



The Clear Solution®

*High Refractive Index Materials in Lighting  
Applications*  
**2019 SSL R&D Workshop**

Dr. Selina Monickam

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# Outline

- Company Overview
- High Refractive Index (HRI) Material
- Application of HRI Materials in OLED Lighting
- OLED Device Results
- Conclusion
- Acknowledgements

# Company Overview

## Disruptive Technology

- Technology leader in Next Generation High-RI Nanocomposites

## Key Markets Served

- OLED Display, HD Display, OLED Lighting, LED Lighting

## Customers & Partners

- 50+ Leading Device, Advanced Materials, & Consumer Electronics Companies

## Manufacturing

- 5 MT Pilot Baltimore, MD
- 40 MT Full-scale, PA, 4Q18

## Locations

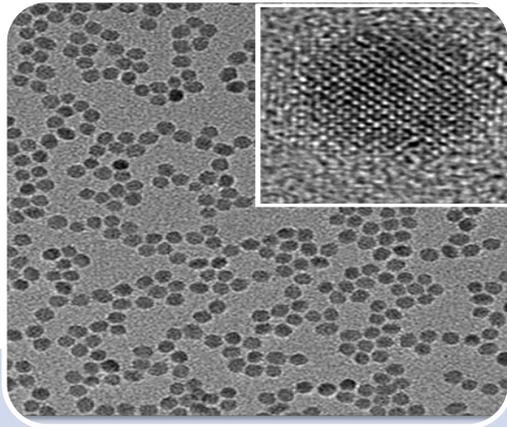
- Baltimore, MD - HQ
- Taipei, Taiwan - Sales

## Distributors

- Korea, Japan, Taiwan



# High Refractive Index Material (PixClear®)



## ZrO2 Nanocrystals

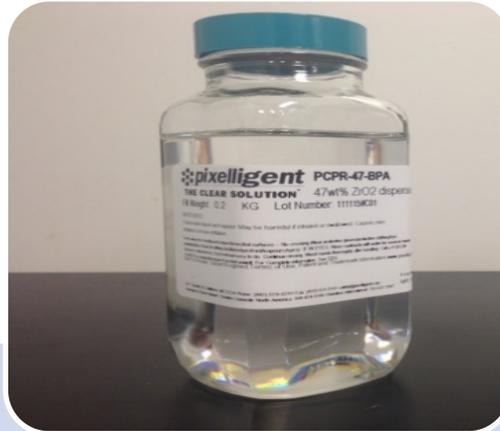
Uniform 5~10 nm spheres

High RI

Transparent

Not photoactive

Bandgap ~5.8 eV



## Nanocrystals in polymer matrix

Disperse in monomer/oligomers with and without solvent

High transparency (>80%)

Low viscosity



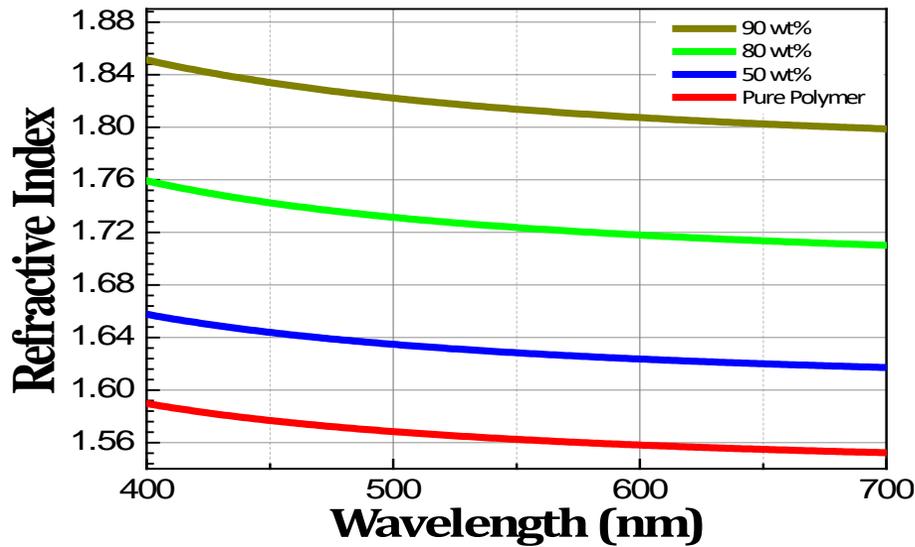
## Nanocomposites

Molded into HRI structures such as thin films, lenses...

