Flexible OLEDs on Corning® Willow® Glass

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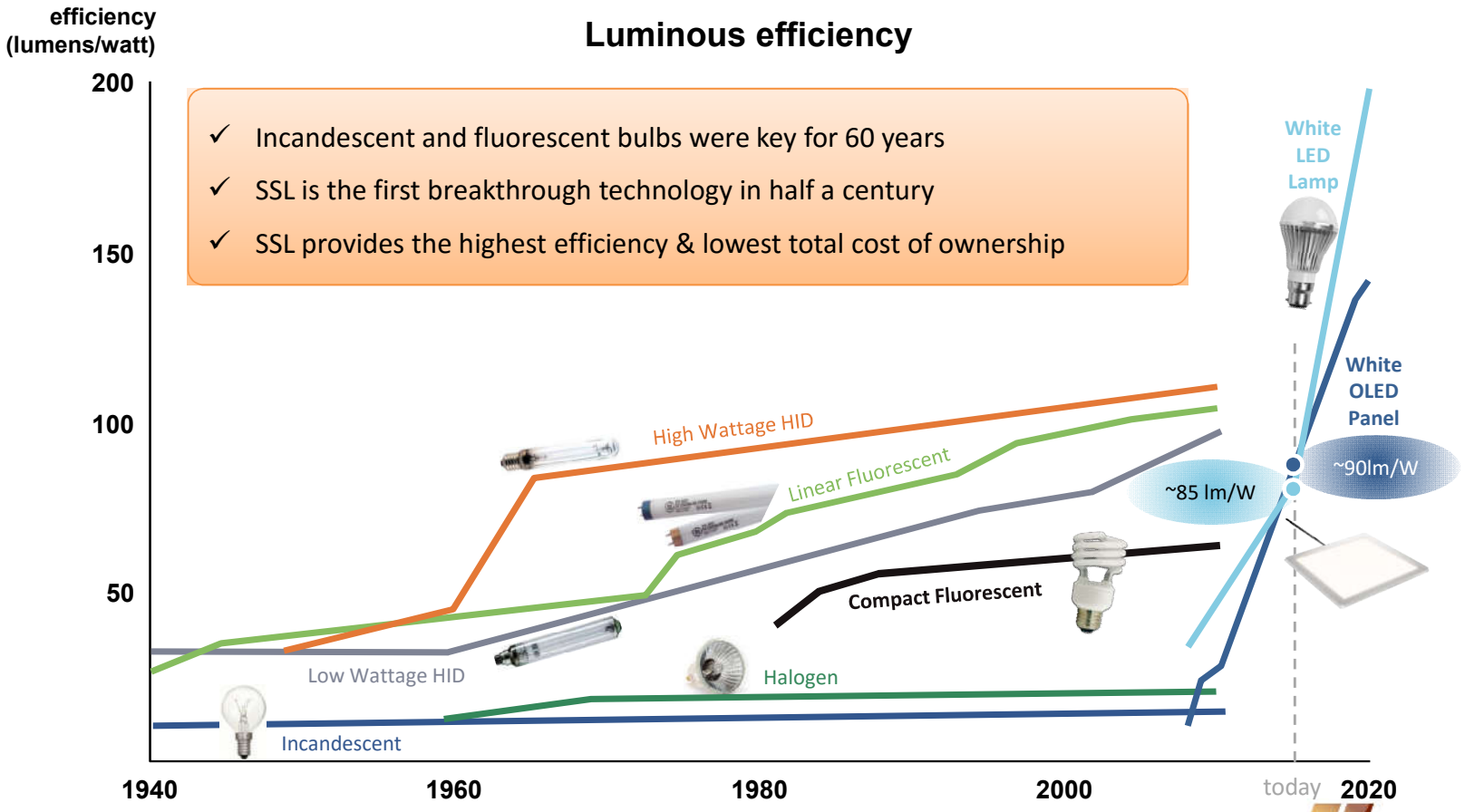
Outline

