CORNING

Flexible Glass
Applications & Process Scaling

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Outline

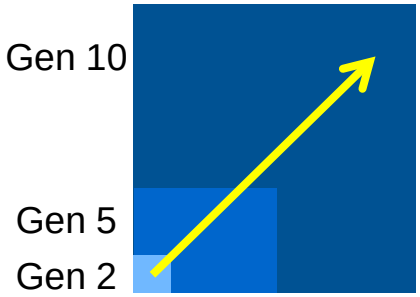
- Flexible Glass
- Applications
- Process Scaling
- Summary

Flexible Glass Enables Revolutionary Scaling of Processes

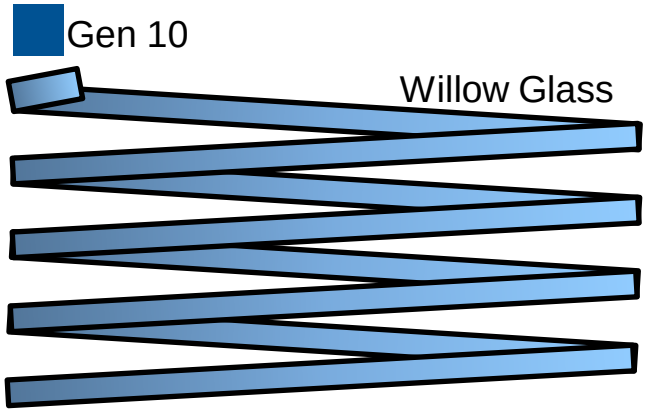
Provides a high quality glass substrate compatible with R2R manufacturing

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

Fusion Forming Process



Substrate Scalability



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

Production Spools

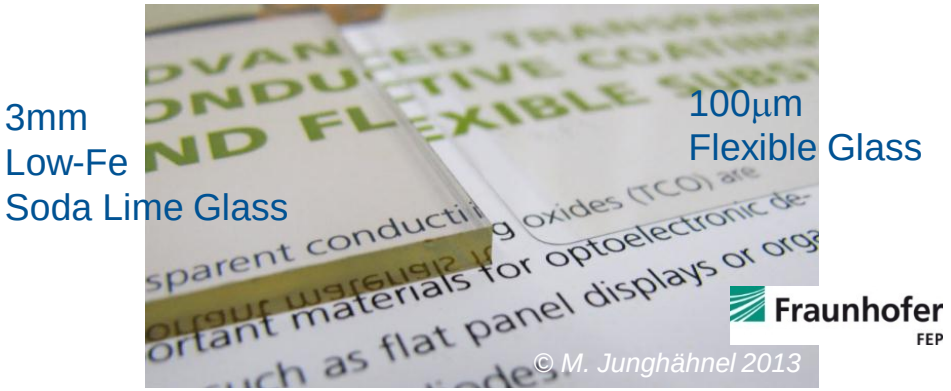
Thickness ≤ 200 μm
Width ≤ 1.3 m
Length ≤ 300 m

Glass Enables Device Process & Performance Optimization

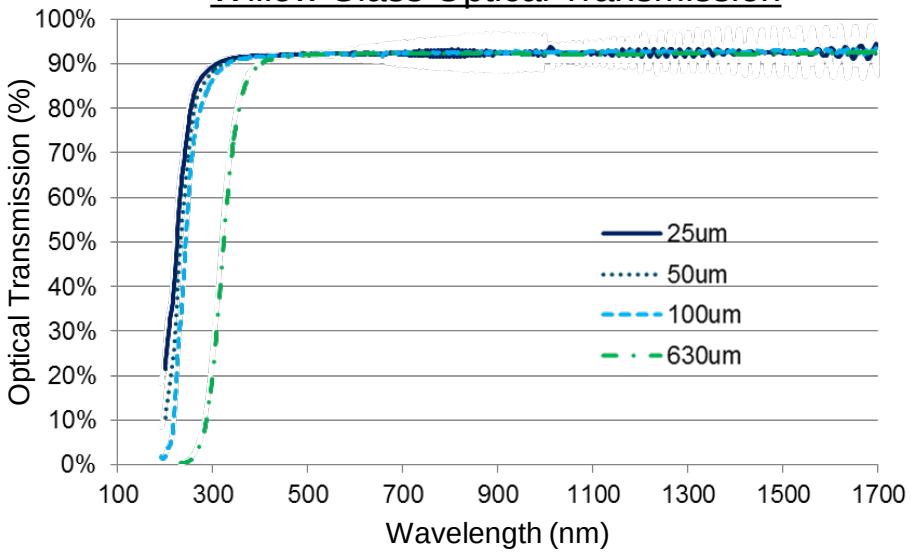
Flexible glass benefits arise from composition and forming process

