VITRIfLEX

Transparent Ultra-Barrier Film Production and Product Integration

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AIMCAL R2R Conference
Flexible, Transparent Barrier Films: Applications

Roll-to-Roll Printed, Flexible Opto-Electronics

Flexible OLED Display

Flexible OLED Lighting

Quantum Dot LCD

Lightweight Thin Film Solar

Audi AG

Samsung Galaxy S7 Edge

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Vitriflex’s Production Deposition System - AEGIS

Web Handling Designed for Barrier Film

Modular Winding Zone Construction

Plasma Pretreat

Six Independent Modular Deposition Zones

Proprietary Sputtering Process Controls

Web widths up to 1400 mm

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Demonstrated Ultra-Barrier Film Production

5 meters

Printed Electronics USA 2015 Best Technical Development Manufacturing Award

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3 Layer WVTR Performance

Patented Multi-layer Thin Film Structure

- Diffusive Layer
- Reactive Layer
- Diffusive Layer

Amorphous
PolyCrystalline
Amorphous

Thicknesses optimized for maximum transmittance

MOCON AQ2 < 5E-04 grms/m²/day

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Production Campaign

- 125 um PET
- 1100 m Rolls
- 1330 mm width
- High Deposition Rate
- Power > 97% of Rated
  - Power Supply Failures
  - Output Cable Failures
- 12 hour Pump to Pump
Transmission 3-Layer Barrier

Overall Average T = 88.7%
Standard Deviation = ± 0.6%

Specification T > 88%

Specular Transmittance 400 nm - 800 nm

As-Deposited (Not Laminated)

Roll Number

A Layer
C Layer
Planarization Layer
Primer Layer
PET

Wavelength (nm)

Total Transmittance (%)
Barrier Film Adhesion

• WVTR Performance vs Plasma Dose
  - Adhesion between Barrier Film & Planarization Layer
  - Optimization of *In Situ* Plasma Treatment Improves WVTR Performance

- Plasma Process
  - SCI envis-ION DMPTS™
  - Remote Plasma Source
  - 40 kHz Excitation
  - 50% Ar/O₂
  - 5 milliTorr

- Sputtered Barrier Film
- Planarization Layer
- Substrate

- Passes X-Hatch Adhesion After 1000 hrs @ 85°C/85%RH

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Barrier Film Just Another Layer in the Stack?

**PV Example**
- **Multiple Layers Laminated Together**
  - Adhesion between Barrier Film/Weathering Layer
  - Adhesion between Barrier Film/Solar Module
    - TPO – Thermal plastic polyolefin
    - POE – Polyolefin Elastomer
    - EVA – Ethyl Vinyl Acetate

**Display Example**
- **Multiple Layers Laminated Together**
  - Optical coupling between Barrier Film/Anti Glare Hard Coat
  - Optical coupling between Barrier Film/Display Device
    - OCA – Optical Clear Adhesive
Achieving Product Integration Success

PV Applications
- Total Light Transmission High > 90%
- UV Stability
- Adhesion to EVA, TPO, POE

Display Devices
- L*, b*, a*
- Optical coupling to OCA

Primary Importance

Stability

Color
Lamination Adhesion Example

- **Barrier Film Architecture**

- **EVA – Organic Primer Adhesion Trial**
  - 2 primers (PE & U)
  - Different EVA Additives and Cure Conditions
  - Pass 0 – 6 week Damp Heat Test > 30 N/cm

- **Test Structures**

  Primer - ~ 100 nm applied in-line on extrusion line

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Adhesion Example

**EVA Cure Condition B; Supplier 2, U-Primer**
- Initial adhesion is excellent
- Interfacial adhesion decreases with exposure duration

**EVA Cure Condition B; Supplier 4, U-Primer**
- Initial adhesion is excellent
- Cohesive Failure of PET as exposure increases
- Interfacial Adhesion Retained

**CONDITIONS**
- 85°C
- 85%RH

**PET Fracture**

Supplier 4 U-Primer Acceptable
Change to Hydrolytically Stable PET
## Results for EVA Adhesion

<table>
<thead>
<tr>
<th>Supplier</th>
<th>PET Backside Primer</th>
<th>EVA Cure A</th>
<th>EVA Cure B</th>
<th>EVA Cure C</th>
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<tr>
<td>2</td>
<td>PE</td>
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<td>X</td>
<td>X</td>
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<tr>
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<td>X</td>
</tr>
<tr>
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<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
<td>X</td>
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<tr>
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</tbody>
</table>

### Implications for Supply Chain

- Limits Manufacturers
- PET not “off-the-shelf” or inventoried
- Order MOQ’s range 5 to 20 Metric Tons
- 6 to 12 week lead time for Extrusion Events
- Requires Customer Commitment for Large Orders
- Logistics for Storage of Rolls
- Shelf Life
Barrier Stack Color Control for Display Application

