pixelligent

The Clear Solution®

Overview of Pixelligent's OLED Lighting Program

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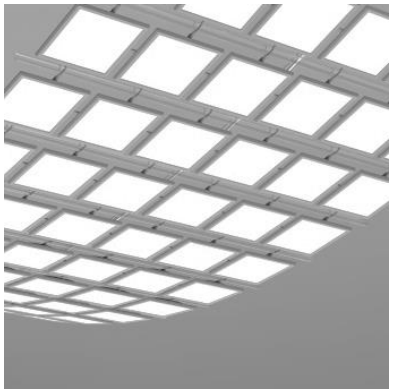
- OLEDWorks

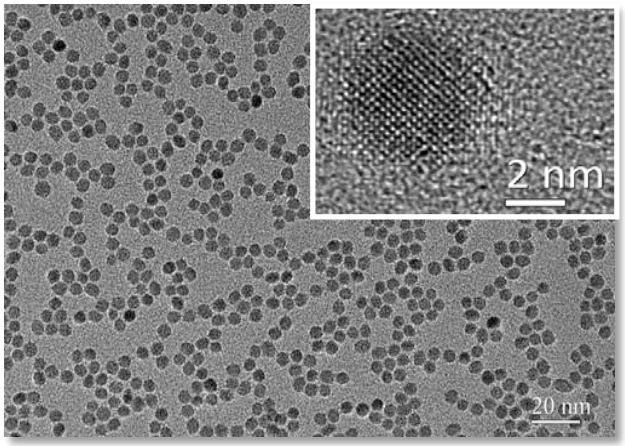
Corporate Highlights

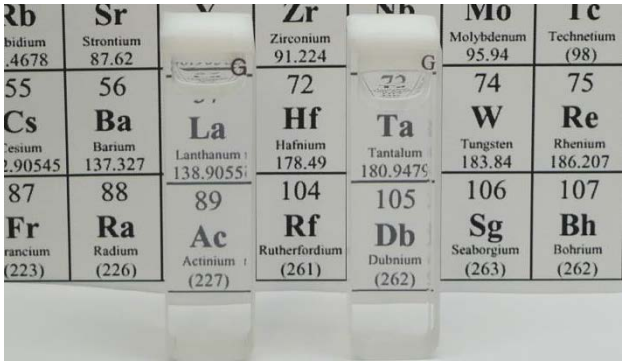
- Advanced Materials Company Leveraging Next Generation Nanotechnology
- Solid State Lighting and Optical Components and Films Markets
- State-of-the-Art Labs & Scaled Manufacturing
- $40M Invested in Product Platform
- Global Customer Base



Technology Leader in Nanocrystal Dispersions

- ZrO_2 Nanocrystal Dispersions
- Best Dispersions Available
  - High Loadings (>80wt%)
  - 95% Transmittance
  - Narrow Size Distribution (5 nm – 10 nm)
  - High RI (>1.8)
  - Tunable Viscosity
- Highly Scalable Process
- Strong IP Position





Left: 50wt% ZrO2 Nanocrystals | **Right:** Pure Xylenes

Manufacturing Process

Current: 5 Ton Pilot Line

Nanocrystal Synthesis

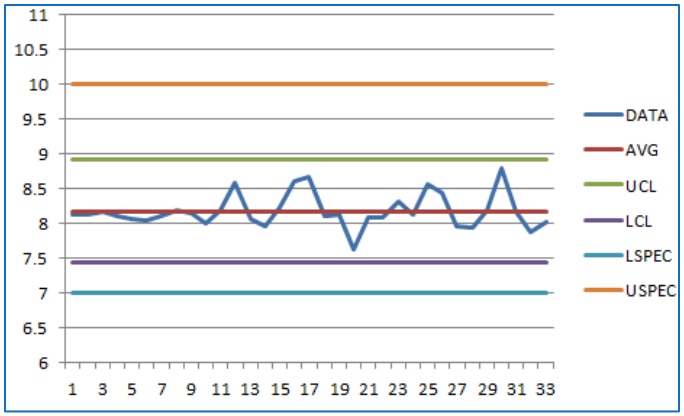
Capping

Purification and Dispersion

- Compliant with US & Int'l EHS Standards
- Q1 2016: 40 Ton Capacity On Line

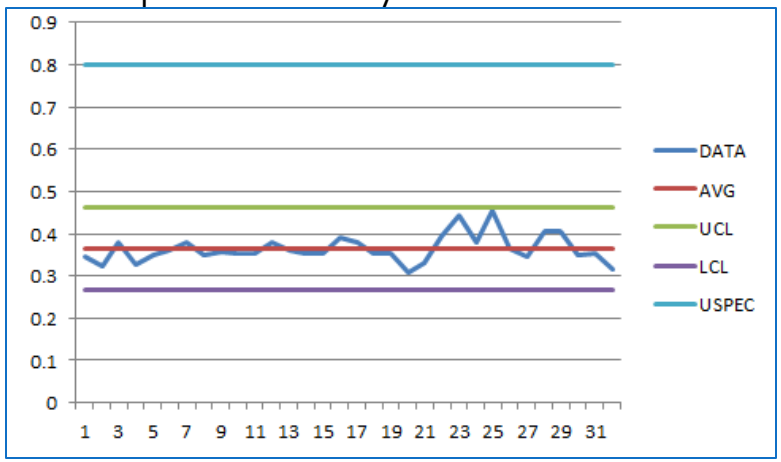
Process Stability– PixClear® PA

Mean Particle Size (nm)