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

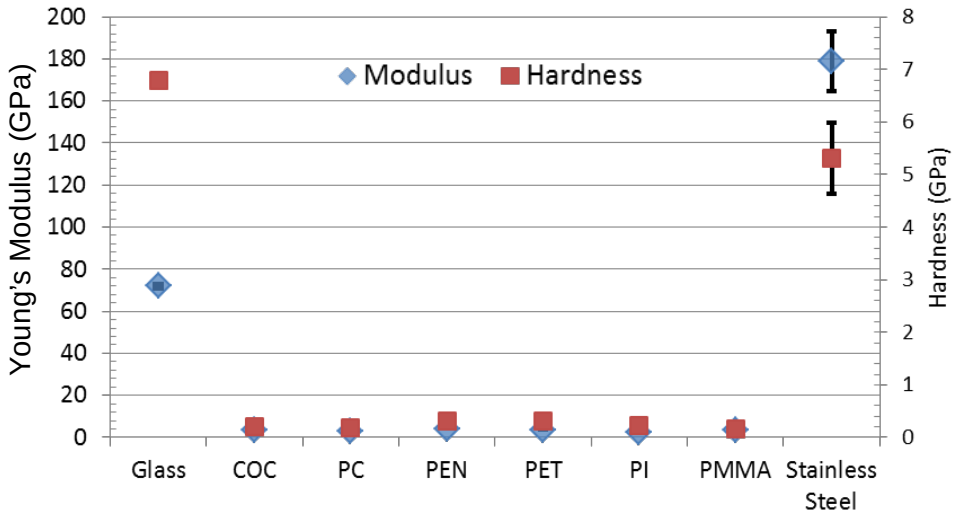
Flexible glass enables thin, light, conformal devices



Willow Glass Optical Transmission



Willow Glass Modulus & Hardness



Flexible Glass: Enabling Thin, Lightweight, and Flexible Electronics, Wiley-Scrivener, 2017.

Applications Value Different Sets of Flexible Glass Attributes

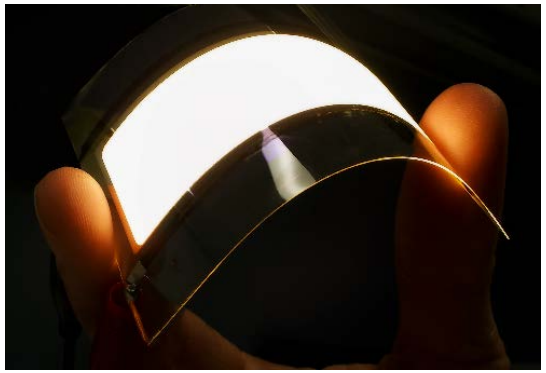
Roll-to-roll or roll-to-sheet manufacturing is the common element

Laminated Flat and Curved Surfaces

- Mechanical properties, large area

OLED Lighting

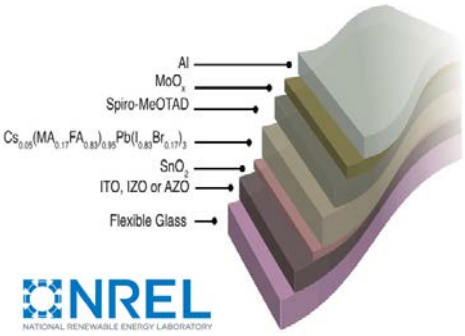
- Hermeticity, flexibility, optical quality

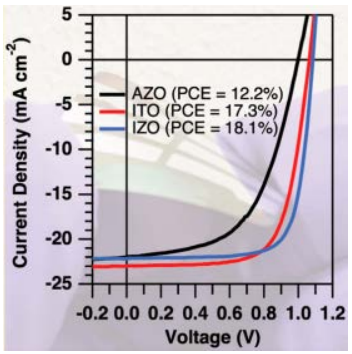


L. Zhang, at al., "Flexible Glass Substrates for Printed Electronic Applications," IWFPE 2016.

Photovoltaic

- Optical quality, hermeticity, surface quality





Perovskite - 18.1%

B. Dou, et al., "High-Performance Flexible Perovskite Solar Cells on Ultrathin Glass: Implications of the TCO" *J. Phys. Chem. Lett.*, v.8, pp.4960−4966, 2017.

Transparent Antenna

- Dimensional stability, optical quality

2.4 GHz Antenna

CAMM

M. Poliks, et al., "Transparent Antennas for Wireless Systems based on Patterned Indium Tin Oxide and Flexible Glass," ECTC 2017.

Glass R2R Reliability Achieved by Controlling Stress & Defects

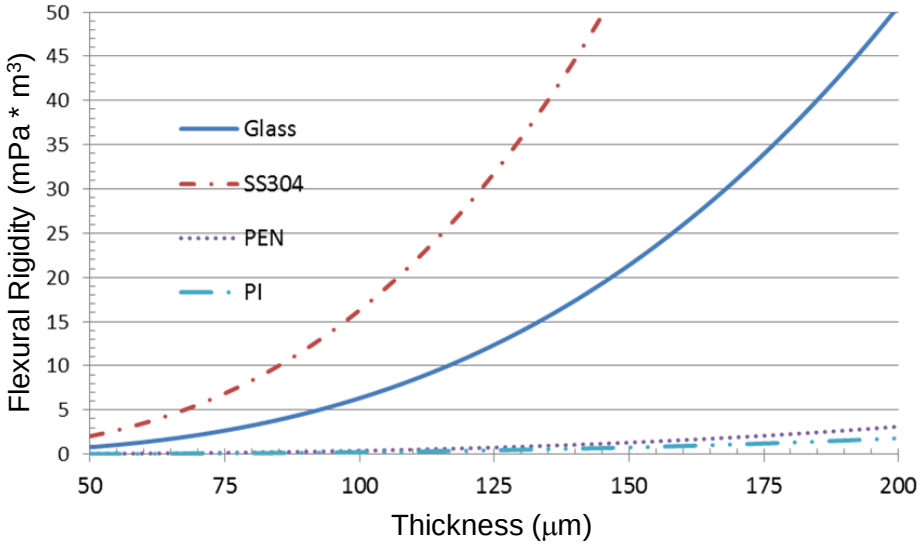
Optimization based on specific requirements of process and device design