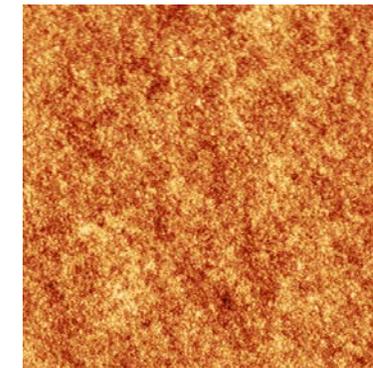
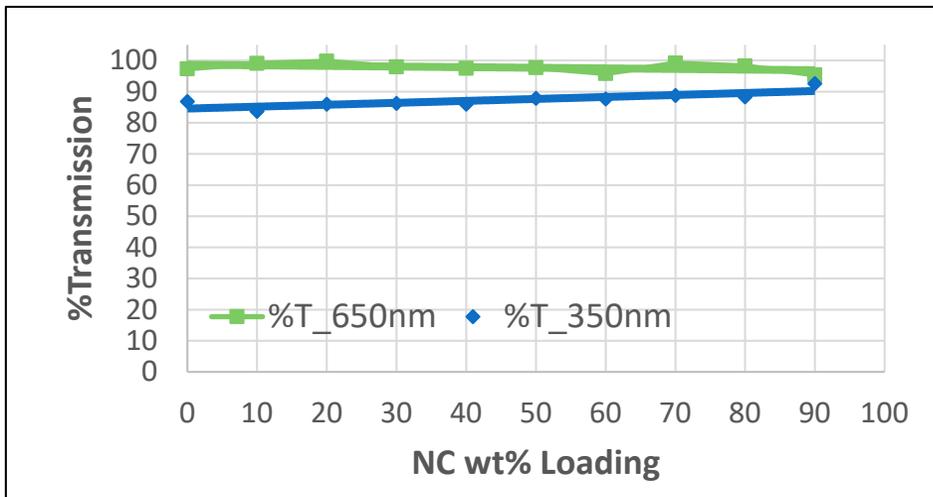
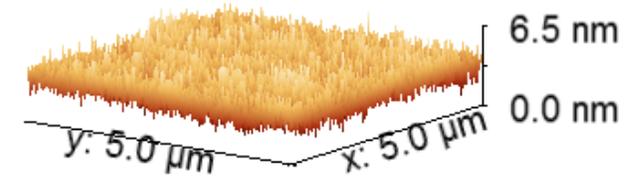
Solution processable

