



The Clear Solution®

Internal Light Extraction Technology for OLED Lighting
2021 DOE-IES Lighting R&D Workshop

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Outline

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- PixClear® Material for Light Extraction
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- Summary

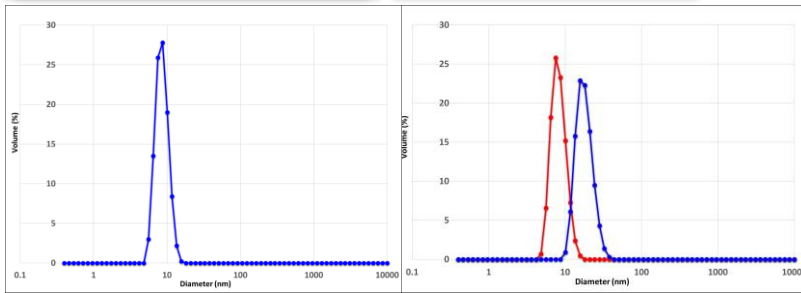
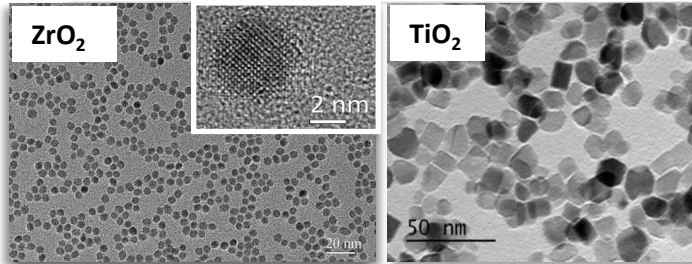
Pixelligent Overview

Technology	High refractive index material for high performance optical application (ZrO ₂ and TiO ₂ nanocrystal dispersions & formulations)
Key Target Applications	AR/VR, Displays such as OLED, micro-LED, QD, Lighting – OLED and LED, sensors
Locations	Baltimore, MD – HQ Taipei, Taiwan – Sales
Manufacturing	10 Ton annual capacity of PixClear® Zirconia nanocomposites 5 Ton annual capacity of PixClear® Titania nanocomposites 15-20 tons of formulated products
Distributors	Korea, Japan, Taiwan
IP	54 issued and pending applications



High Refractive Index Materials (PixClear®, PixNIL™, PixJET™)

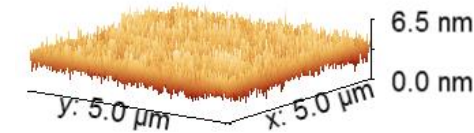
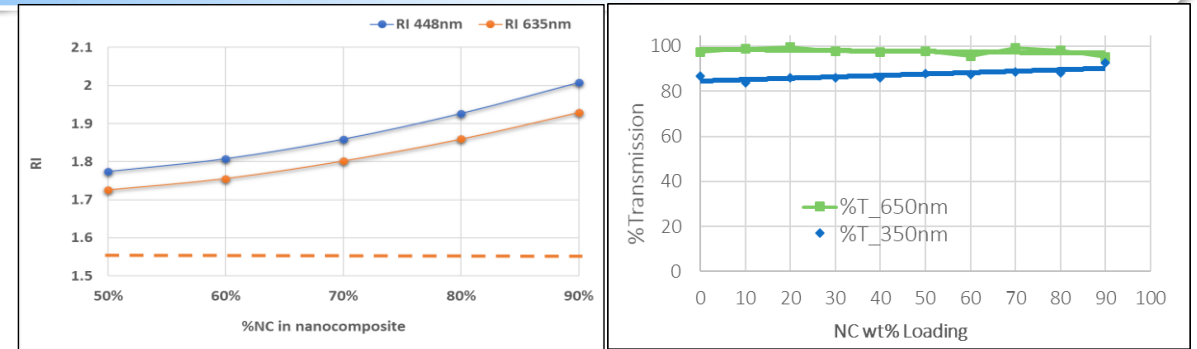
Nanocrystal /Dispersions