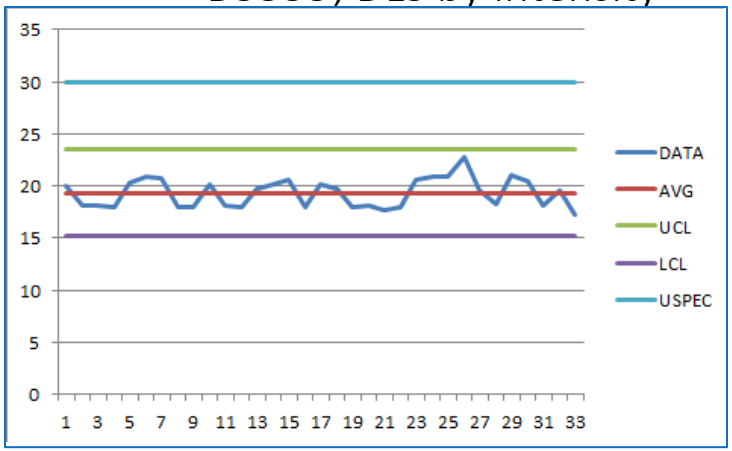
Spec: 7 – 10 nm

Optical Density at 400 nm



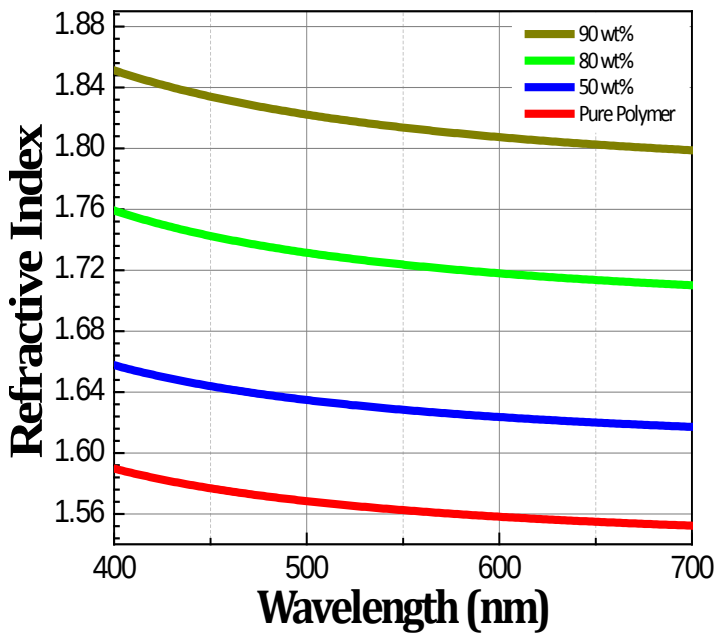
Spec: OD Less than 0.8

D9999, DLS by intensity

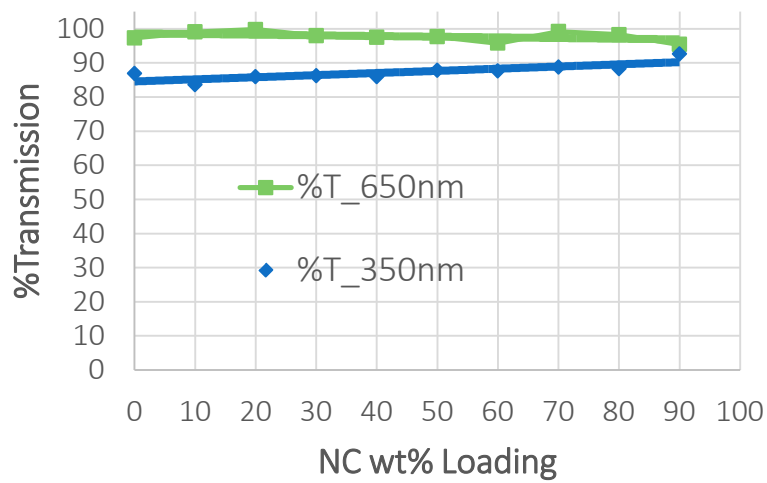


Spec: D9999 Less than 30 nm

PixClear® Nanocomposite Performance

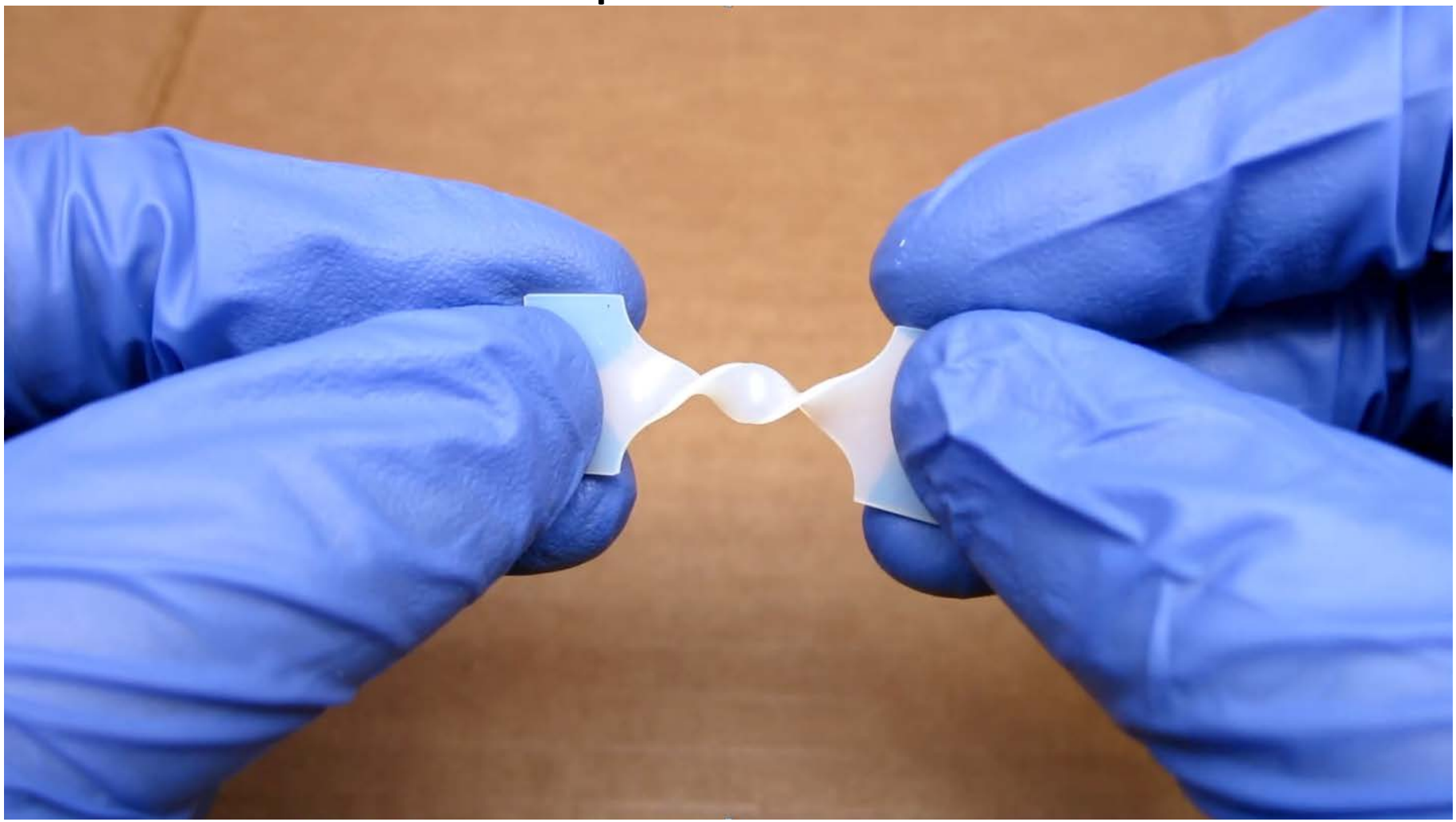


Loading	k	Haze
90 wt%	$<10^{-3}$	0.5%
80 wt%	$<10^{-3}$	0.5%
50 wt%	$<10^{-3}$	0.5%
0 wt%	$<10^{-3}$	0.4%



3 Micron Film in Acrylic Polymer
Measured by J.A. Woollam with VUV-VASE
Measurements on solid films

PixClear® Nanocomposite Performance



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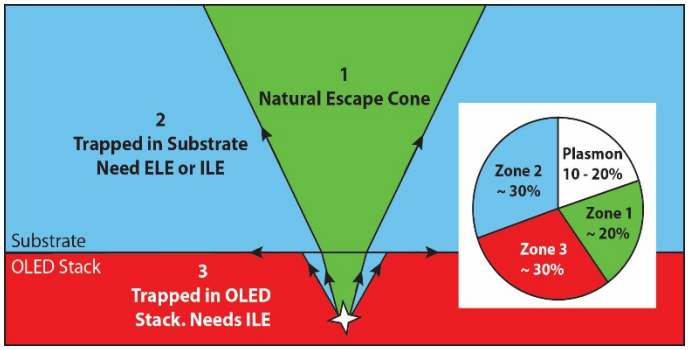