Compatible with many different deposition methods

# High Refractive Index Nanocomposite



High RI, High Transmittance, and Smooth Surface

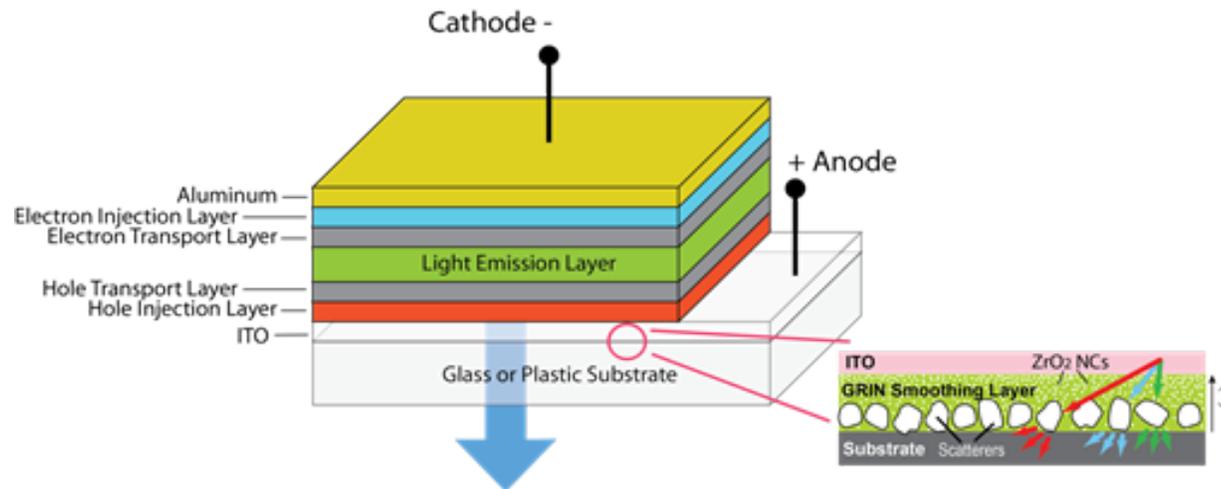


Ra = 0.529 nm  
 RMS = 0.665 nm  
 Rz = 6.455 nm

5 x 5 µm scan area

# Pixelligent's HRI Material in OLED Lighting:

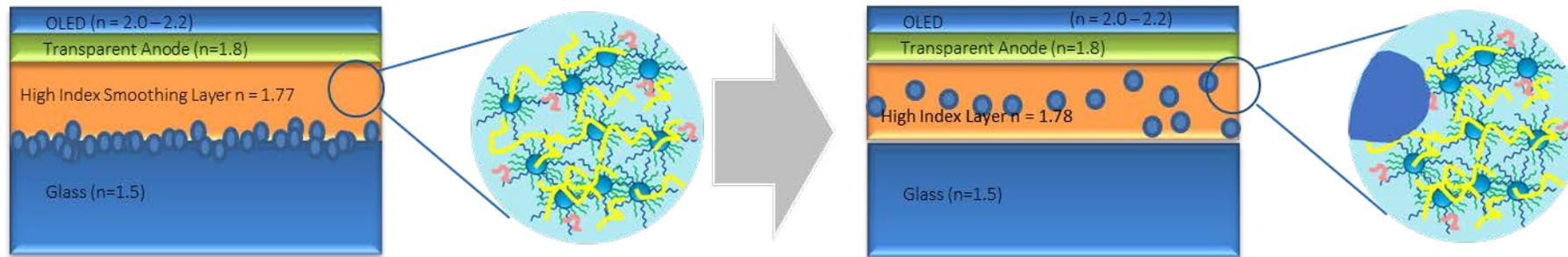
- for Internal Light Extraction (ILE) Layer



- High Refractive Index - reduces index mis-match between the ITO and the substrate
- Low surface roughness
  - smoothing layer for scatterers or textured surfaced
  - Binder for suspending scatterer particles