Formulation



Nanocomposite



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

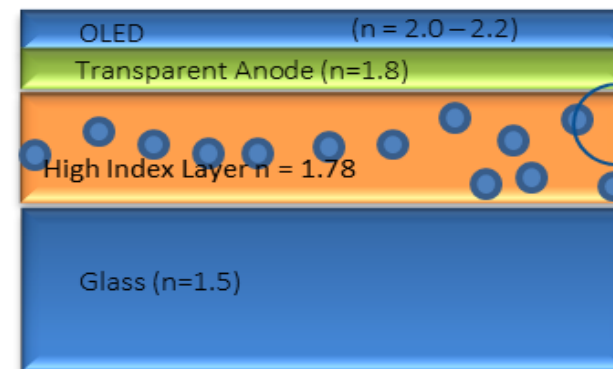
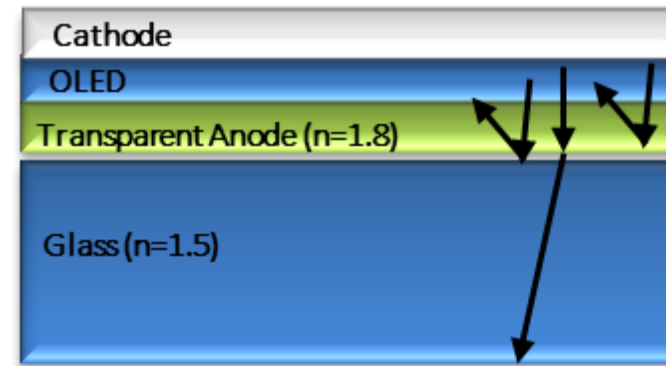
- Surface modified to be compatible in solvents, monomers, polymers
- Monodispersed – aggregate free

- PixClear® in Monomers/oligomers/polymer
- Increases the RI of the polymer

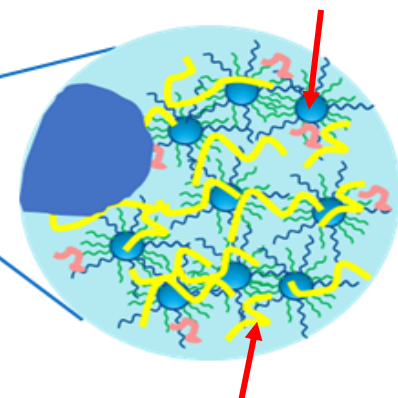
- Refractive index **1.77 – 2.0** (adjustable based on NC %loading in films)
- High transmittance
- Smooth surface
- Applicable for many optoelectronics applications

PixClear[®] for Light Extraction

- Major challenge of OLEDs – low light output (~20% - 30%)
- Most light is trapped within the device by “Total Internal Reflection”
- Light re-directed at the ITO/Substrate is more efficient
 - Access to most of the light
 - Minimal impact to device
 - Most mature manufacturing processes
- PixClear[®] High Refractive Index Formulation as an **Internal Extraction Layer (IEL)**
- Reduces index mis-match between the ITO and the substrate
- Scatterers randomizes the light and re-directs out of the substrate layer



ZrO₂ nanocrystal



polymer

Pixelligent's HRI Formulation for ILE

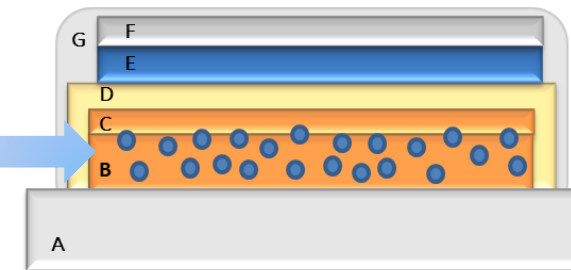
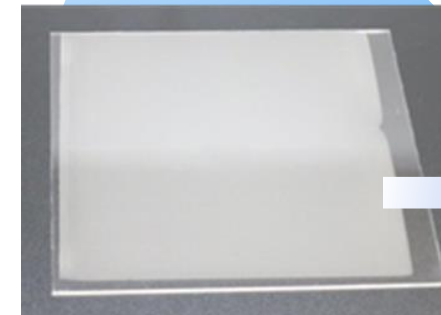
- SBIR Grants – developed a formulation for HRI-ILE layer
- Developed 2 HRI formulations
 - Scatterer formulation
 - Optimal scattering concentration to maximize light output at all visible wavelengths
 - Stable ink-jettable formulation
 - $R_a < 5 \text{ nm}$
 - Smoothing layer formulation
 - Provides surface roughness, $R_a < 2 \text{ nm}$
 - Index matching with ITO