- OLED lighting value proposition
- Challenges in building flexible OLED panels
  - Review of state of technology
  - OLEDWorks/Corning approach
- OLEDWorks Panel
  - Status
  - Flexible integrated substrate value
- Summary

OLED Lighting Value Proposition

Technology adoption is driven by efficiency and operating cost in lighting; white LED is the forerunner today



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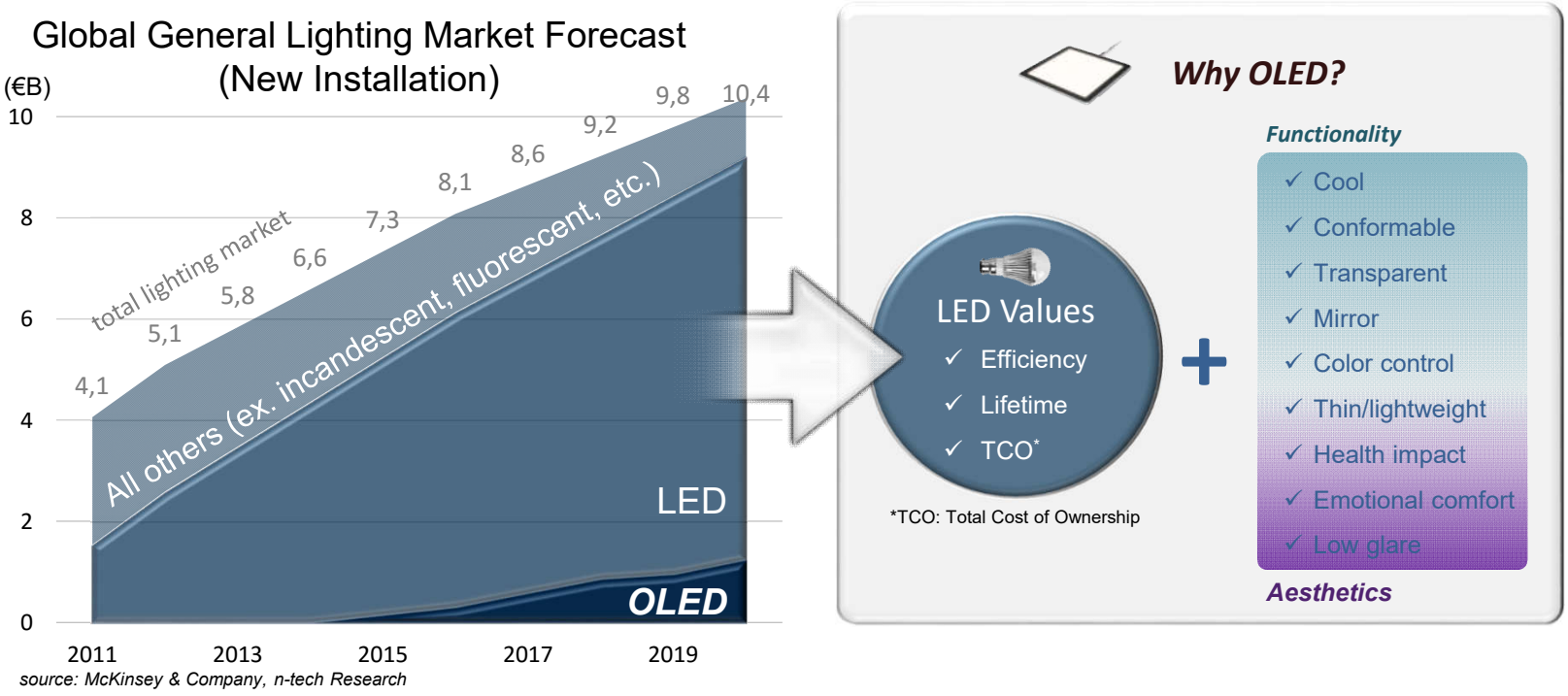
OLED Lighting Value Proposition

Next generation lighting will be driven by integration, light quality, and function