asking more from chemistry®

OLED Lighting Challenges & Solutions

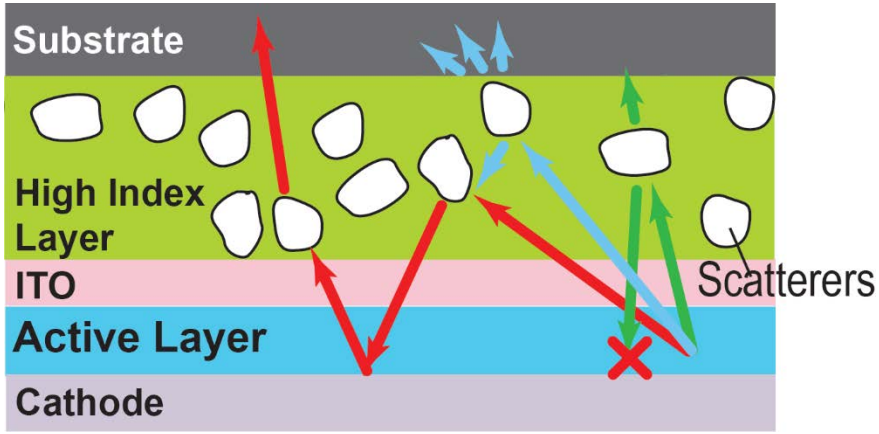
OLED Light Extraction Problem

- Total Internal Reflection traps most of the light in the device
- Some light escapes naturally – most needs to be redirected
- Different light extraction schemes vary in how and where light is redirected
- Broad agreement for next commercial products that ITO/Substrate interface is where light should be redirected and that scattering is how light should be redirected
  - Access to most of light
  - Minimal impact to device
  - Most mature manufacturing processes