- 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

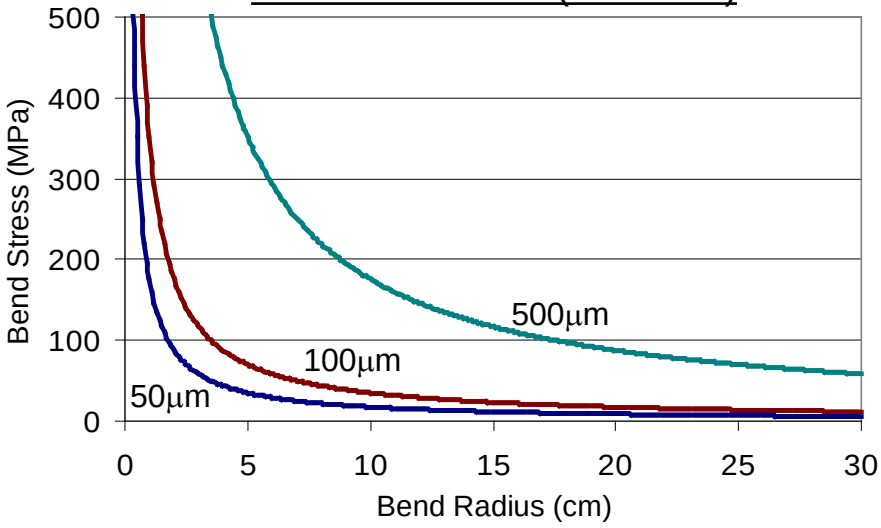
R2R Perovskite & IZO Films

NREL NATIONAL RENEWABLE ENERGY LABORATORY | SERIIUS | CAMM

Rigidity ~ E * (thickness)^3



Bend Stress ~ E * (thickness)

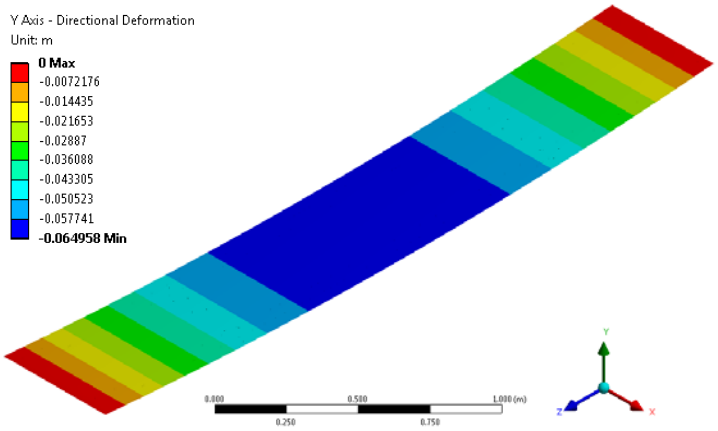


Flexible Glass: Enabling Thin, Lightweight, and Flexible Electronics, Wiley-Scrivener, 2017.

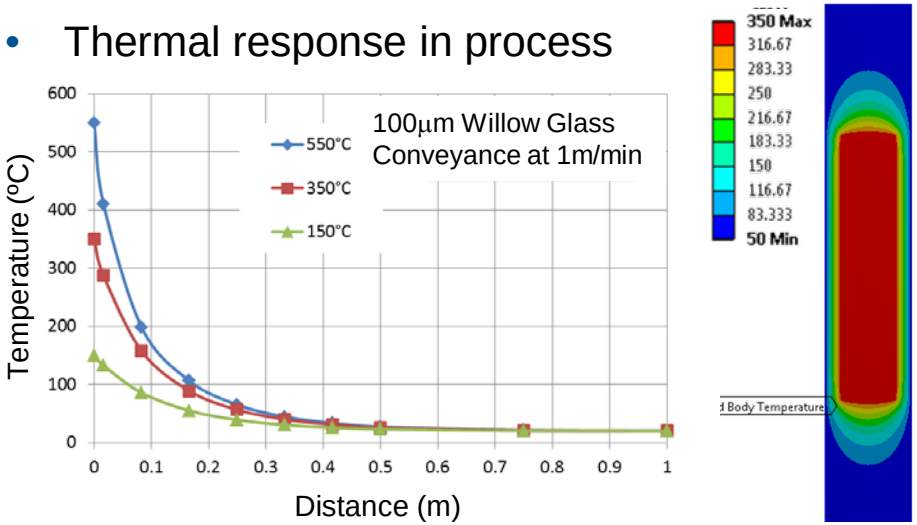
Modeling Enables Optimization of Substrate, Process, Device