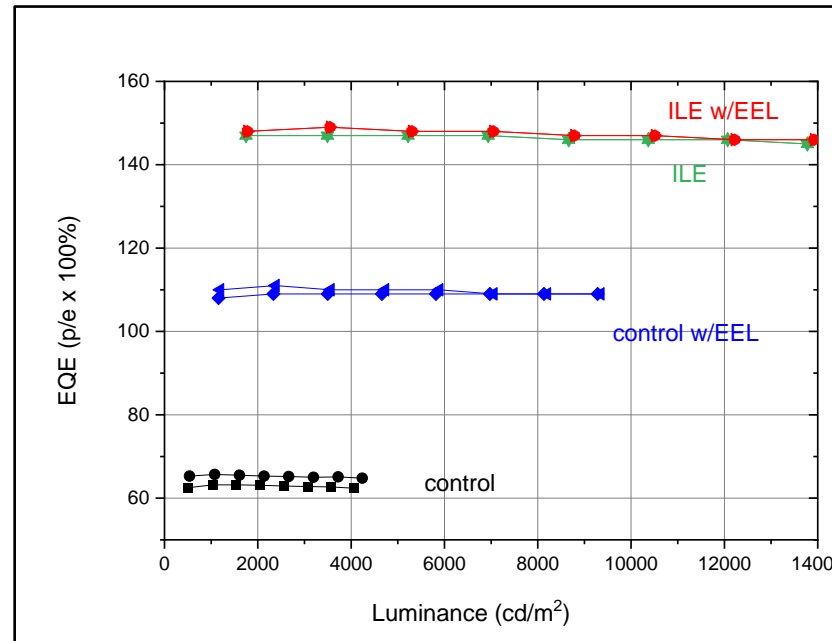
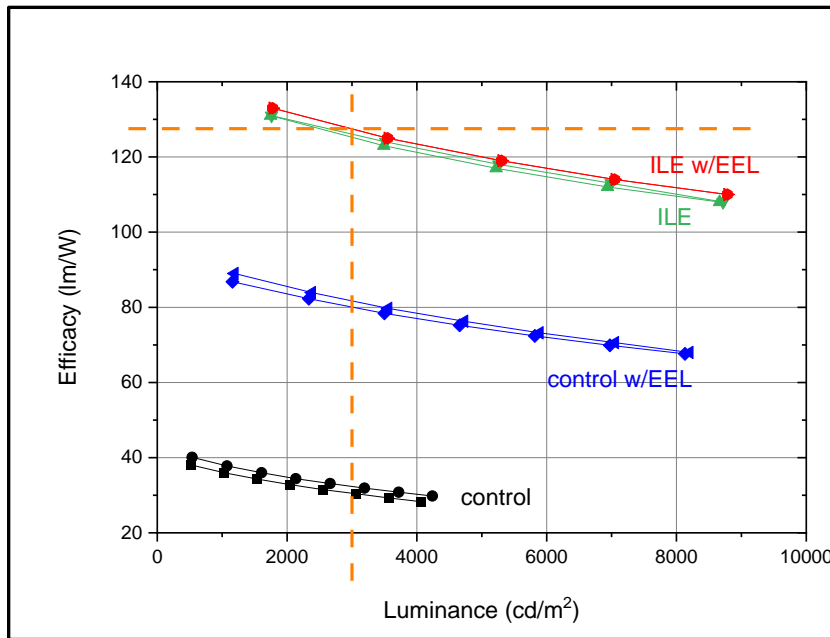
Scatterer formulation



