OLED Lighting Manufacturing Challenges

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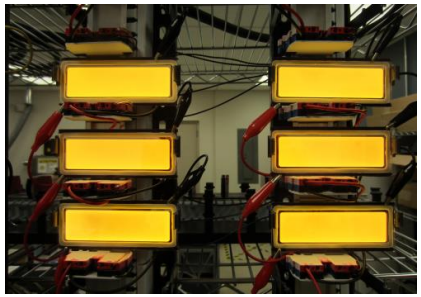
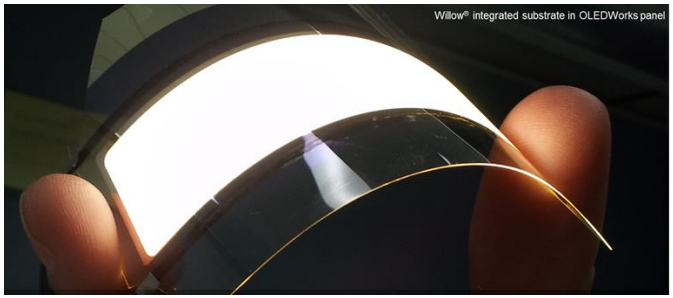
Outline

- OLEDWorks Introduction
- Status of OLED Performance for General Lighting
- Status of OLED Lighting Manufacturing
- Flexible OLED Lighting Panels
- Conclusions and Outlook

OLEDWorks introduction

- OLEDWorks LLC is OLED lighting manufacturer based in Rochester, NY
- On October 31st 2015, completed acquisition of Philips OLED lighting assets which are now its fully owned subsidiary, OLEDWorks GmbH
- Focus on manufacturing and R&D for OLED lighting panels
- DoE OLED test site for industry evaluations
- Target markets include all major professional and consumer applications

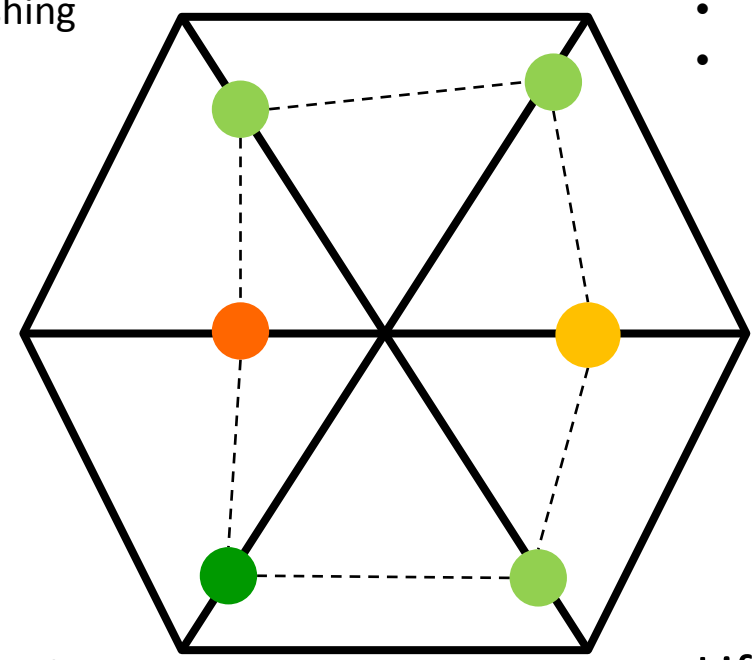




Status of OLED Performance for General Lighting

Design freedom
- Size, shape, flexibility
- Off-state, finishing

Light quality
- High CRI (80..95)
- Small angular dependence
- Good Uniformity (70..95%)



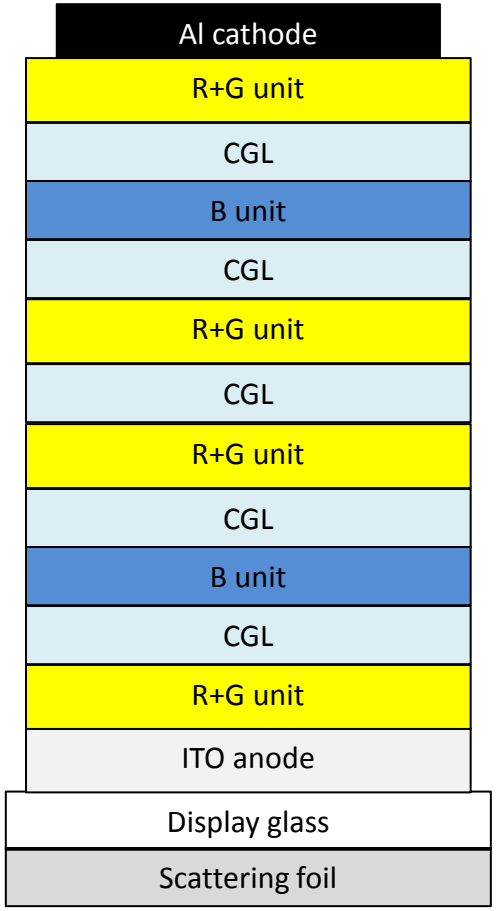
Cost (>10 lm/$)
- Materials
- Processing
- Yield