# HRI Material for Light Extraction

Developed 2 HRI Formulations

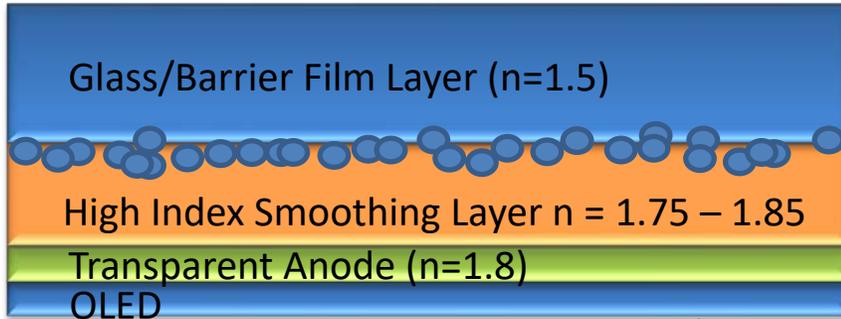


High Refractive Index Formulation

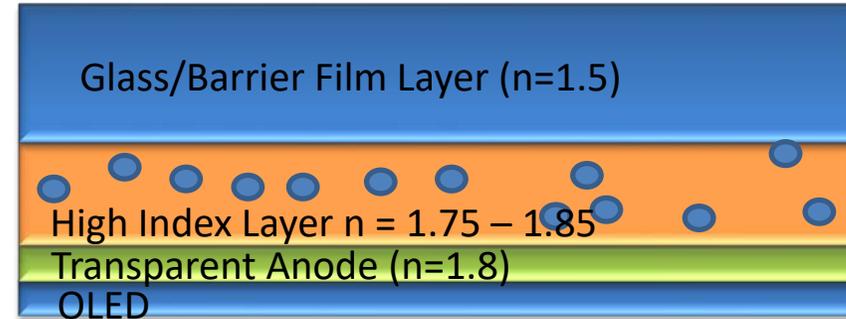


High Refractive Index Scatterer Formulation

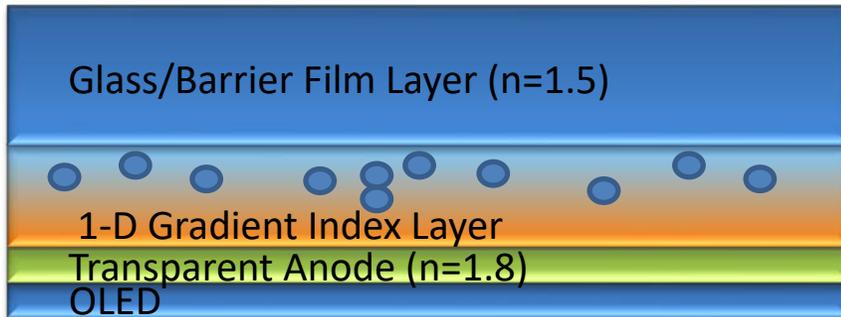
# Light Extraction Structures



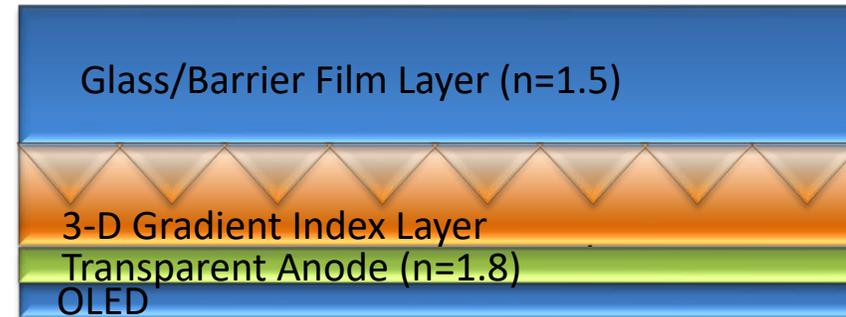
Generation 1 ✓



Generation 2 ✓