	Today Bulb/luminaire replacement	***Future*** Lighting integrated with other functionalities
Value Drivers	✓ Cost & performance • $/klm • lm/W • Color temperature (K)	✓ Added aesthetics & functionalities • Lighting without light bulbs • Overall operating expense • New user productivity/experience
Light Sources Quality	✓ Replace existing bulb ✓ Maintain form factors 	✓ Light quality: CRI>90 ✓ Low glare ✓ Integration with fixture ✓ Integration into walls, furniture, shelving 
Integration Controls	✓ Simple controls • On/off • Dimmability 	✓ Building controls integration ✓ Sensor-based control ✓ Wireless controls using Zigbee and Bluetooth 
Function	✓ Lumens only 	✓ Health benefits ✓ Location services ✓ Data communication 

OLED Lighting Value Proposition

LEDs are expected to prevail in the lighting market;
With cost reduction, OLEDs will also become popular



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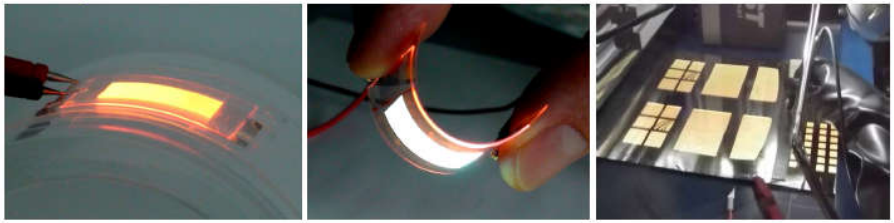
Challenges in building flexible OLED panels

Review of state of technology

- Multiple options for flexible OLEDs
- Which problems to solve?
- Balance cost and performance

FUTURE OLED LIGHTING WILL BE FLEXIBLE

Thin glass | Plastic foil | Metal foil



- What means „FLEXIBLE OLED“?
- folded? wrapped? rolled? twisted? „crumpled/creased“? curvable? bendable? conformable?
- with neglible effect on its electronic function
- consensus : use of flexible substrate
- Different applications ask for different types of „Flexibility“!
- 1-dimensional, 1.5-dimensional, 2-dimensional curvature

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Christian May, OLEDs World Summit, 10/28/2015

Flexible Substrate for OLED

KONICA MINOLTA

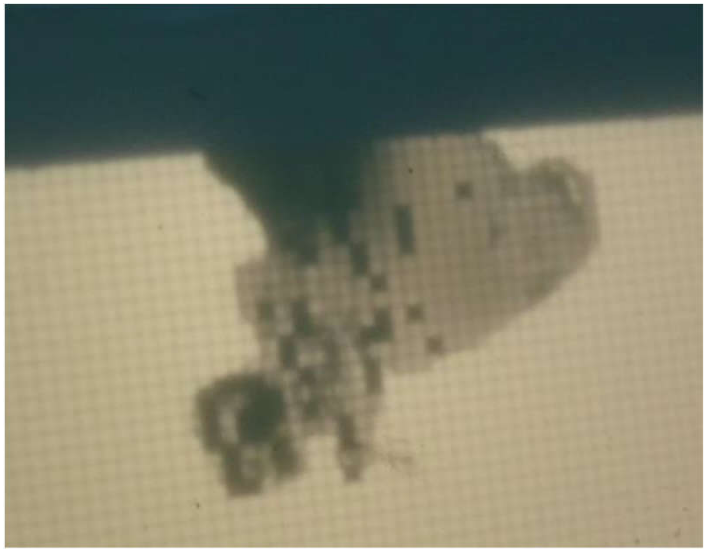
	Plastic	Metal Foil	Thin Glass
	 KONICA MINOLTA	 alanod	 Nippon Denki Glass
Suitability for R2R process	○	×	×
Surface smoothness	○	×	○
Flexibility	○	○	×
Heat resistance	×	○	○
Barrier property	×	○	○
Remark (Key Points)	–good property for R2R process and flexibility –high performance barrier film is required –poor property for high temperature process	–possibility of bent and broken in R2R process –flattening layer is required –transparent OLED can not be made	–good property for barrier –possibility of broken in R2R process –OLED panel can be easily broken