Efficacy (>50 lm/W)
- Stack materials & design
- Light out-coupling

Lumen output
- Stack design
- Size

Lifetime and reliability
- $L_XB_YC_Z$ (10-50 khr)
- Application conditions (≤50 °C)

Reference device – Current White Lighting Panels



Parameter	Value	Target
Voltage (V)	20	↓
Power (W)	7.4	↓
Luminous flux (lm)	300	→
Efficacy (lm/W)	40-50	↑
L70 (hr)	>10,000	↑
Luminance (cd/m^2)	8,300	→
CRI	80	↑

Status of OLED Lighting Manufacturing

- In the US, OLEDWorks is only lighting panel manufacturer.
- OLED lighting manufacturers outside US
  - **LG Display, Korea – White lighting panels**
  - Kaneka, Japan – White and colors; small production
  - Konica Minolta, Japan – Flex R2R production and color changing panels
  - First O-Lite, China – White panels
  - Black Body, France – Custom installations
  - Osram, Germany – Automotive

Manufacturing Challenges

1. Internal Light Extraction Substrates
2. Thin Film Encapsulation
3. Control of OLED Deposition

Manufacturing Challenges

1. Increase Efficacy while maintaining lifetime, reliability, high yield, and without significantly increasing cost
   - We are working with several vendors of Internal Light Extraction substrates
     - We have a DOE project to evaluate and select an internal light extraction substrate, and to deliver 80 lm/W panels to Acuity for a luminaire
       - See our poster at tonight's poster session.
   - The good news is that the efficacy goals appear to be achievable.
   - Problems/concerns that are encountered with internal light extraction:
     - Increased occurrence-rate of shorting during LT70 lifetime
     - Today internal light extraction processes add significant cost
     - Concern about uniformity and particles if extraction layers need patterning

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- **Continue support for Internal Light Extraction Substrate work.**

Manufacturing Challenges

2. Thin-film Encapsulation – suitable for Flexible OLEDs
   - Existing TFE processes work for rigid substrates
   - Alternative processes are required which have:
     - Lower capital cost for equipment
     - Lower operating cost for equipment
   - Alternative processes are required for flexible/bendable substrates

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- **Continue support for Thin Encapsulation, for Rigid and Flexible/Bendable substrates**

Manufacturing Challenges

3. OLED Deposition – for tighter control of color point
   - Sensing and control of vapor deposition rates (for vacuum thermal evaporation systems)
     - Less noise than current QCM system
     - Longer lifetime than current QCM systems
   - While market growing, we need the ability to change formulations and products frequently and rapidly at lower cost
     - This requires machines to change operating points quickly.

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- **Continue support for Manufacturing – Vapor Deposition Rate Sensing**

Flexible OLED Panels

- Thin Flexible/Bendable OLED Lighting Panels
  - LG has announced flexible panels on plastic base
  - Konica Minolta has built a large machine for making OLEDs on plastic R2R
  - We are working with Corning to develop technology for products using Willow® glass
- Challenges
  - Bonding flex substrates onto carriers, and de-bonding from carriers after deposition – with no effect of substrate and OLED processing steps
  - Improve robustness of final panels - to prevent breakage in customers hands and during installation into fixtures
  - Requires robust flexible encapsulation and low-cost flexible electrical connections

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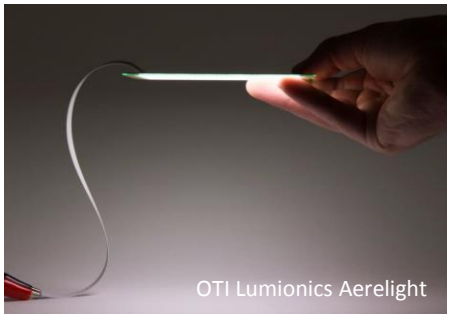
- **Continue support for Flexible/Bendable process work**
- **Continue support for Flexible/Bendable luminaire product**

Conclusion and Outlook

- OLED lighting is ready for wide application – efficacy, lifetime, quality
- Overcoming manufacturing challenges are critical to the cost-reductions and the new products necessary for market growth
- Flexible lighting products are necessary for development of exciting new OLED products. This need process development and luminaire development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