System-level decisions incorporate influence of flexible glass properties

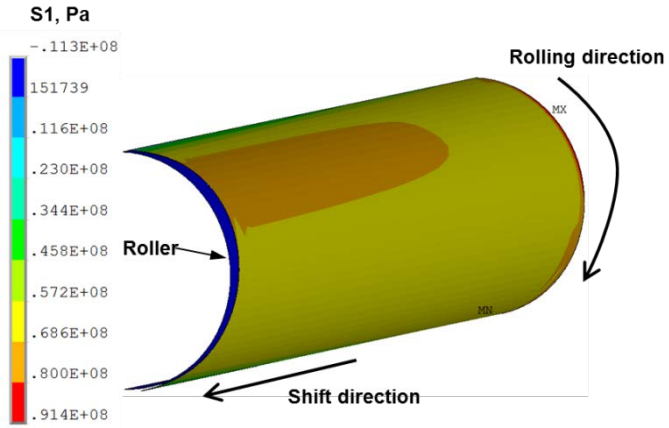
- Glass web shape in roller free-span



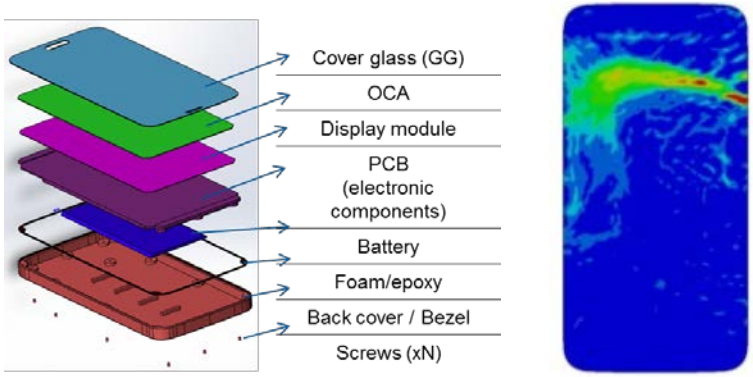
- Thermal response in process



- Glass web stress in conveyance deviations



- Packaged device stress during impact

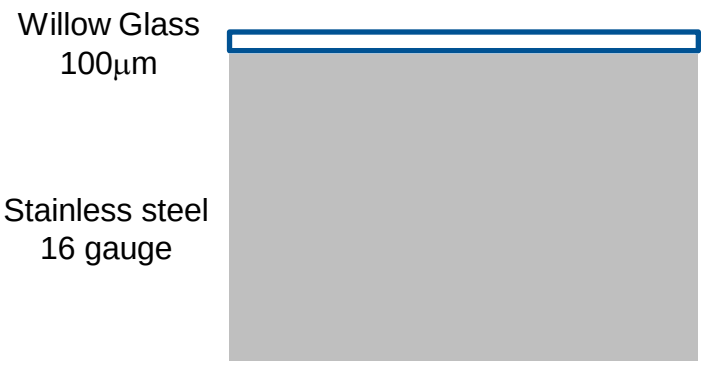


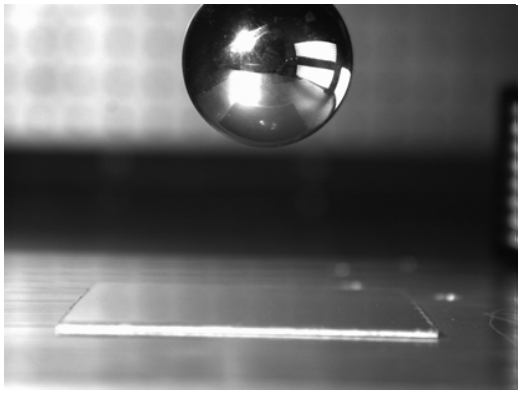
Application Reliability Requires System-Level Optimization

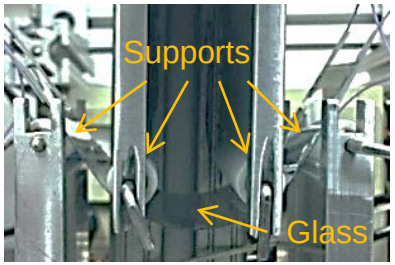
Individual materials and methods have combined effect