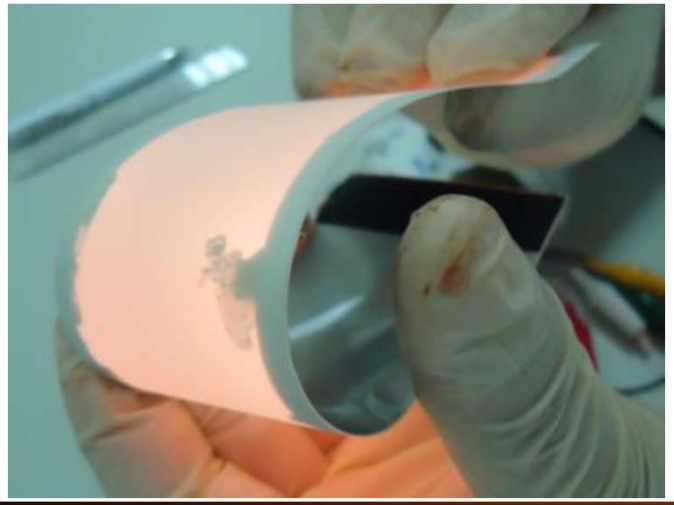
Takatoshi Tsujimura, OLEDs World Summit, 10/27/2015

Challenges in building flexible OLED panels

Review of state of technology

- Barrier-coated plastic substrates, under development by several organizations (Fraunhofer, Holst, Konica-Minolta, Sumitomo, Vitriflex, etc.)
- Konica-Minolta: R2R mass production plant has started
- LG Chem: Plastic-based OLED light panel samples are available at very high price

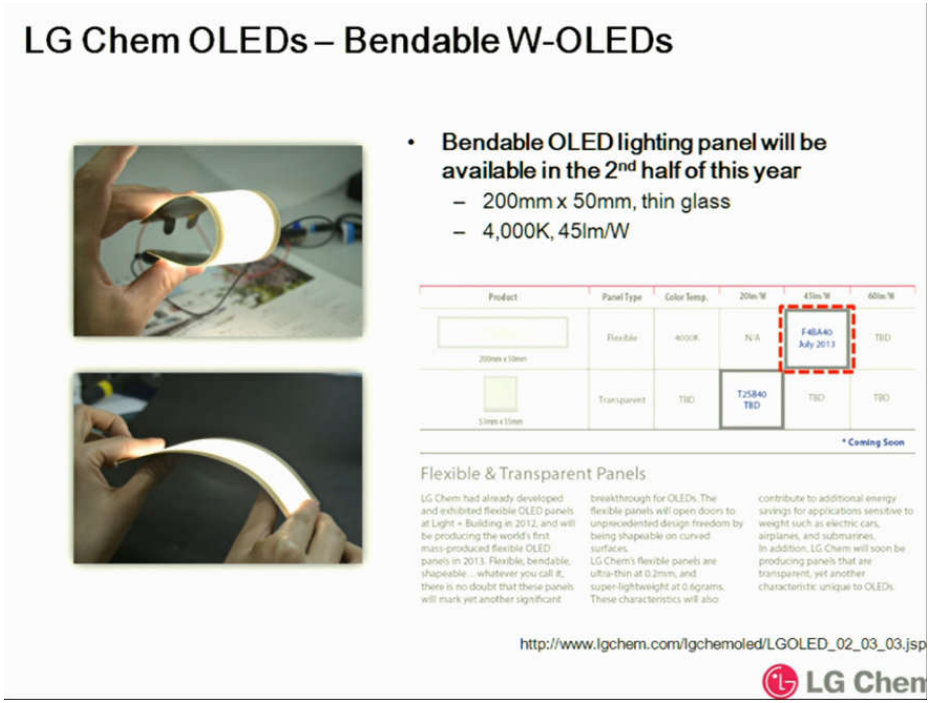




Challenges in building flexible OLED panels

Review of state of technology

- Thin Glass OLEDs
- LG Chem introduced in 2013, but apparently no longer selling
- Fraunhofer demonstrated in 2015, but identified challenges with reliable low resistance electrical contacting