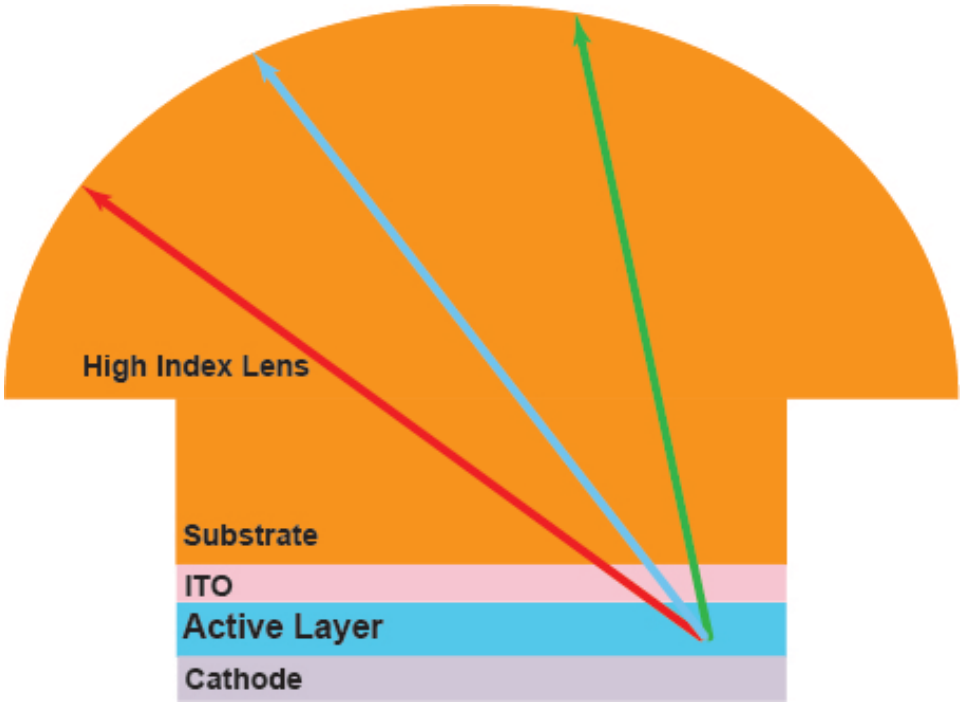
Scattering Approach

- Scattering is a random process
  - Limited ability to control which light gets scattered and direction of scattering
- Improved light extraction relies on multiple passes through the device
  - Maximize reflection at cathode
  - Minimize absorption
  - Minimize path length through device – enough scattering



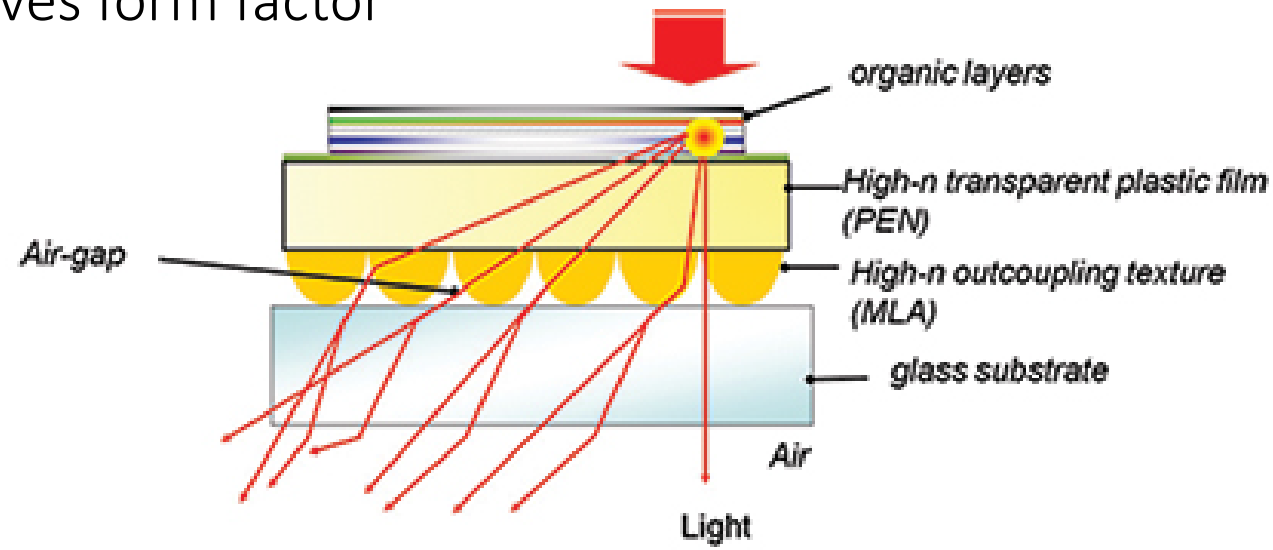
Focusing – High Index Lens

- Highest possible efficiency – all light extracted on first pass
- Absorption in device and cathode reflectivity are less important
- Not practical – too expensive and ruins form factor



