



The Clear Solution®

# *Use of High Refractive Index Materials In Display and Optical Devices*

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Product Development Manager



## Outline

- Pixelligent overview
- Core technology -  $\text{ZrO}_2$  nanocrystals
- High Refractive Index Nanocomposite
- Applications and benefits
- Conclusion
- Acknowledgements



## Pixelligent Overview

### Technology

High Refractive Index Nanomaterial (PixClear®) for high performance optical applications

### Key Markets Served

AR/VR, Displays such as OLED, microLED, QD, OLED and LED Lighting, CMOS Sensors

### Locations

Baltimore, MD - HQ  
Taipei, Taiwan - Sales

### Manufacturing

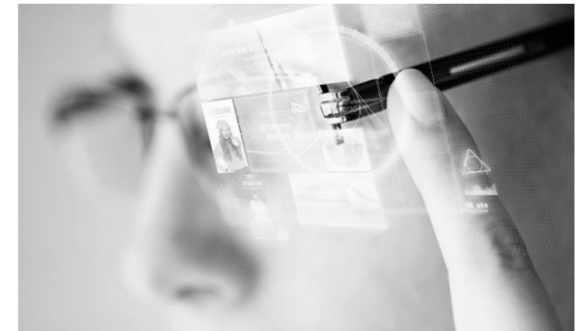
5 MT Pilot Baltimore, MD

### Distributors

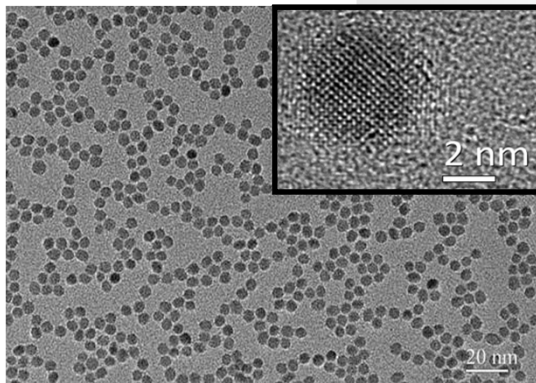
Korea, Japan, Taiwan

### IP

60 issued and pending patents



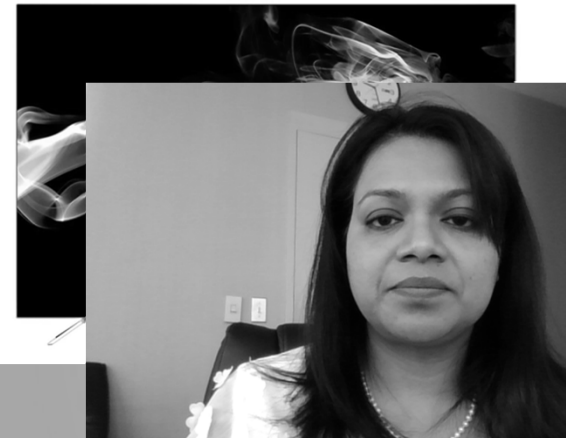
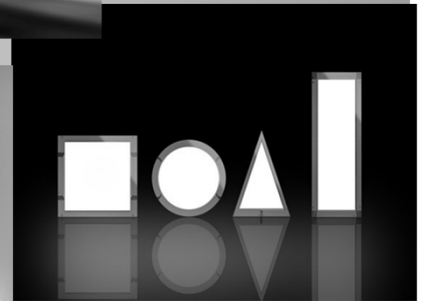
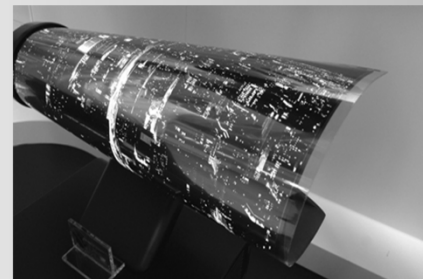
# PixClear® High Refractive Index Material Can Enable Displays Brighter – Higher Efficiency – Longer Life