Ball Drop Example

- Laminated Willow Glass
- 0.5kg ball
- 1.3m drop

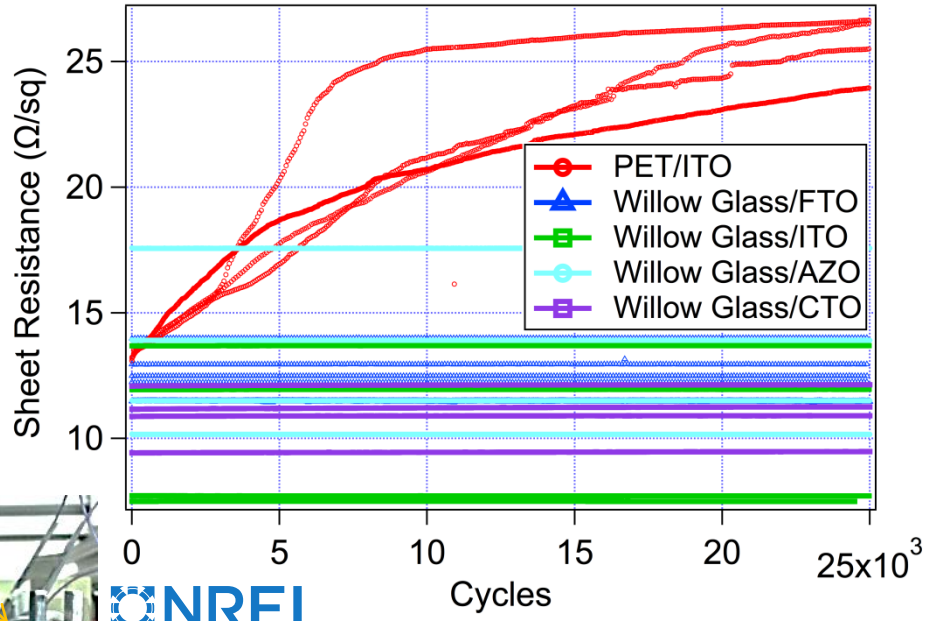






Cyclic Bend Example

- 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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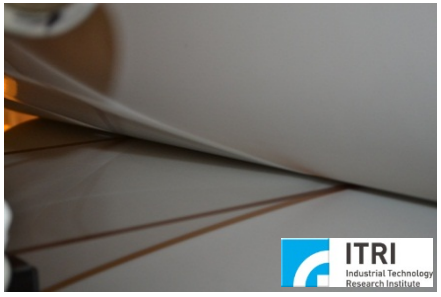
NATIONAL RENEWABLE ENERGY LABORATORY

J.M. Burst, et al., *2014 IEEE-PVSC*, Denver, June 9-13, 2014.

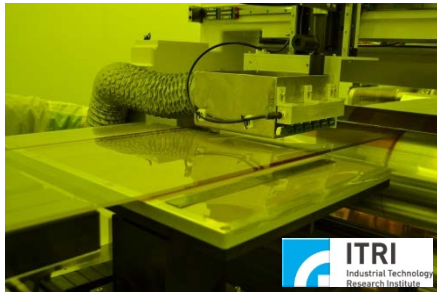
The Flexible Glass R2R Ecosystem is Growing

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

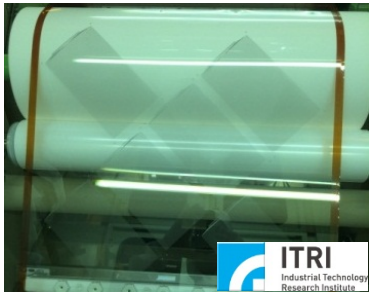
Lamination



Laser Patterning



Printing

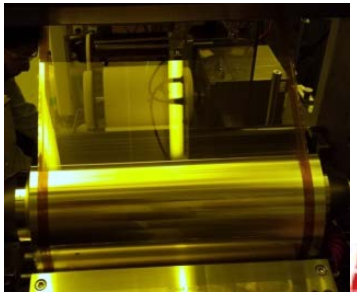


Glass web conveyance is central element

Vacuum Deposition

Photolithography

Solution Coating

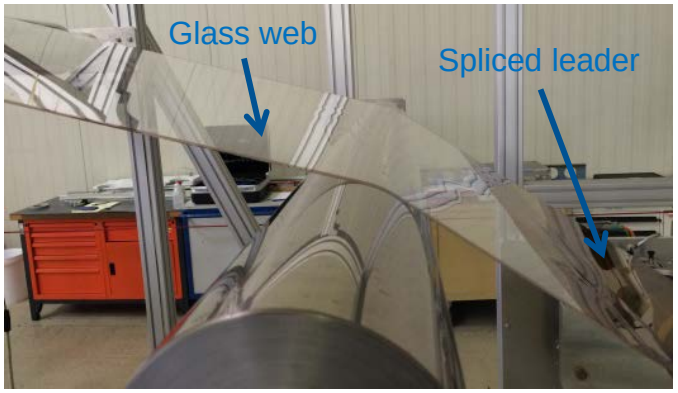


Conveyance – Handling Glass Web at Production Width

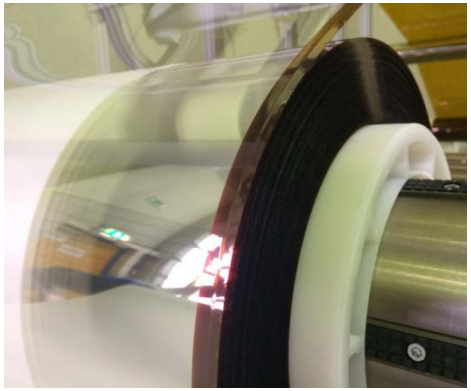
Demonstrated 1m-width glass conveyance in process configuration