J Moon et al., 2013 Society for Information Displays

Christian May, OLEDs World Summit, 10/28/2015

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Challenges in building flexible OLED panels

OLEDWorks/Corning approach

- Glass is established low cost substrate for OLED lighting
- Cost is the major inhibitor to OLED lighting adoption
- “Bendable” is significant and sufficient improvement over no curvature
- Sheet processing is sufficient for initial OLED lighting volumes. R2R processing capability will help drive down cost at high volume.
- Flexible glass OLEDs require improvements in glass properties and in flexible encapsulation and electrical contacting

Challenges in building flexible OLED panels

OLEDWorks/Corning approach

- Joint development program between OLEDWorks and Corning
  - Develop process and equipment technology needed to manufacture flexible OLED lighting panels on Willow glass
- Corning responsible for
  - Willow to Carrier bond/de-bond process and equipment
  - Integrated substrate materials, processes and equipment
  - Singulation process and equipment
- OLEDWorks responsible for
  - OLED fabrication
  - Encapsulation materials, processes and equipment
  - Panel finishing (EEL, electrical contacting, packaging and testing)

Challenges in building flexible OLED panels

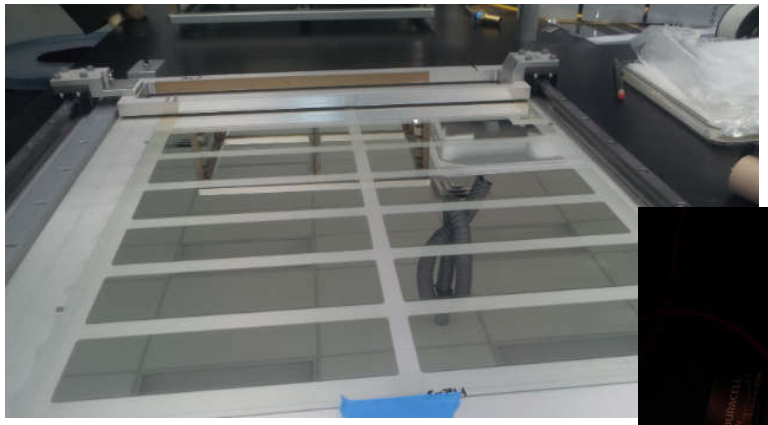
Initial issues

- 2-up 43mm x 102mm panel design, 102mm x 102mm substrate
- 0.1mm Willow bonded to 0.7mm carrier substrate by Corning
- OLED coating and encapsulation by OLEDWorks
- Poor and variable bonding quality with low debonding yield
- Able to demonstrate first working samples
- Poor overall yield – breakage when flexed