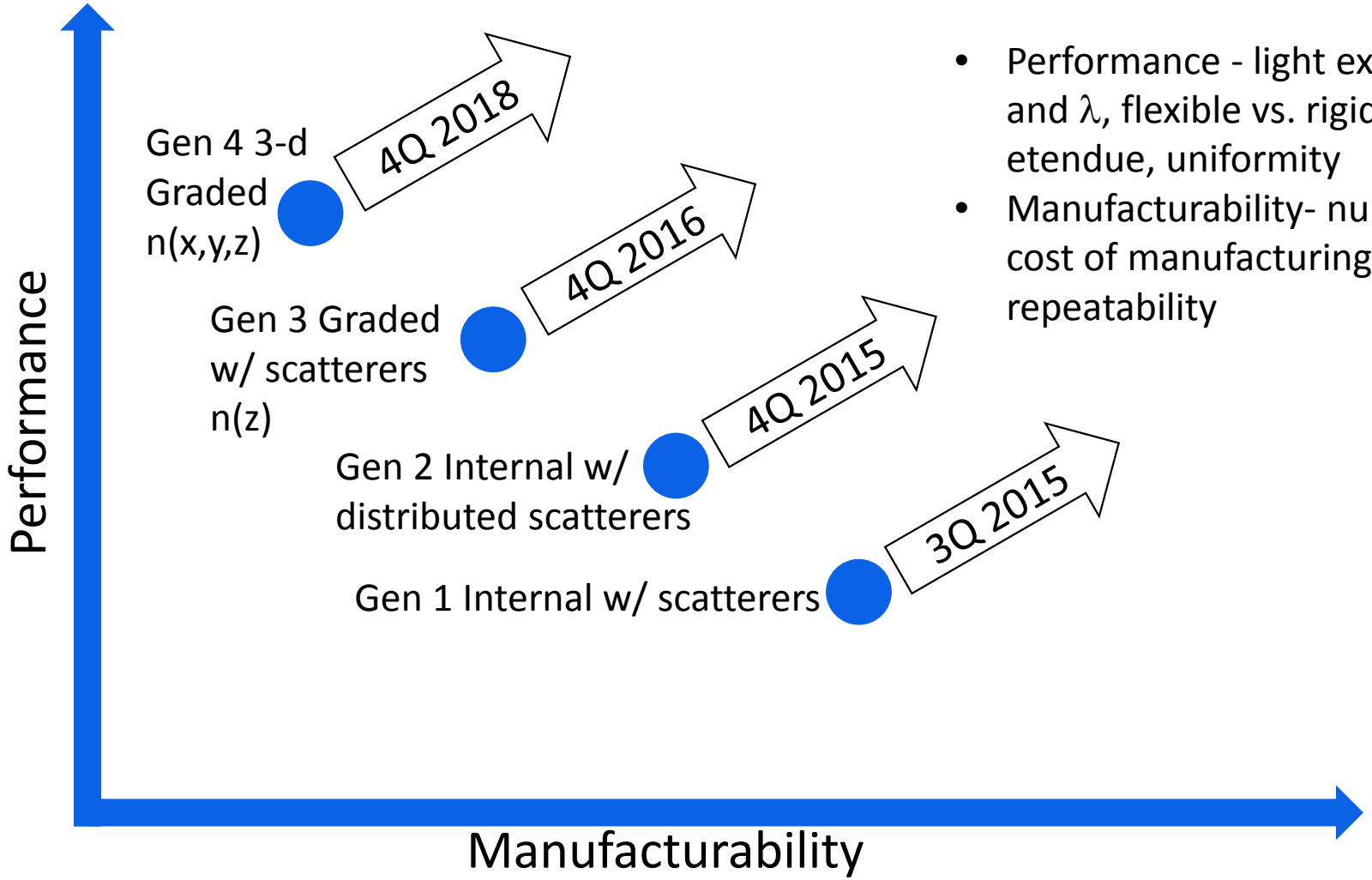
Focusing - Microlens

- Not a random process but light still makes multiple passes through device
- Absorption in device and cathode reflectivity are less important
- Preserves form factor



Source: Panasonic Built Up Light Extraction Substrate

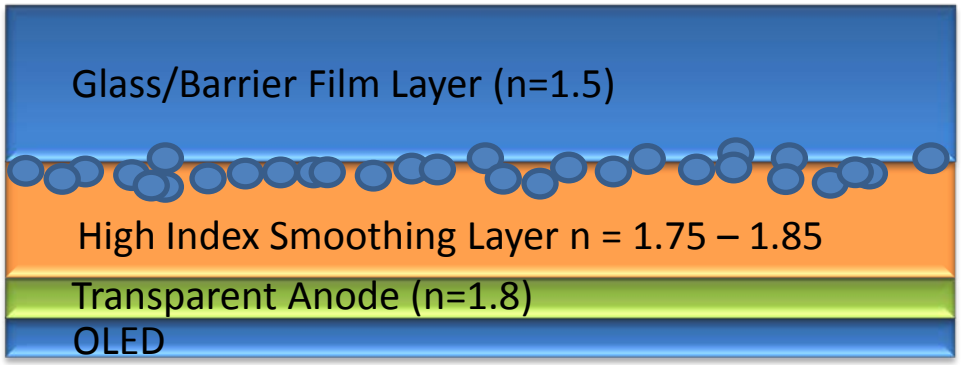
Pixelligent OLED Lighting Roadmap



- Performance - light extraction vs. θ and λ, flexible vs. rigid, control of etendue, uniformity
- Manufacturability- number and cost of manufacturing steps, yield, repeatability

Generation 1

- Condensed Scattering Layer with high index smoothing



- May eliminate need for external light extraction
- Pixelligent recently launched an OLED family of commercial products

Generation 1 Product Launched August

- Formulated nanocomposites – High refractive index smoothing layer

  and

- Unformulated dispersions

PixClear® 4OLED

Includes:

PixClear® OPA
PCOPA-50-PGA

PixClear® OPM
PCOPM-50-PGA

PixClear® OPR Formulated
PCOPR-47-BPA

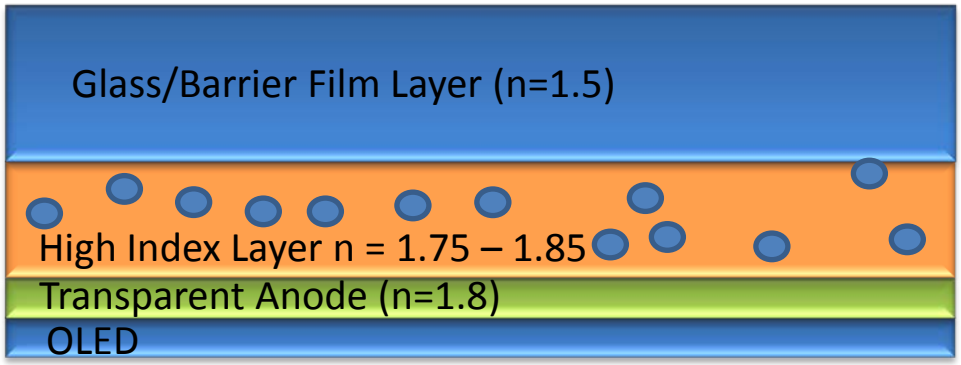
PixClear® OPM Formulated
PCOPM-47-BPA

Summary of High RI Smoothing Layer (Gen 1)

Performance Criteria	Performance Targets	Pixelligent ILE
Optical Properties		
Refractive Index	> 1.75 – 1.85@ 550 nm	✓
% Transmittance	> 90% in visible region	✓
Physical Properties		
Smoothing Surface	Planarize scattering structures on substrate <1 nm Ra	✓
Compatible With Current Manufacturing Processes	Spin coating, slot die coating, screen printing, vacuum coating process, etc.	✓
Thermal Stability		
150 C – 250 C 30 min	Maintain High R.I. and High % T	✓
Chemical Properties		
Compatible with polymers	Maintain uniform, transparent planarizing coatings	✓
Compatible with scatterers	Maintain uniform, transparent planarizing coatings	✓
Compatible with chemical processing	Stable to ITO patterning processes, acids, bases, solvents, etc.	✓

Generation 2

- Distributed Scattering Layer with high index layer



- More efficient than condensed scattering layer
- More functional material but simpler manufacturing process than Gen 1

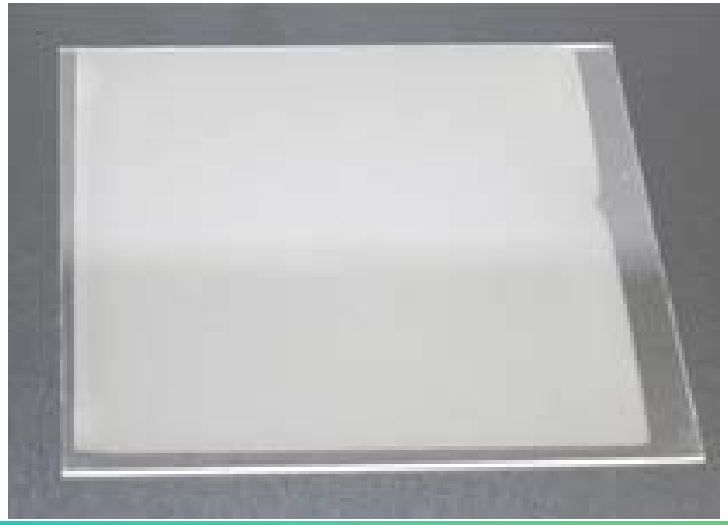
Device Tests

EQE% of White OLED Devices on Slot-Die Coated ILE

Source: OLEDWorks

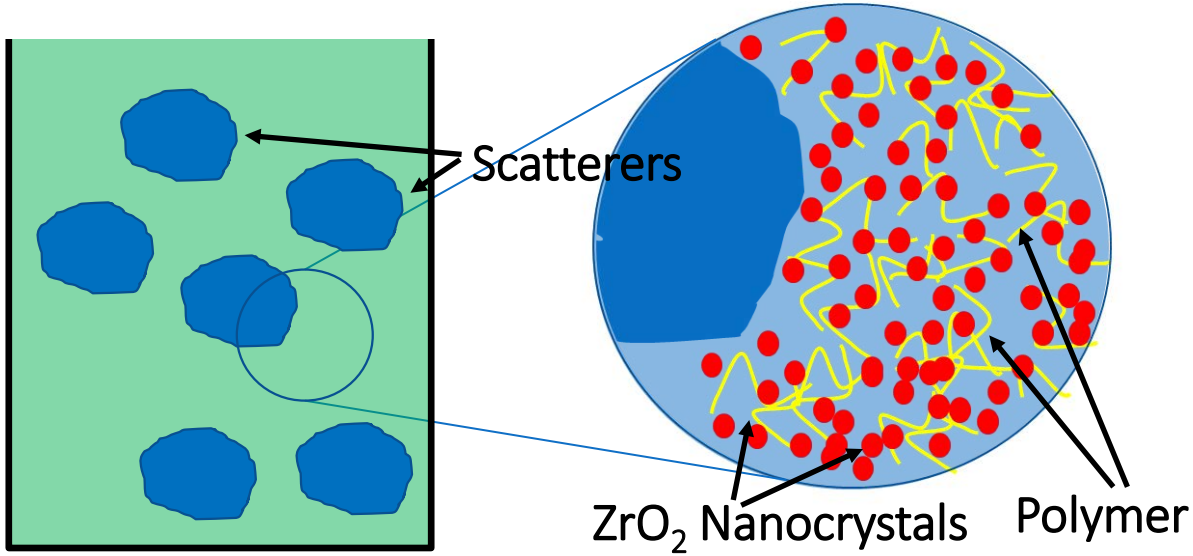
		No EEL		EEL	
Control (No IEL)	0 deg	28.1		48.3	1.7X
	Integrate	32.3		46.2	1.4X
With Pixelligent IEL	0 deg	56.5	**2.0X**	57.3	**2.0X**
	Integrate	67.9	**2.1X**	61.9	**1.9X**