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

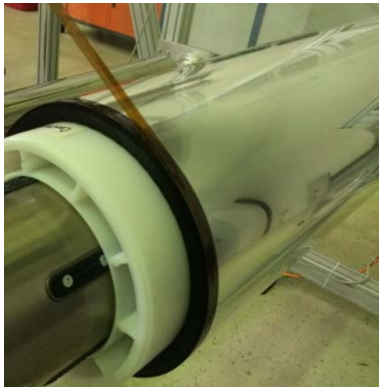
Roller Conveyance



Spool Unwind With Interleaf



Spool Rewind No Interleaf

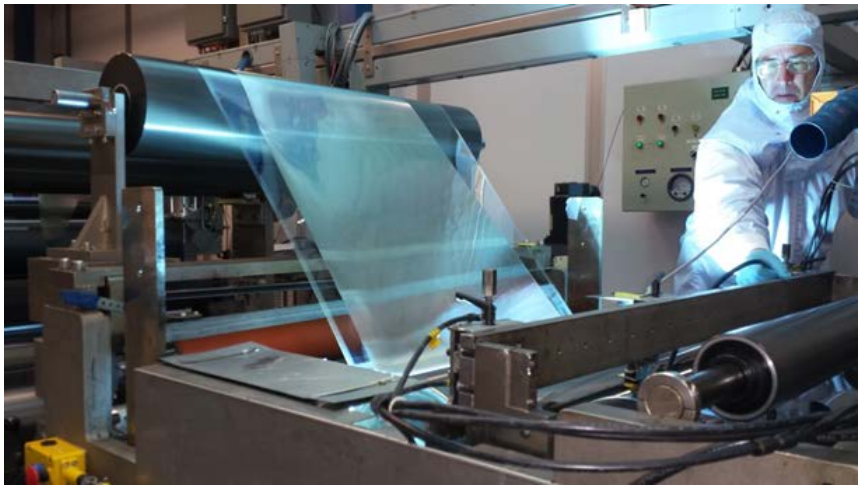


Glass web width	1 m
Glass web length	50 m
Conveyance speed	1.5 m/min
Path length	>10 m
Roller wrap angles	20 - 130 deg

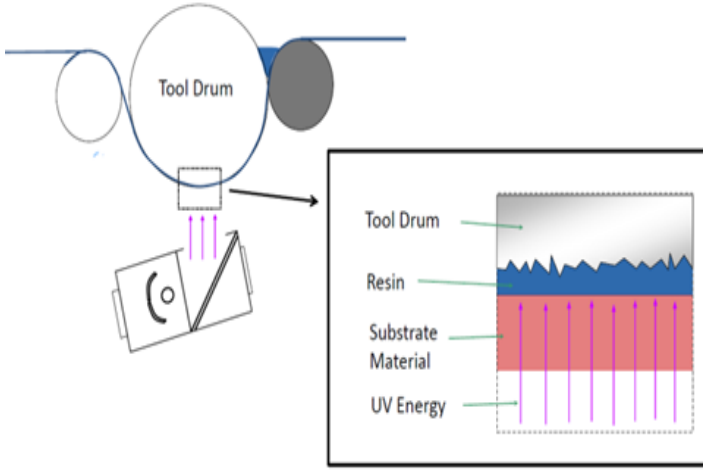
Microreplication – Wide, Dimensionally Stable Glass Web

Patterned example structures on 750mm-width glass web

Willow Glass Exiting Process Nip

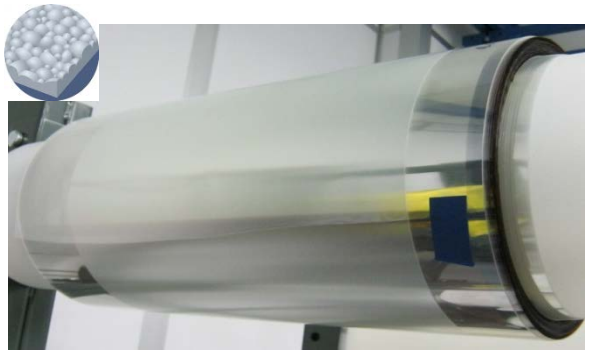


Resin Coating & Replication



- Created single and double-side patterns
- Glass width – 750 mm
- Glass length – 40 m

Diffuser Patterned Glass Spool



Prism (cross-section)

Diffuser (cross-section)

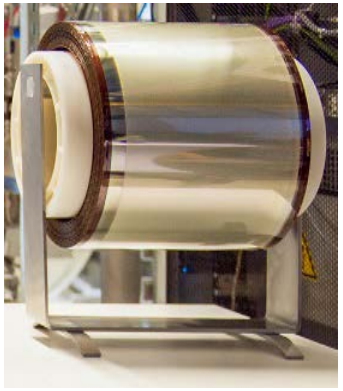
Lenticular (top view)

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

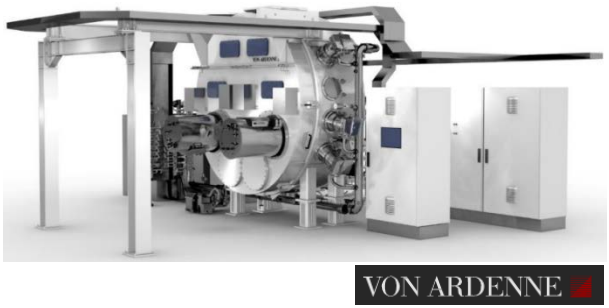
- Deposited ITO for OLED lighting
  - 350ºC process temperature
  - 12 Ω/sq, 170 µOhmcm

