Flexible Glass Applications & Process Scaling

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Outline

• Flexible Glass
• Applications
• Process Scaling
• Summary
Flexible Glass Enables Revolutionary Scaling of Processes
Provides a high quality glass substrate compatible with R2R manufacturing

- Continuous fusion forming produces a display-grade glass surface at scalable dimensions

- Corning® Willow® Glass is compatible with both sheet (carrier) and R2R manufacturing

Fusion Forming Process

Substrate Scalability

Production Spools
Thickness ≤ 200 μm
Width   ≤ 1.3 m
Length  ≤ 300 m
Glass Enables Device Process & Performance Optimization
Flexible glass benefits arise from composition and forming process

- Flexible glass advantages include:
  - Optical quality
  - Surface quality
  - Thermal capability
  - Dimensional stability
  - Chemical compatibility
  - Hermeticity

Flexible glass enables thin, light, conformal devices

Willow Glass Optical Transmission

Willow Glass Modulus & Hardness
Applications Value Different Sets of Flexible Glass Attributes
Roll-to-roll or roll-to-sheet manufacturing is the common element

Laminated Flat and Curved Surfaces
- Mechanical properties, large area

OLED Lighting
- Hermeticity, flexibility, optical quality

Photovoltaic
- Optical quality, hermeticity, surface quality

Transparent Antenna
- Dimensional stability, optical quality


Glass R2R Reliability Achieved by Controlling Stress & Defects
Optimization based on specific requirements of process and device design

- Roller systems efficiently convey flexible glass web
- Equipment designs affect glass stress
  - Conveyance path, rollers, steering, tension,…
- Cutting processes and controlling contact address defects
  - Edges - slitting and cutting optimization
  - Surfaces - edge tab / laminate / interleaf

Rigidity $\sim E \times (\text{thickness})^3$

Bend Stress $\sim E \times (\text{thickness})$
Modeling Enables Optimization of Substrate, Process, Device System-level decisions incorporate influence of flexible glass properties

- Glass web shape in roller free-span
- Glass web stress in conveyance deviations
- Thermal response in process
- Packaged device stress during impact

**100µm Willow Glass Conveyance at 1m/min**

Distance (m) vs. Temperature (ºC)

**Y Axis - Directional Deformation**

- Max
- 0.007126
- 0.014262
- 0.021313
- 0.028367
- 0.035421
- 0.042475
- 0.049531
- 0.056587
- 0.063643
- 0.070700
Application Reliability Requires System-Level Optimization
Individual materials and methods have combined effect

**Ball Drop Example**
- Laminated Willow Glass
- 0.5kg ball
- 1.3m drop

**Cyclic Bend Example**
- Cyclic 4-point bend testing ~27mm radius
- 25,000 cycle testing
- *In situ* van der Pauw measurement
- Evaluated TCO-coated substrates
  - Flexible glass – FTO, ITO, AZO, CTO

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The Flexible Glass R2R Ecosystem is Growing

Processes scaling: proof-of-concept → pilot line → manufacturing

Lamination

Laser Patterning

Printing

Vacuum Deposition

Glass web conveyance is central element

Solution Coating

Photolithography
Conveyance – Handling Glass Web at Production Width
Demonstrated 1m-width glass conveyance in process configuration

- Repeated conveyance cycles with no interleaf
- Stable web shape
- Good wind quality with no web steering

<table>
<thead>
<tr>
<th>Glass web width</th>
<th>1 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass web length</td>
<td>50 m</td>
</tr>
<tr>
<td>Conveyance speed</td>
<td>1.5 m/min</td>
</tr>
<tr>
<td>Path length</td>
<td>&gt;10 m</td>
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<tr>
<td>Roller wrap angles</td>
<td>20 - 130 deg</td>
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</tbody>
</table>
Microreplication – Wide, Dimensionally Stable Glass Web
Patterned example structures on 750mm-width glass web

- Created single and double-side patterns
- Glass width – 750 mm
- Glass length – 40 m
Vacuum Deposition – High Temperature, Production Length
Deposited ITO at 350ºC on 100m-length glass web

- Repeated conveyance cycles
- Stable web shape
- Good wind quality with no web steering
- Deposited ITO for OLED lighting
  - 350ºC process temperature
  - 12 Ω/sq, 170 µOhmcm

**ITO-Coated Willow Glass**

- Width - 330 mm
- Length - 100 m

**FOSA Labx 330 Glass**

**Sheet Resistance**

**UV-Vis Transmittance**
Flexographic Printing – High Speed, Long Complex Web Path
Patterning up to 20 m/min in system with 90m-length web path

- Complex 90m-length web path
  - >30 rollers (2 dancers)
- Printing at 15-20 m/min
  - <80 µm features (non-optimized)
  - Ink drying limited speed
- Slot die coating at 15 m/min
  - Ink drying limited speed
- Conveyance at 30 m/min
- Glass web
  - Width - 330 mm
  - Length >40 m
Flexographic Printing at 15 m/min
Summary

• Flexible glass offers advantages for device designs and processes
  – Includes optical & surface quality, dimensional & thermal stability, hermeticity

• Mechanical reliability of glass is understood
  – Form with high initial strength & minimize defect creation
  – Manage stresses with appropriate handling & conveyance
  – Optimized solutions are application specific

• A disruptive flexible glass ecosystem is emerging
  – Equipment specifically optimized for glass processing

<table>
<thead>
<tr>
<th>Highlighted Ecosystem Processes</th>
<th>R2R Glass Web Demonstrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microreplication</td>
<td>Web width</td>
</tr>
<tr>
<td>Vacuum deposition</td>
<td>1 m</td>
</tr>
<tr>
<td>Flexographic printing &amp; coating</td>
<td>Web length</td>
</tr>
<tr>
<td></td>
<td>100 m</td>
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<tr>
<td></td>
<td>Web speed</td>
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<tr>
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<td>20 m/min (flexo)</td>
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<td></td>
<td>30 m/min (convey)</td>
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