Smoothing layer formulation



Pixelligent's HRI-ILE Integrated OLEDs

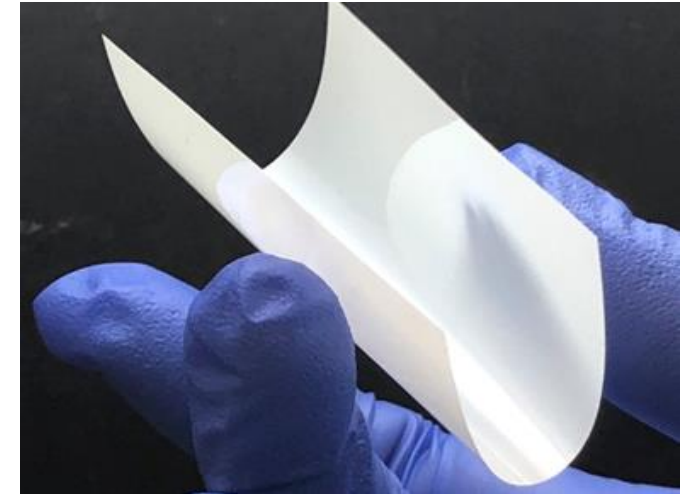
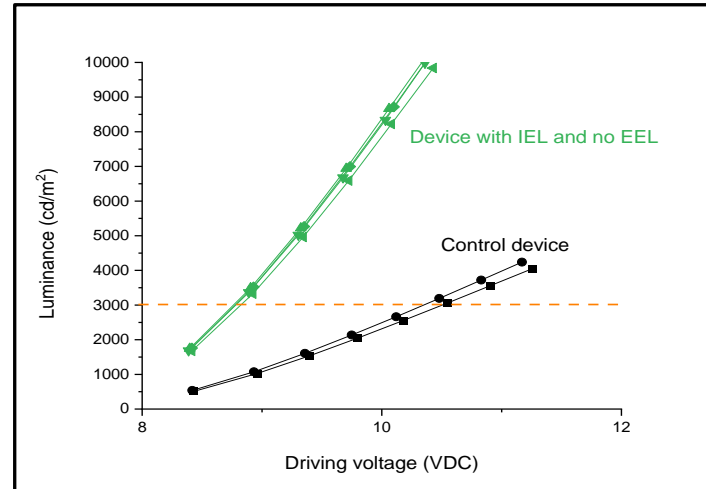
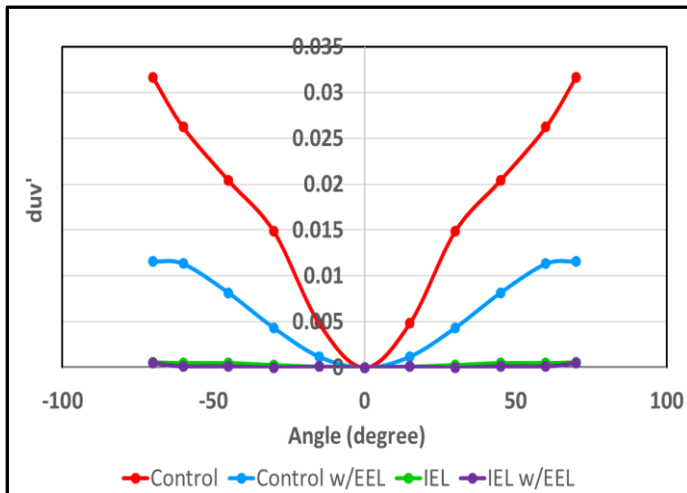


Data Source: OLEDWorks

- Functional 3-stack white OLED prototype devices
- Have achieved **~125 lm/W** at 3000 cd/m² without External Extraction Layer (EEL)
- 2.3X extraction efficiency based on EQE compared to control (~50% extraction efficiency)
- High efficiency and device performance achieved by optimization of the ILE and co-optimizing with the device structure