ZrO<sub>2</sub> nanocrystals



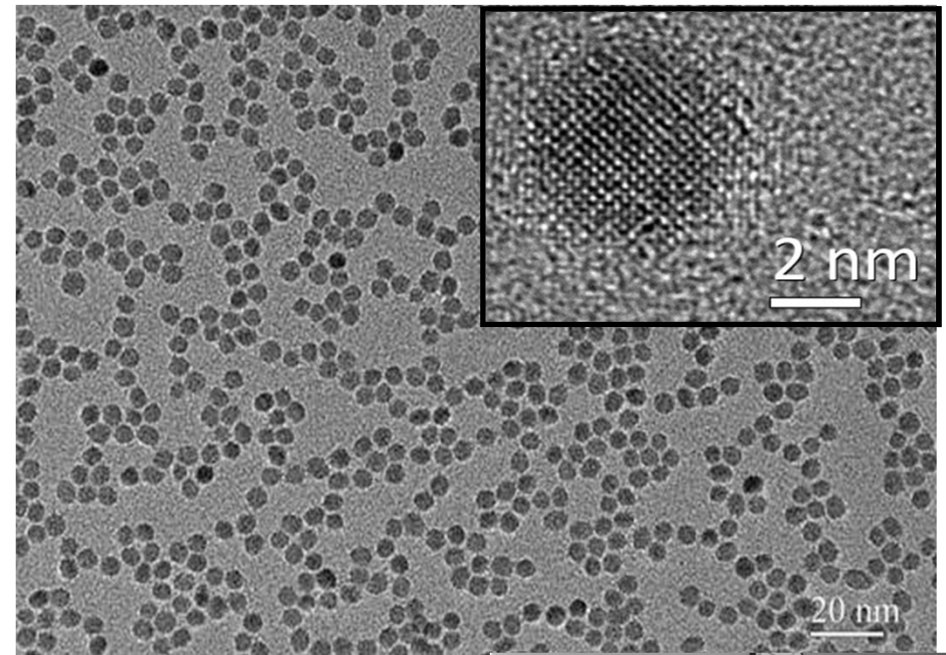
Increases Refractive  
Index in polymers





## ZrO<sub>2</sub> Nanocrystal

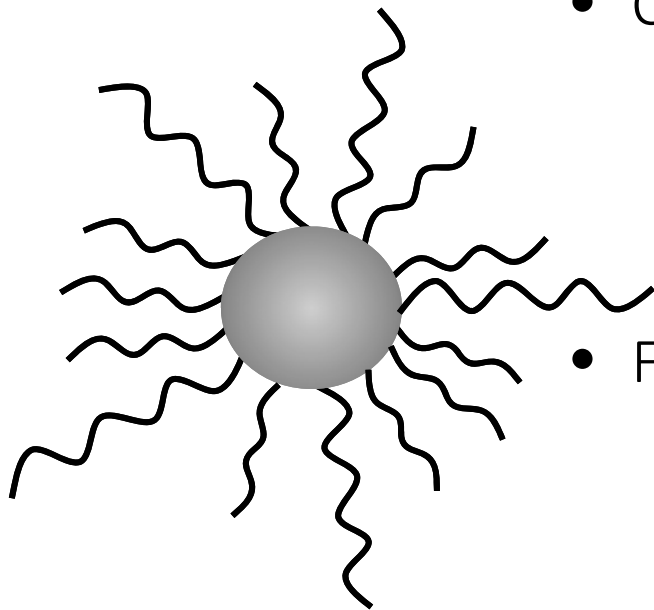
- ZrO<sub>2</sub> nanocrystals
- 5 nm core, crystalline
- RI of 1.75+
- Increase the refractive index of polymers
- 95%+ Transparency
- Broad compatibility with a wide range of solvents and polymers
- Stable for years



```

graph LR
    A[Nanocrystal Synthesis] --> B[Surface Modification]
    B --> C[Nanocrystal Dispersion]
    C --> D[Nanocrystal Formulation]
    D --> E[Nanocomposite]
  
```

Nanocrystal Synthesis → Surface Modification → Nanocrystal Dispersion → Nanocrystal Formulation → Nanocomposite



- Capping agents
  - Improves dispersibility
  - Increases compatibility
  - Reduces surface effects with better surface coverage
- Functional capping agents
  - Crosslink into polymer
  - Acrylic, epoxy, other...
  - Can control crosslinking density