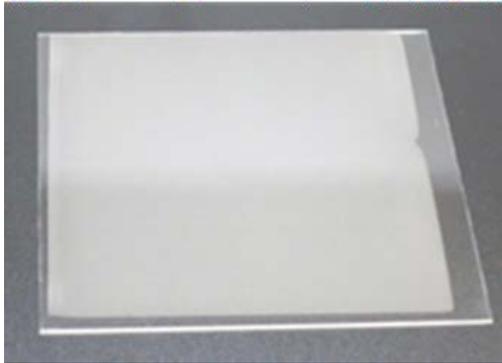


Generation 3 ✓



Generation 4 ✓

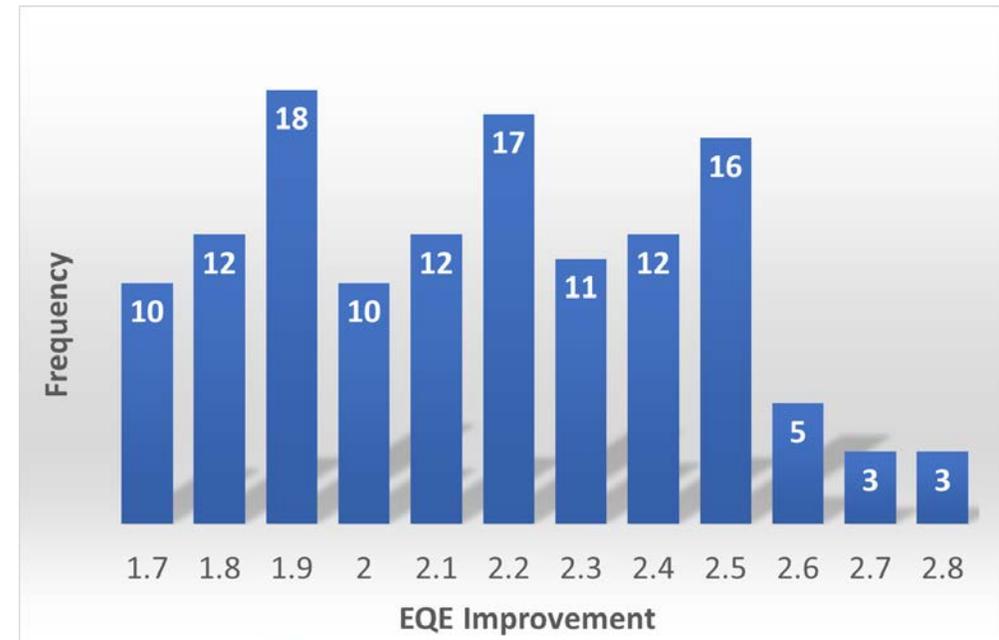
# OLED Lighting Device with HRI ILE



Formulation coated on glass

As high as **2.8X Improvement in Light Extraction** in Device with Pixelligent ZrO<sub>2</sub> ILE compared to controls

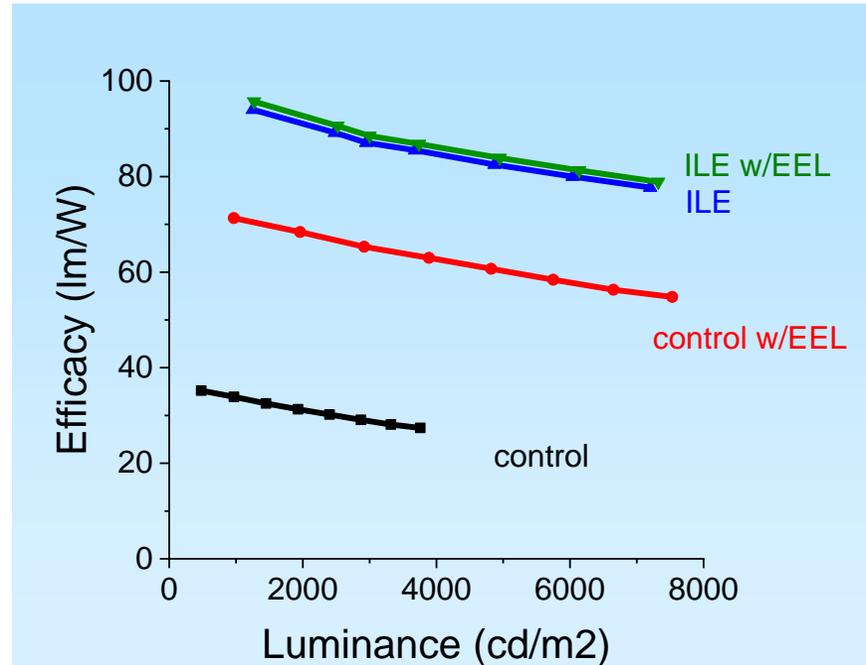
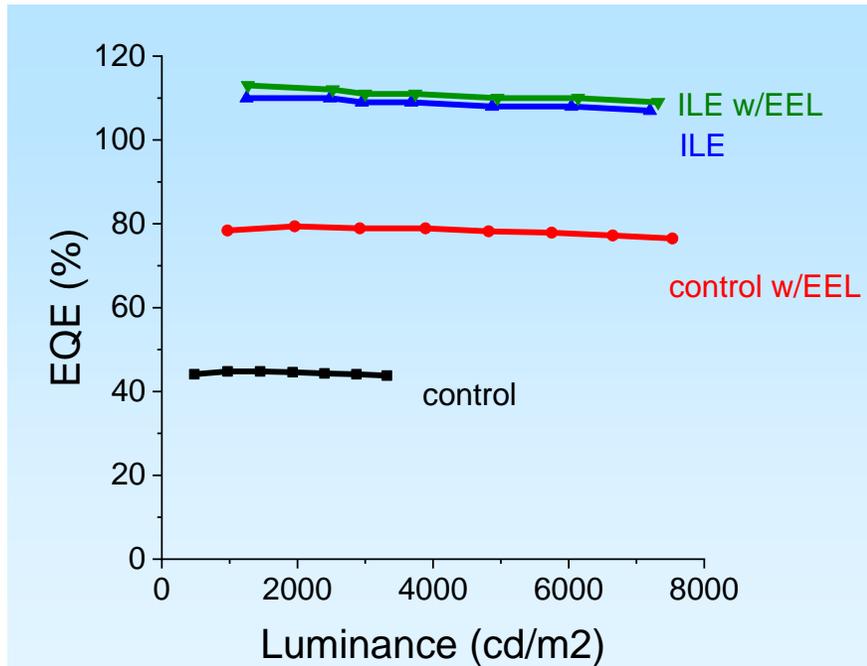
Extraction efficiency



