Improved Light Extraction for a 130 lm/W OLED Lighting Panel

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Project Objectives

To develop a High Refractive Index – Light Extraction (HRI-LE) formulation for OLED lighting that will demonstrate an efficacy of **130 lm/W**.

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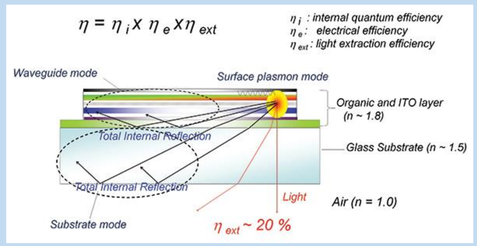
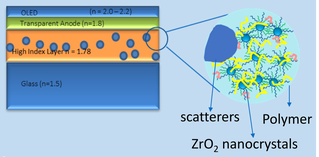
Project Technology

- **Pixelligent's High Refractive Index materials** can solve OLED lighting's biggest problem – low light output
- Only ~20% of the light generated by the device is extracted
- One of the causes of the low light output is Total Internal Reflection (TIR) at the ITO/substrate interface
- TIR is due to refractive index mis-match between ITO (~1.8) and the substrate (~1.5)
- TIR can be reduced by incorporating a High Refractive Index layer between the ITO and the substrate known as **Internal Light Extraction (ILE)** layer



Pixelligent's High Refractive Index ILE

- ILE layer based on Pixelligent's high quality ZrO_2 nanocrystals
- The HRI- ILE layer is sandwiched between the ITO and substrate
- Has an RI in the range between 1.75 and 1.8 and contains scatterers

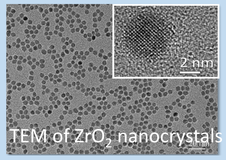


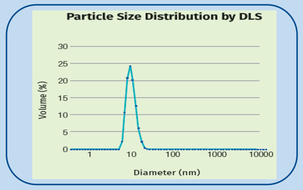
Project Progress

	Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
First performance Period																									
Task 1	Develop HRI scatterer formulations with different types of scatterers																								
Task 2	Create HRI scatterer formulation for OLED device structure optimization																								
Task 3	Build ILE integrated OLED devices at OLEDWorks																								
Second Performance Period																									
Task 4	Optimize the physical properties of the HRI-ILE																								
Task 5	Refine Flexible Formulation																								
Task 6	Second Round OLED Panel Tests at OLEDWorks																								
Task 7	Commercialization of HRI-LE Formulation																								

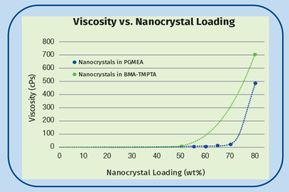
High Refractive Index Material

- Characteristics of ZrO_2 nanocrystals
  - 5 nm monodisperse spheres
  - Enables high RI >1.8





Uniform dispersion in solvents and formulation



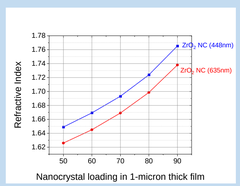
Low viscosity at high nanocrystal loading

- Broad compatibility in solvents and polymers
- Pixelligent's HRI formulation
  - comprises nanocrystals, monomers/oligomers, additives and curing agents >95% transparency
  - 6+ month shelf life
  - Compatible with various deposition methods
  - Solution processable

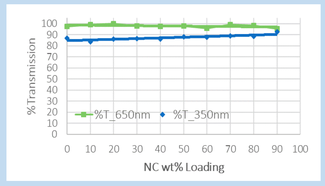
HRI formulation

Transparent nanocomposite film

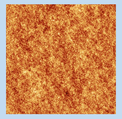
Tunable High RI



>95% %transmittance

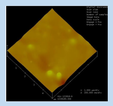


Low surface roughness



5x5 micron – AFM:
Ra = 0.529 nm
RMS = 0.665 nm
Rz = 6.455 nm

- Scattering particles are incorporated in the formulation to yield HRI scattering ILE
  - Uniformly and monodisperse
  - Low viscosity at higher nanocrystal loading
  - Compatibility with various deposition methods; IJ printing, spin coating, slot-die coating



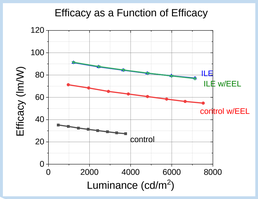
5x5 micron – AFM
Ra = 7.52 nm
RMS = 10.7 nm
Rz = 70.3 nm

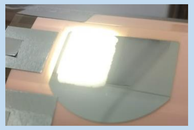
Phase I Results

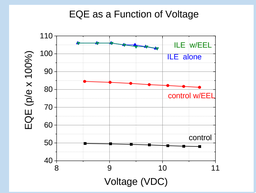
Optimization of scatterer loading in the HRI ILE led to white OLED devices with efficacies as high as 90 lm/W at 3000 cd/m^2.

Device	Highest Efficacy (lm/W)		Extraction efficiency
	No EEL	With EEL	
Control (no ILE)	32	67	-
HRI-ILE	87	**90**	53% (2.3X)

Devices with ILE integrated demonstrated significant improvement in efficacy and extraction efficiency

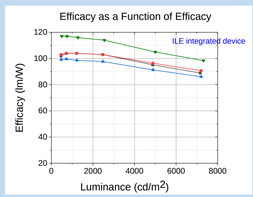






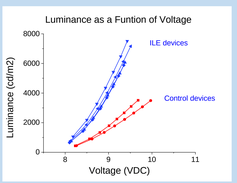
Phase II Preliminary Results

Demonstrated an efficacy as high as 104 lm/W at 3000 cd/m^2

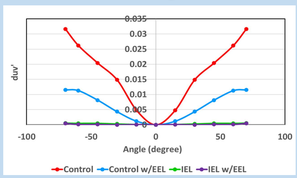


- Optimization of the ILE properties
- Co-optimization of the ILE along with the device structure

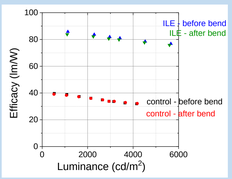
Additional Benefits of Pixelligent ILE in OLED Devices



Lower driving current at higher luminance



Reduced angular color variation



Compatibility in flexible OLED

Prototype OLED devices have passed reliability tests

- ~50,000 hours of lifetime
- ~1000 hours of 85C/85% RH

Next Steps

- Formulation optimization
  - Further increase RI of the ILE
  - Modify formulation to improve surface roughness
- Optimize RI contrast between scatterers and ILE matrix
- Adopt methods to reduce absorption

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