ITO-Coated Willow Glass

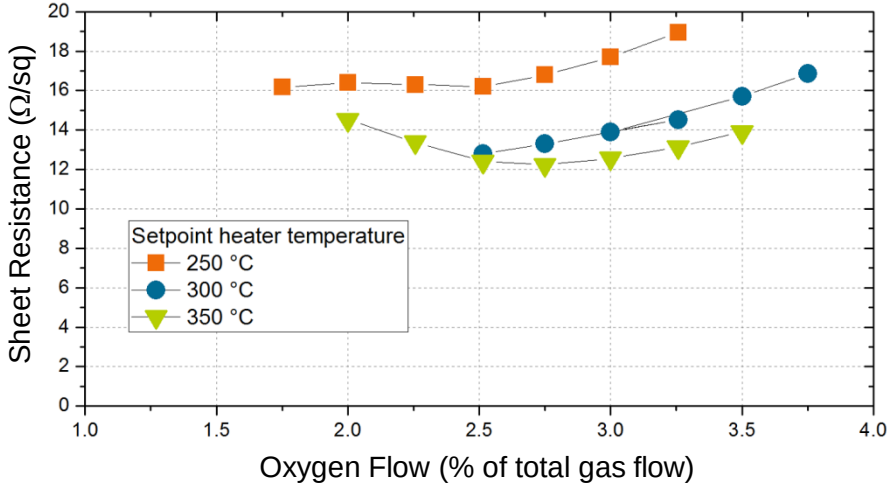


Width - 330 mm
Length - 100 m

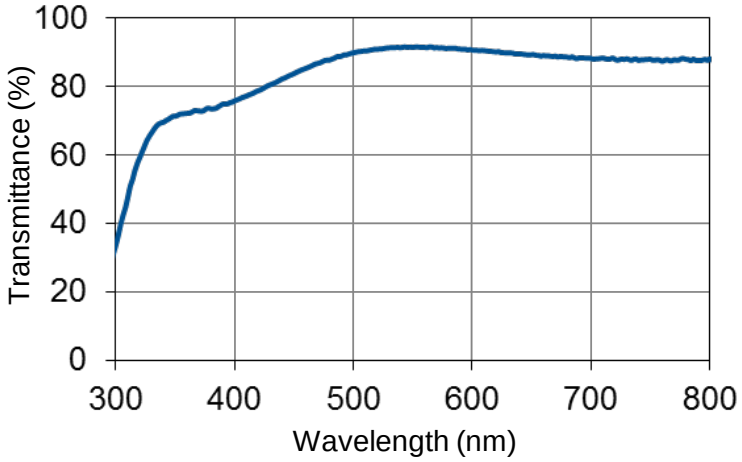
FOSA Labx 330 Glass



Sheet Resistance



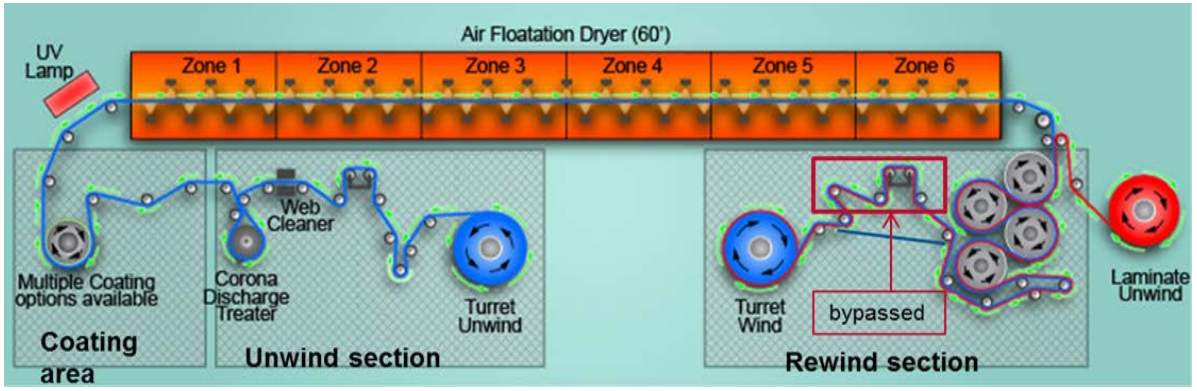
UV-Vis Transmittance



Flexographic Printing – High Speed, Long Complex Web Path

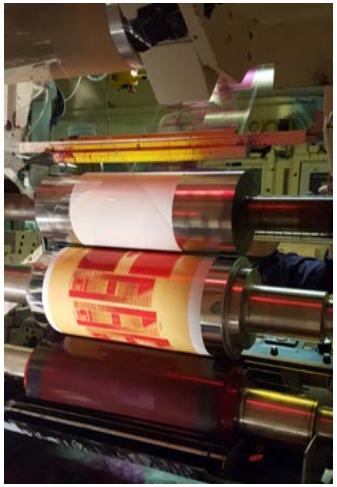
Patterning up to 20 m/min in system with 90m-length web path

R2R Printing and Coating System



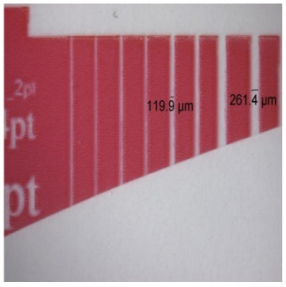
- Complex 90m-length web path
  - >30 rollers (2 dancers)
- Printing at 15-20 m/min
  - <80μm features (non-optimized)
  - Ink drying limited speed
- Slot die coating at 15 m/min
  - Ink drying limited speed
- Conveyance at 30 m/min
- Glass web
  - Width - 330 mm
  - Length >40 m