(Source: OLEDWorks)

# OLED Lighting Device with PixClear HRI ILE

Extraction efficiency and Efficacy as a function of Luminance

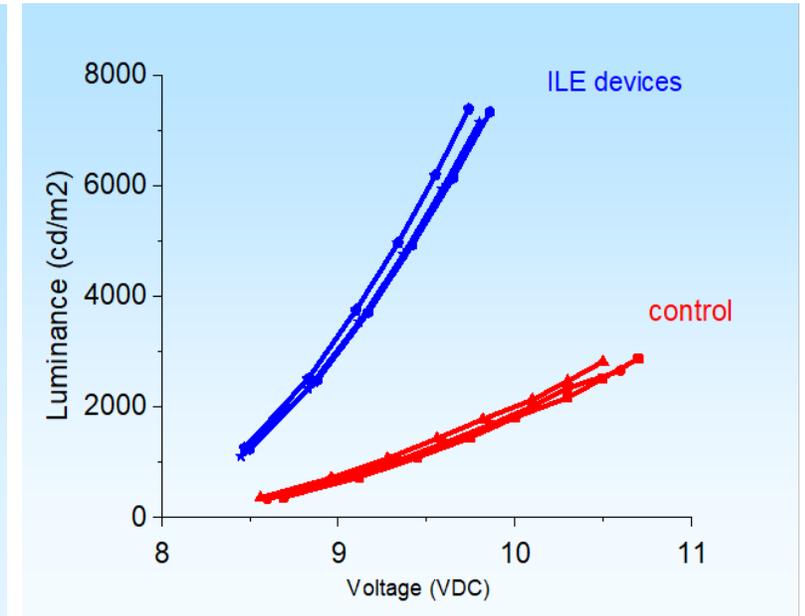
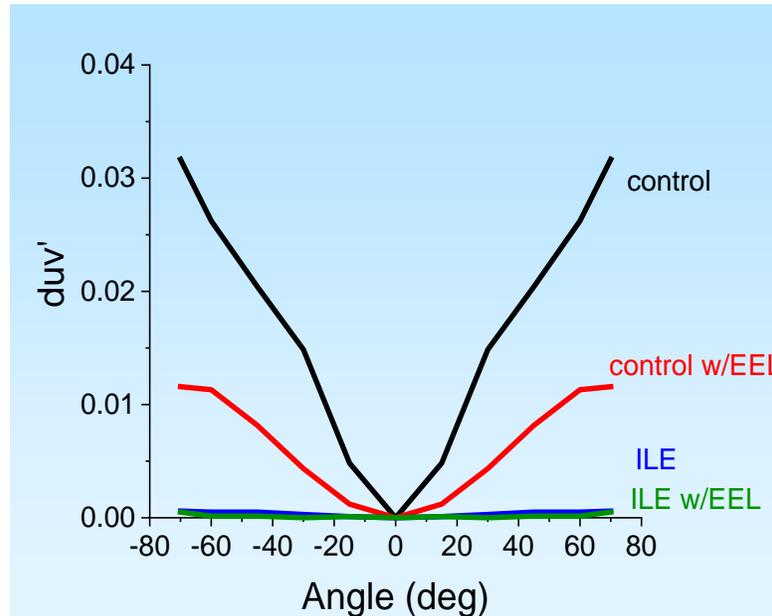
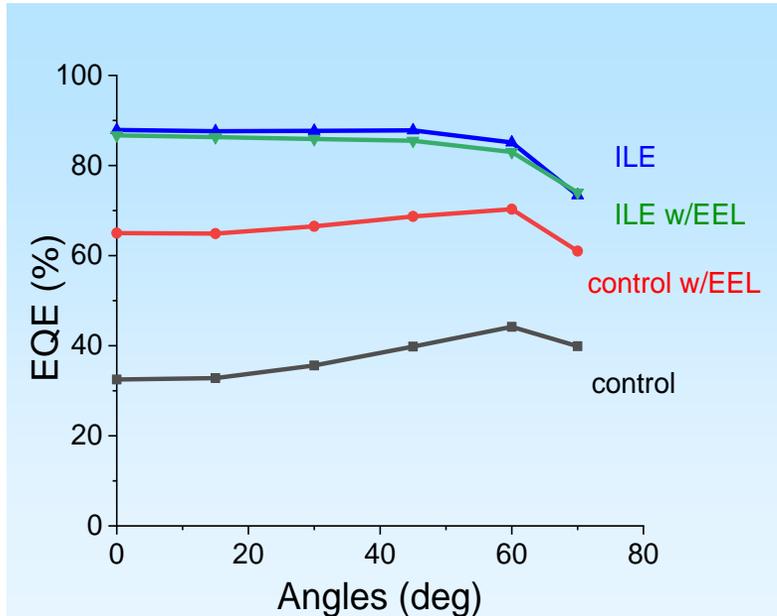