Note: not to scale



## High Quality ZrO<sub>2</sub> Dispersions

Nanocrystal  
Synthesis

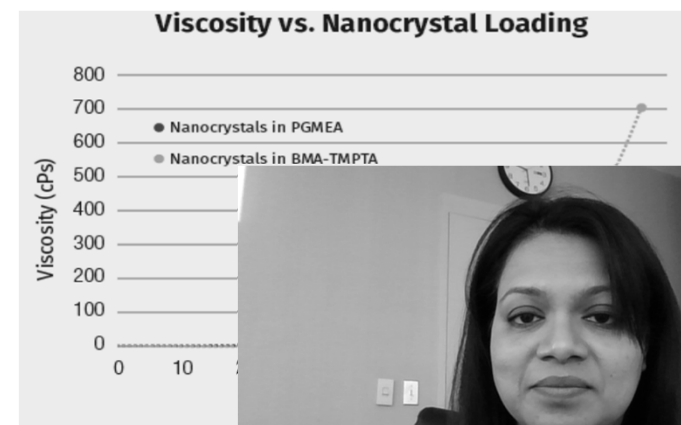
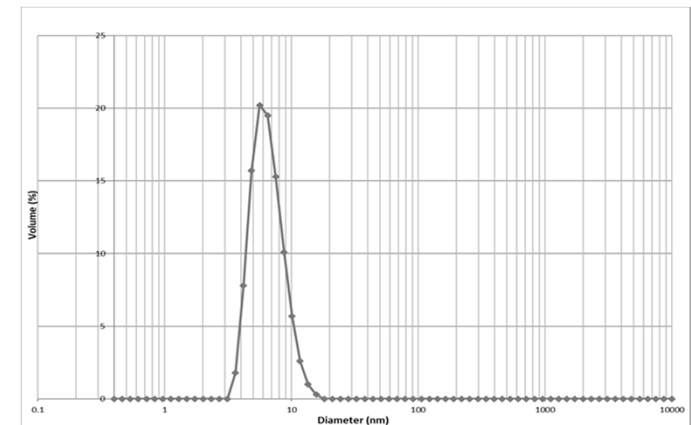
Surface  
Modification

