Heat stable
- Electrical interconnects for flexible devices
- Large area transparent conductors
  - ITO alternatives
  - Pattern-able
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