- The slot-die scattering films passed high pressure water jet cleaning process, ITO deposition process, and OLED manufacturing process
- The control devices were tri-layer white OLED with color temperature ~ 3000K



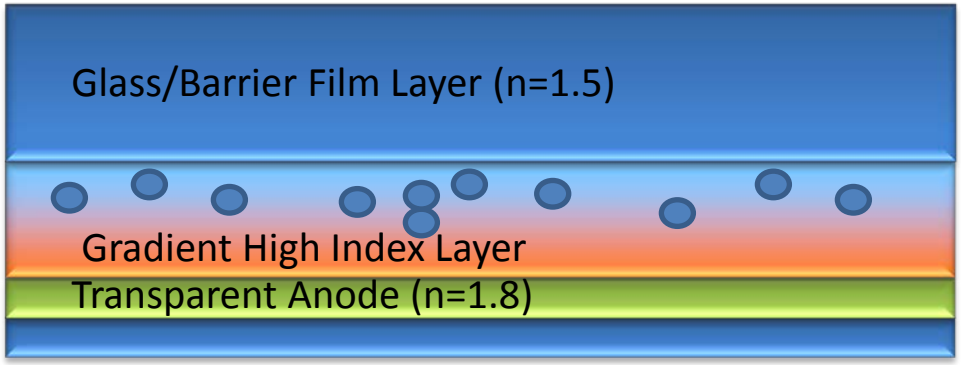
Prototype Gen 2 Formulations Available for Testing

- Nanocomposite plus scatterer
- Tunable viscosity
- Uniform thickness
- Uniform scatterer loading
- Low defect rate
- UV Curable
- Slot-die, spin, or inkjet coating
- Low surface roughness
- NDA required



Generation 3

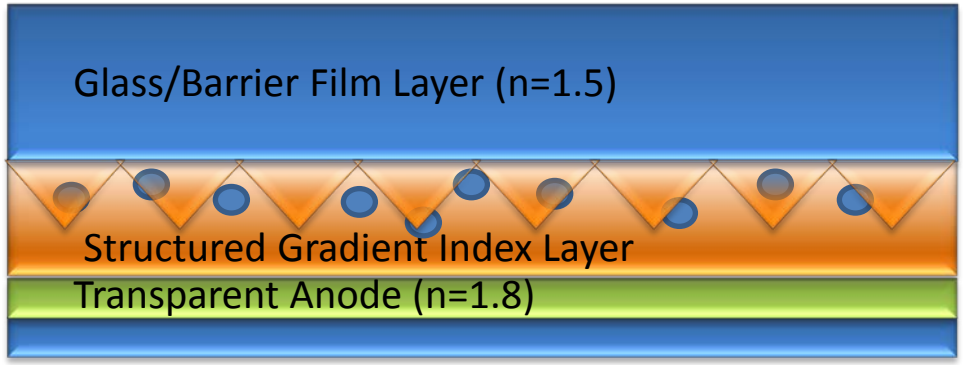
- Distributed Scattering Layer with gradient high index layer



- More efficient than distributed scattering layer
- More complex manufacturing process
- Pixelligent currently developing materials and manufacturing processes