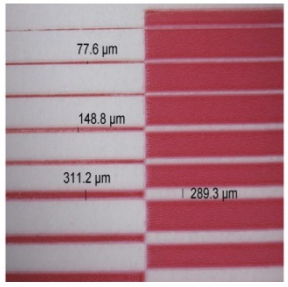
Flexo Printing

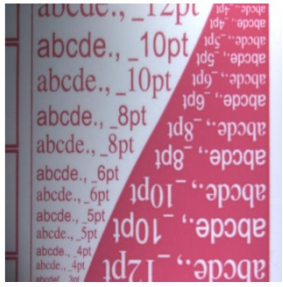


Slot Die Coating

Flexo Print Direction ⟶

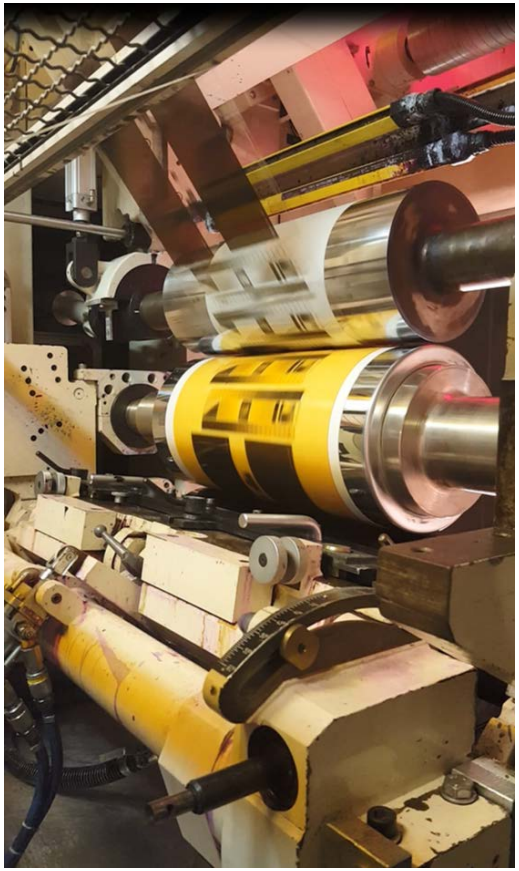




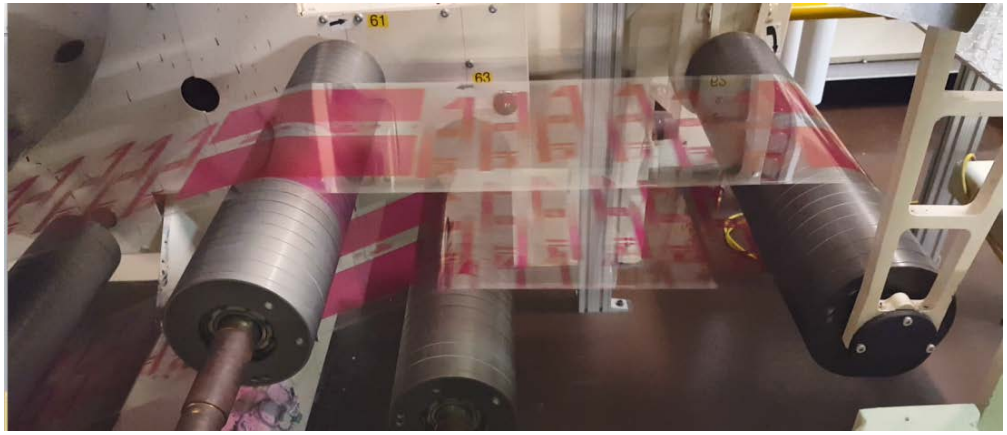


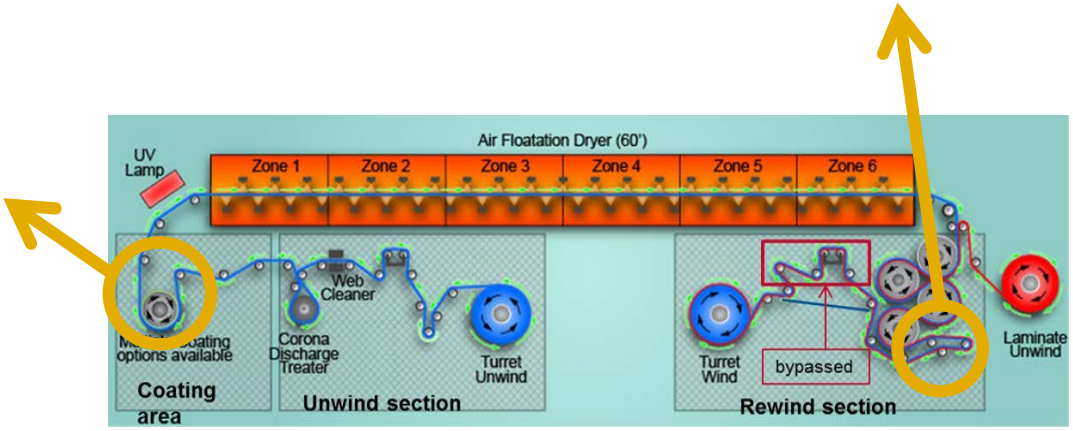
Flexographic Printing at 15 m/min

Flexo Printing



Conveyance





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

Highlighted Ecosystem Processes
Microreplication
Vacuum deposition
Flexographic printing & coating

R2R Glass Web Demonstrations	
Web width	1 m
Web length	100 m
Web speed (equipment / ink limit)	20 m/min (flexo) 30 m/min (convey)