OLEDWorks Panel

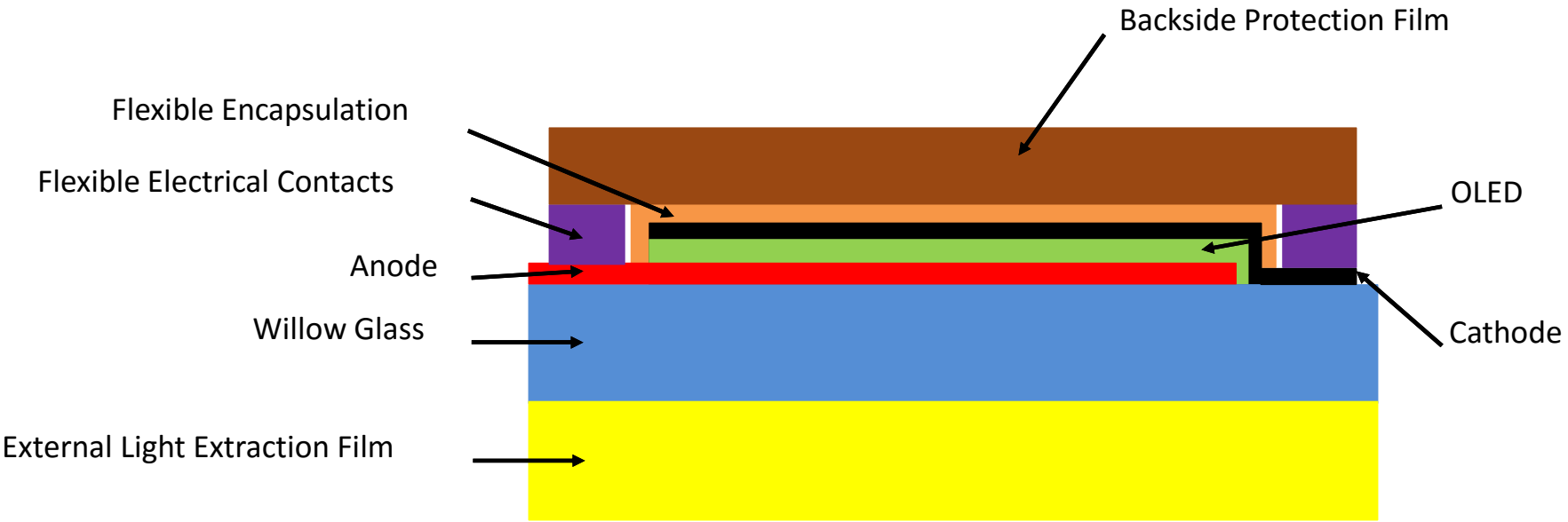
Current status

- Corning developed improved bonding process for Gen2/2.5 samples
- Corning developed improved singulation process
- OLEDWorks coated OLEDs onto Gen2 Willow on Carrier (65mm x 175mm panels)
- OLEDWorks developed improved processes and materials for flexible encapsulation, electrical connection, and packaging



OLEDWorks Panel

Current structure



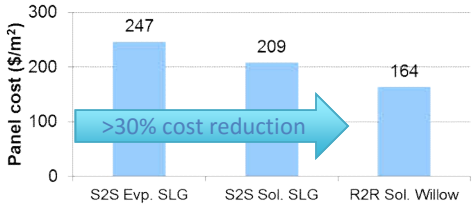
Flexible Integrated Substrate Value

Three key value propositions for Corning Willow Glass based Integrated substrate

2016 Extraction Efficiency Target
2.5x (50%)
(best in industry)

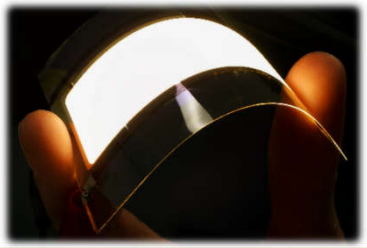
❶ Integrated substrate

- ❑ Internal light extraction layer (ILEL) provides 40% (2x) light extraction leading to higher efficiency
- ❑ Reduces cost and complexity for panel makers by providing a deposition-ready substrate



❷ R2R process capability → >30% cost reduction

- ❑ Drives faster market adoption by lowering cost
- ❑ Provides substrate with highest barrier property in a R2R format



❸ Unlocks the conformability value element

- ❑ Conformable products are important to applications such as hospitality and transportation