- Optical Displays require excellent color fidelity
  - CIE Lab Color space requirements
    - $b^* < \pm 1.75$
    - $a^* < \pm 1.5$
    - $L > 93$

### Layer Thicknesses

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>RI</th>
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<tbody>
<tr>
<td>Hard Coat Layer</td>
<td>2 $\mu$m</td>
<td>1.55</td>
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<tr>
<td></td>
<td></td>
<td>1.65</td>
</tr>
<tr>
<td>Primer Layer</td>
<td>~ 0.7 $\mu$m</td>
<td>1.58</td>
</tr>
<tr>
<td>PET</td>
<td>15 $\mu$m</td>
<td>1.48</td>
</tr>
<tr>
<td>Planarization Layer</td>
<td>~ 1.7 $\mu$m</td>
<td>1.48</td>
</tr>
<tr>
<td>A Layer</td>
<td></td>
<td>1.65</td>
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<td>Barrier Film</td>
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<td>1.70</td>
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<tr>
<td>OCA/PSA</td>
<td></td>
<td>1.58</td>
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<tr>
<td>Display Device</td>
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<td>1.58</td>
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</tbody>
</table>

Individual Layer Thicknesses Optimized for $a^*$, $b^*$ and $L^*$

Optical Absorption in Primer
Design and Results

- Two Different 3 Layer Barrier Designs
  - Design is constrained by tolerance of solution coating layer thickness variation
  - OptiLayer™ Stack Design Module used for Optimization

<table>
<thead>
<tr>
<th>Design 1</th>
<th>Design 2</th>
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<tbody>
<tr>
<td>$L_{\text{avg}}$</td>
<td>93.37</td>
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<tr>
<td>$a_{\text{avg}}^*$</td>
<td>0.13</td>
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<tr>
<td>$b_{\text{avg}}^*$</td>
<td>1.69</td>
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<tr>
<td>$\Delta L$</td>
<td>0.19</td>
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<tr>
<td>$\Delta a^*$</td>
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<tr>
<td>$\Delta b^*$</td>
<td>0.85</td>
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</table>

Design 2 has higher tolerance to solution coating layer thickness variations.
Calcium Test Independent Evaluation by Customer

- Calcium Reaction Method
  - 1000 total hrs
  - 2 samples

Calcium Test Setup

Barrier Film Size: 28 mm x 64 mm
Ca Spot Size: 10 mm x 10 mm
Ca Thickness: 10 nm
Dry Time: 70 °C, 16 hours
Environment: 40°C @ 90%RH

<table>
<thead>
<tr>
<th>試料名</th>
<th>処理時間</th>
<th>水蒸気透過度[(g/m²/day)]</th>
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<tbody>
<tr>
<td>ハイバリアフィルム</td>
<td>1001 h</td>
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</tr>
<tr>
<td></td>
<td>n = 1</td>
<td>$8.2 \times 10^{-6}$</td>
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<tr>
<td></td>
<td>n = 2</td>
<td>$6.9 \times 10^{-6}$</td>
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<tr>
<td></td>
<td>平均</td>
<td>$7.5 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Achieving Protection for Flexible OLED Lighting

**OLED Substrate Barrier**

- **OLED constructed on barrier film** (bottom emitting)
  - Barrier surfaces must meet OLED deposition requirements
  - Thermo-mechanical stability for process integration
    - Vitriflex barrier layers are *all inorganic* and thermally stable
  - Design optical stack for maximum light extraction
    - Vitriflex barrier stack is tunable for index matching

**Hybrid Barrier**

- **Combine substrate barrier with barrier film and PSA**
  - Improve lifetime without significant additional capital
  - Increase redundancy over that of the individual components
    - Meets demanding automotive applications

**Barrier PSA**
Pressure Sensitive Adhesive
With H₂O and O₂ Getters

*tesa* Product # 61501
WVTR of 3 Layer Barrier + Barrier PSA

WVTR: $< 5 \times 10^{-5} \text{ g/m}^2\text{-day}$

40°C / 100%RH
WVTR Flex Testing of 3 Layer Barrier + Barrier PSA

Flex conditions: 10,000 cycles, R = 5mm

TC2017-0410-4

DATA POINTS

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<th>Rate/Event</th>
<th>Time</th>
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WVTR: < 5 x 10^{-5} g/m²·day

40°C / 100%RH

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Integration of Barrier Film and Silver Nanowires for PMOLED

• 3 Layer Barrier Stack Incorporates Sinovia© Technologies Silver Nanowires in Top Coat
  – Enables Flexible and Rollable Single Color Display

![Diagram of PMOLED stack](image)

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Thank You

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