Pixelligent HRI-ILE Integrated OLEDs

Data Source: OLEDWorks



- ✓ Low D_{uv}'
- ✓ Uniform light distribution at all angle

- ✓ Lower driving voltage - Less waste heat and longer lifetime
- ✓ Low surface roughness of ILE
- ✓ ~50,000 hours under normal conditions at 3000 cd/m^2 and 1000 hours of 85/85 storage tests

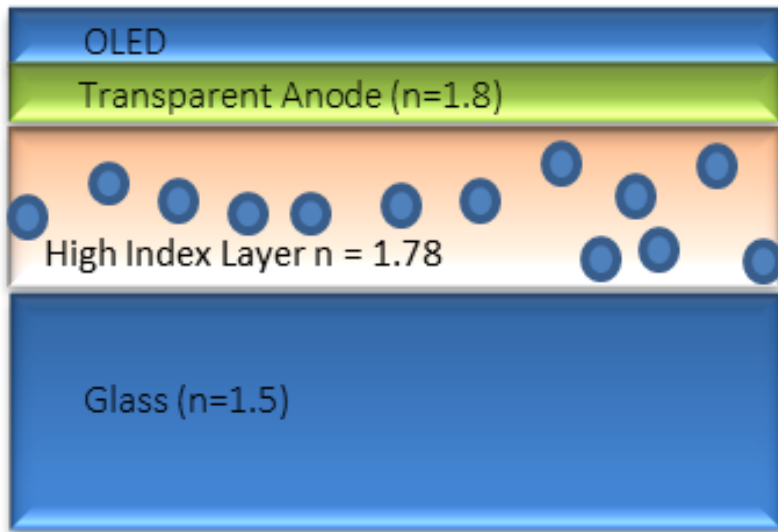
- ✓ Flexible
- ✓ Compatible with common plastic substrates
- ✓ 0.5% change in lumen after one time bend of the lit OLED around a 50-mm radius

- **High efficiency and reliability demonstrated in prototype devices**
- **Next step – Repeat these at commercially relevant sizes**

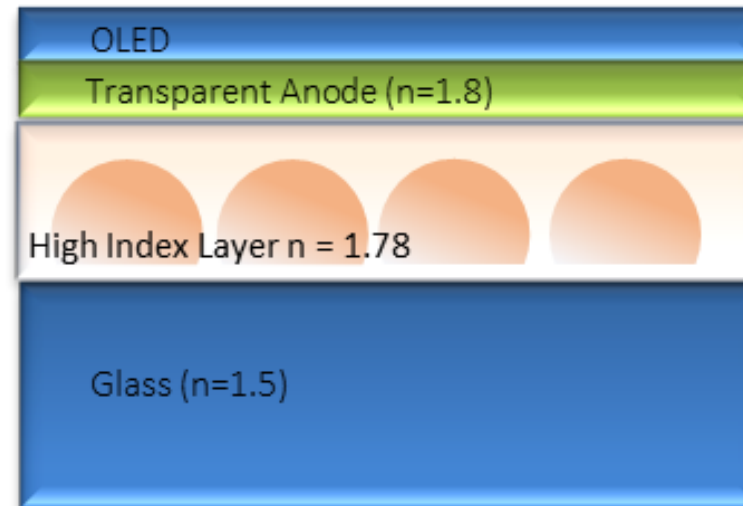
Other Proof-of-Concept Light Extraction Structures

Other approaches of light extraction structures for OLEDs include:

Graded Index ILE (RI is graded in z-direction)



Graded Index lens structure



Summary

- HRI ILE is necessary for light extraction – immediate solution to higher efficiency
- Pixelligent's ILE has demonstrated efficiency, reliability, uniform light distribution, and compatibility with general OLED manufacturing processes
- Refractive Index ranges from 1.77 – 2.0
- Using Pixelligent's material can lead to reduced cost
 - No need for additional EEL
 - Can reduce organic stacks
- Pixelligent's HRI-ILE can achieve:
 - Higher light extraction – up to 55%
 - Reduced cost
 - OLED lighting's success in market

Acknowledgments

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

Thank you

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