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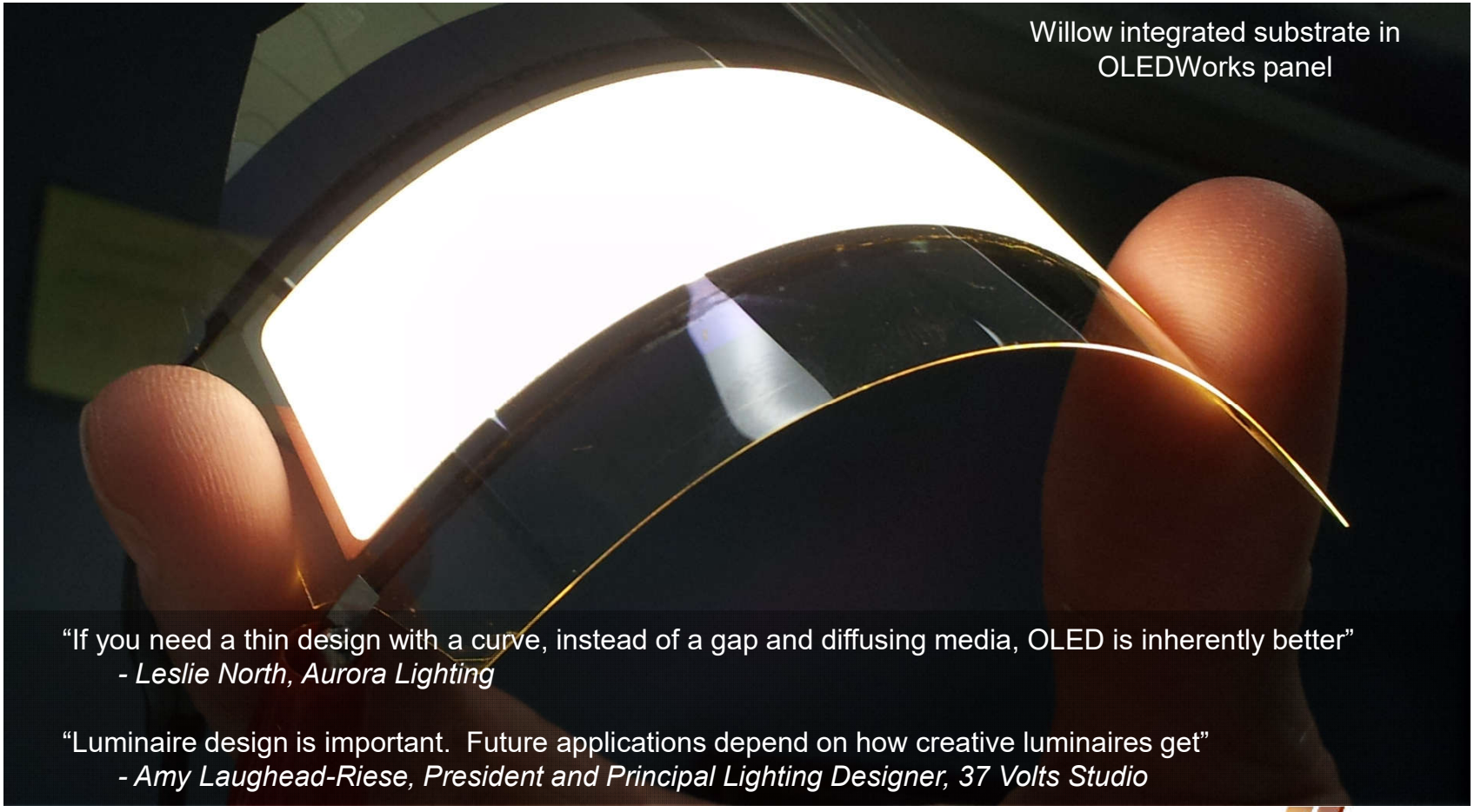
Flexible Integrated Substrate Value

Flexible glass unlocks the conformability value element for OLED lighting



"If you need a thin design with a curve, instead of a gap and diffusing media, OLED is inherently better"
- Leslie North, Aurora Lighting

"Luminaire design is important. Future applications depend on how creative luminaires get"
- Amy Laughead-Riese, President and Principal Lighting Designer, 37 Volts Studio

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Summary

- Solid State Lighting is the Future
- Thinness, Lightness and Flexibility of OLED will be a Key Differentiator to LED
- Glass, Plastic and Metal Substrates each have Pros and Cons
- Willow Glass Enables Cost Effective Conformability
- OLEDWorks/Corning JDA is Developing the Processes and Equipment Needed to Manufacture Cost Effective Flexible OLEDs on Willow Glass