HRI integrated devices

- ✓ Uniform extraction efficiency and efficacy
- ✓ Can achieve ~90 lm/W at 3000 cd/m²

(Source: OLEDWorks)

# OLED Lighting Device with HRI ILE

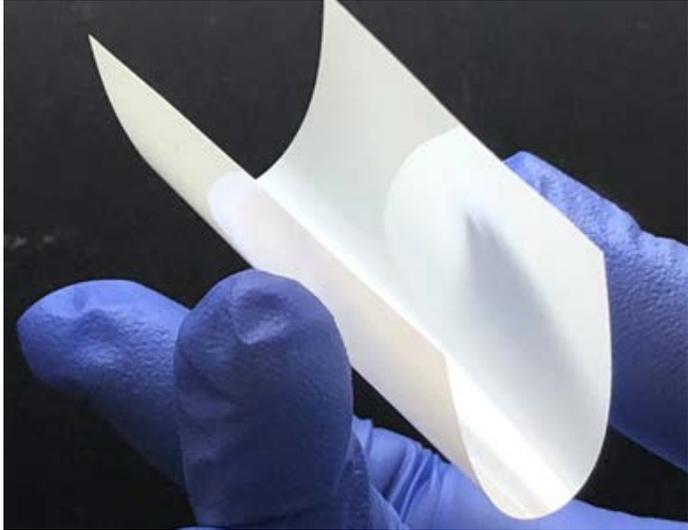


## HRI integrated devices

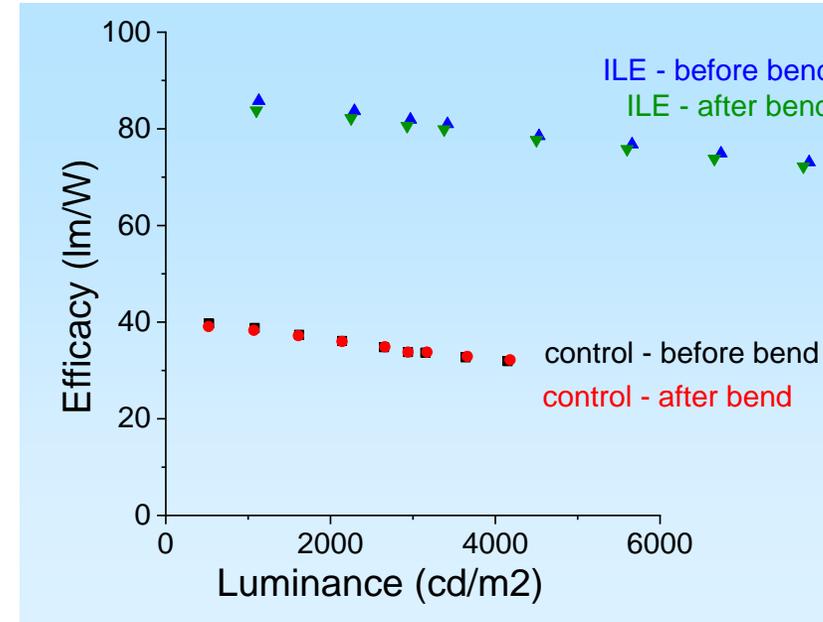
- ✓ Uniform extraction efficiency over angles
- ✓ Much reduced angular color variation (<0.001)
- ✓ Much lower voltage at high brightness
- ✓ >50,000 hours lifetime based on accelerated tests