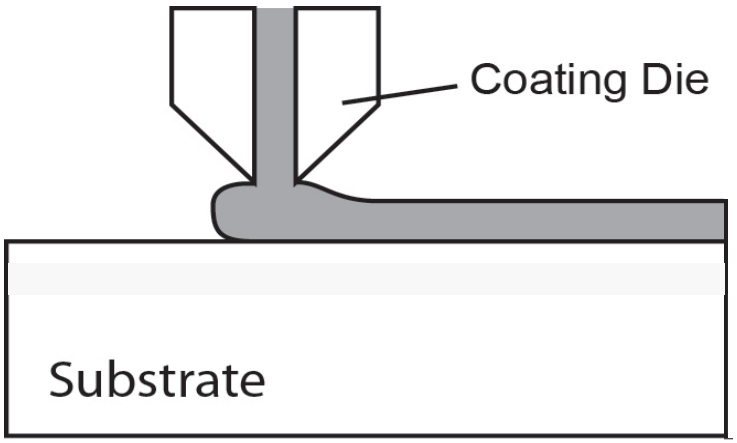
Generation 4

- 3-dimensional graded index with or without scatterers



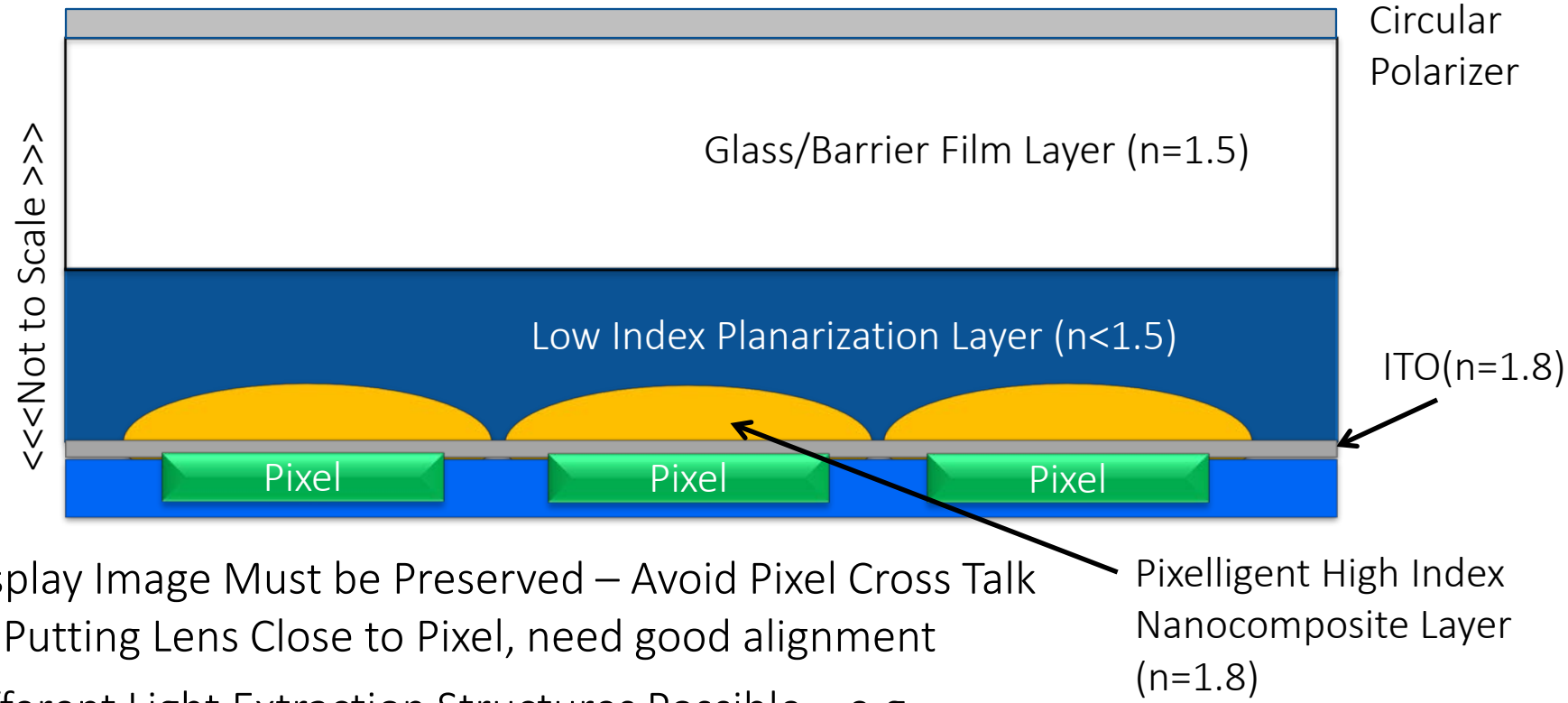
- Highest efficiency
- Offers ability to direct light – non-lambertian
- Most complex manufacturing process
- Subject of Future work

Simple Manufacturing



- Pixelligent Formulation compatible with multiple deposition methods – *slot-die*, spin coat, inkjet, spray coat, …
- Not dependent on substrate – flexible or rigid, film or glass,
- Pattern with slot-die, inkjet, UV patterning, …

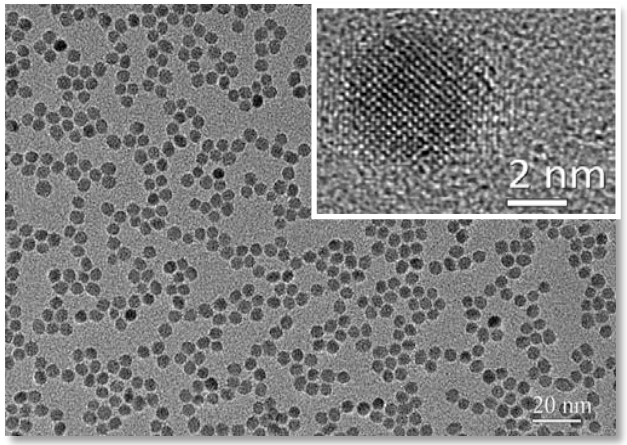
Light Extraction for OLED Displays

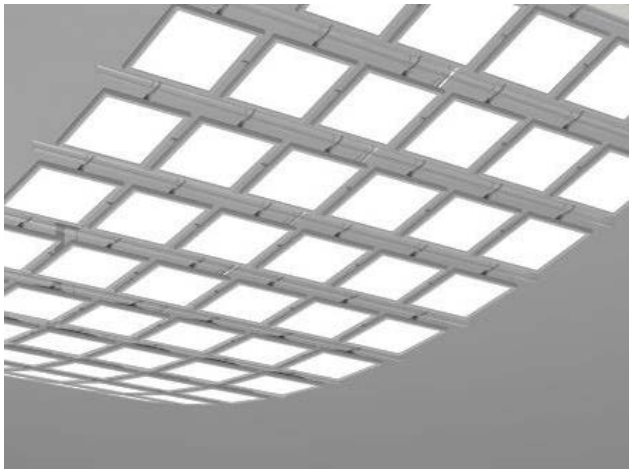


- Display Image Must be Preserved – Avoid Pixel Cross Talk by Putting Lens Close to Pixel, need good alignment
- Different Light Extraction Structures Possible – e.g. Conventional or Fresnel Lens, Many Ways to Optimize
- Lenses preserve polarization to maintain absorption of ambient light – high contrast ratio

Summary

- Pixelligent makes solution processable nanocomposites with tunable properties superior to pure polymers
- High index nanocomposite formulations used to make efficient internal light extraction
- Compatible with a wide variety of OLED manufacturing (and potential manufacturing) processes
- Prototype Gen 2 Formulation now available for testing under NDA





Source: Acuity Brands

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