(Source: OLEDWorks)

## HRI ILE in flexible OLED Lighting Device



Formulation coated on polyimide substrate

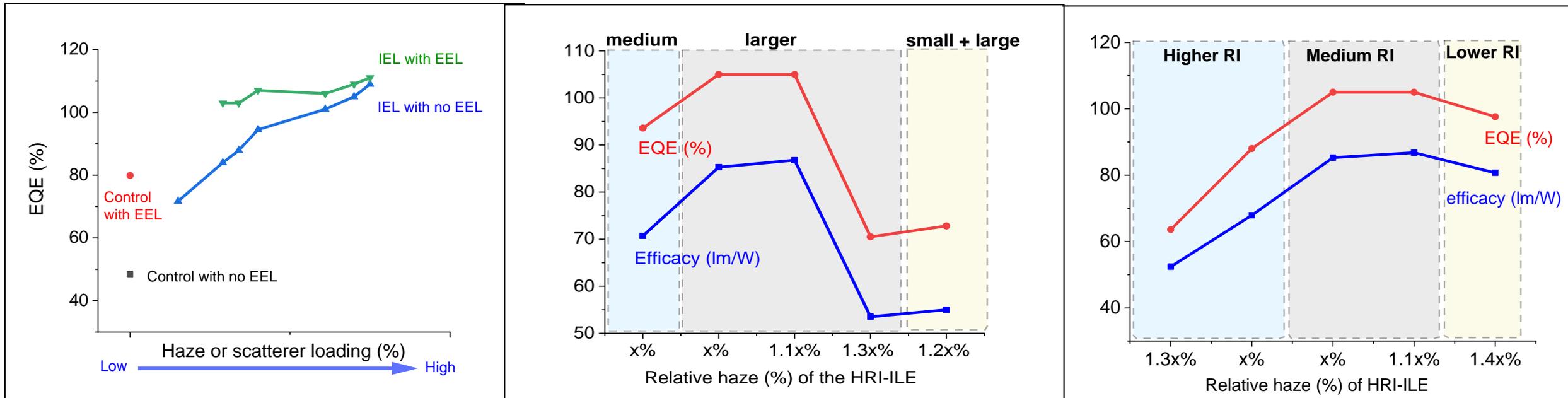


HRI integrated devices

- ✓ Minimal to no change in efficacy after device is bend once around 50 mm radius

(Source: OLEDWorks)

# Optimization of ILE Properties



Properties that can improve device efficiency

- Scatterer concentration
- Scatterer size
- Binder RI

(Source: OLEDWorks)

### Shown Feasibility

- ✓ Working OLED devices
- ✓ High extraction efficiency (~50%)
- ✓ High lumens (~90 lm/W)
- ✓ Uniform efficiency over all angles
- ✓ Better angular color uniformity
- ✓ Flexibility
- ✓ Passed preliminary reliability test



### Next Steps and Challenges

- Prove ILE integrated OLEDs on larger panels
  - Processibility
  - Compatibility with other layers
- Uniform ILE surface and low surface roughness
- Low Moisture permeability



**Commercialize**



### Room for more improvements

- Optimum scatterer size
- Optimum binder RI
- Optimum scatterer RI



## Conclusion

- High Refractive Index is needed to improve light extraction efficiency
- PixClear High Refractive Index structures can improve efficiency in OLED lighting devices achieving as high as 90 lm/W efficacy
- The formulation is solution processable and can be used for both rigid as well as flexible substrates

## Acknowledgements

- DOE SBIR Phase I, Phase II and phase IIB  
Award #DE-SC0011295
- DOE SSL Award #DE-EE0006673
- DOE SBIR Phase I Award #DE-SC0017038,  
DE-SC0018604
- OLEDWorks LLC
- FROST & SULLIVAN Manufacturing Award



A growing number of companies are working hard to create and strengthen an SSL manufacturing base here in the U.S. [Read their stories.](#)



# Thank you

For more technical details, read our white paper:

<http://www.pixelligent.com/resources/>

**Dr. Selina Monickam (Product Development Manager)**  
stthomas@pixelligent.com