Nanocrystal  
Dispersion

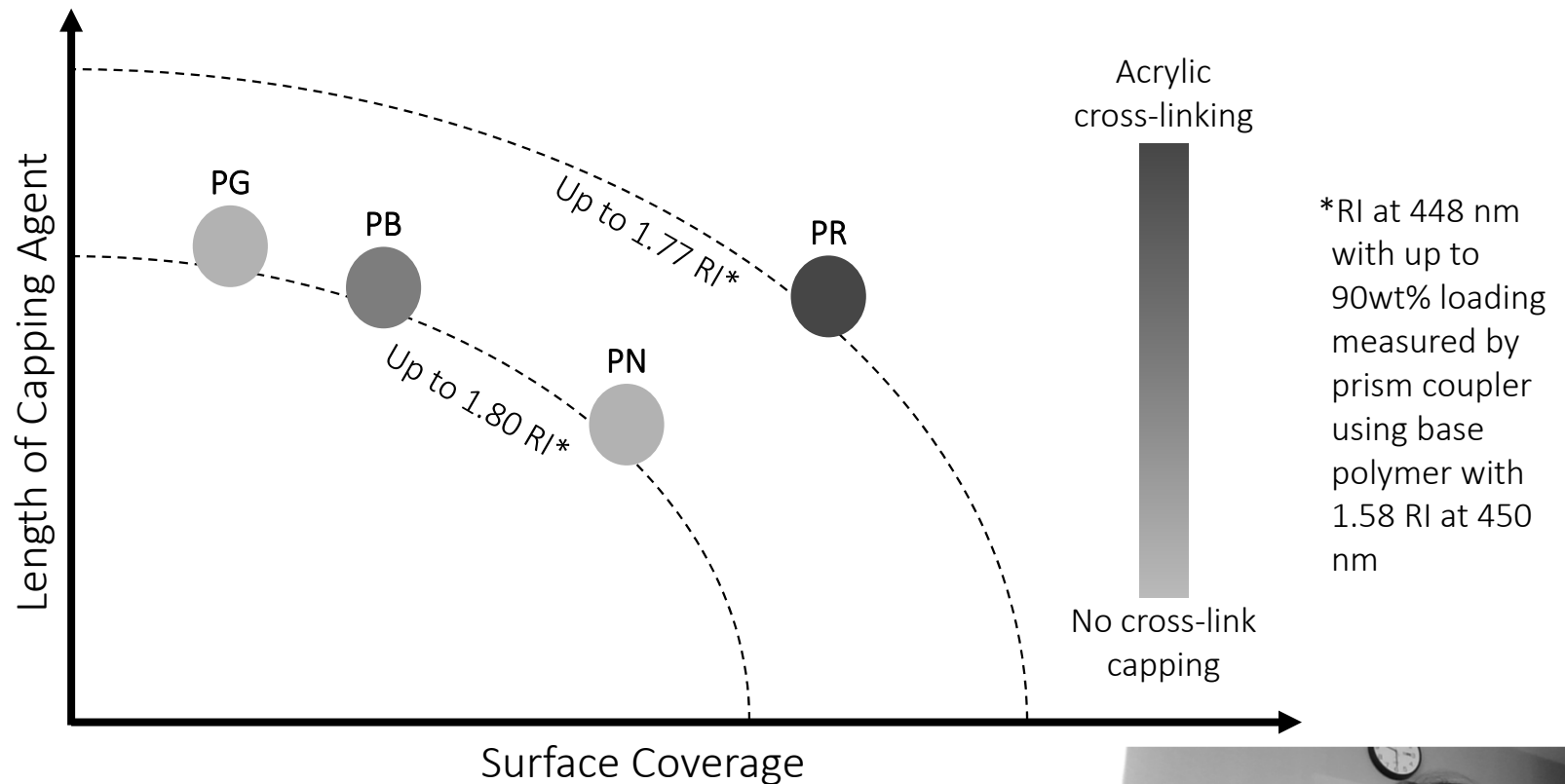
Nanocrystal  
Formulation

Nanocompo  
site

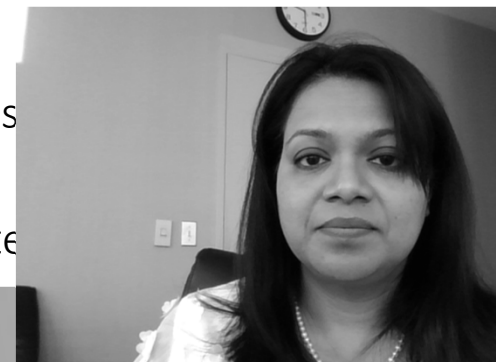
- Capped nanocrystals dispersed in solvents/monomers
- Many choices of capping agents depending on solvent
- High transparency (>95%)
- Low viscosity increase even at high loading of 75 wt%
- No aggregation or settling
- Good long-term stability: months to years
  - 6 months guaranteed for standard products



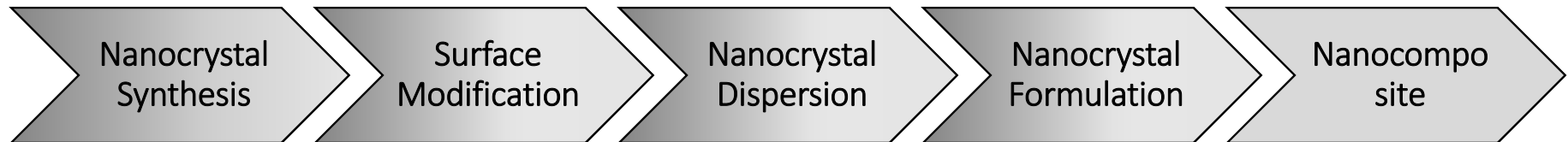
## Capping Variations and Impact on RI – PixClear® 4pack



- PR - higher acrylic cross-linking for greater substrate adhesion, hardness performance with processing chemicals
- PB has higher dispersibility capping leading to higher RI nanocomposites



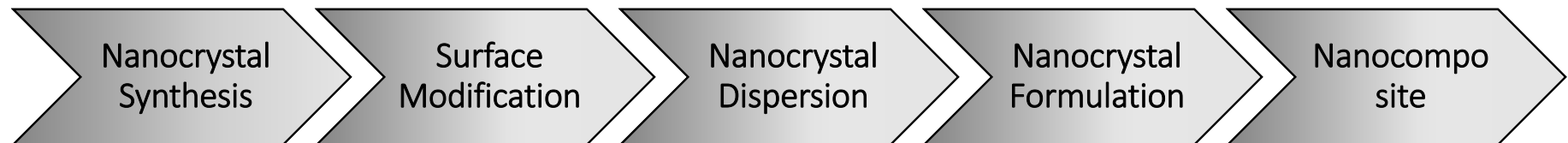
## High RI Formulations



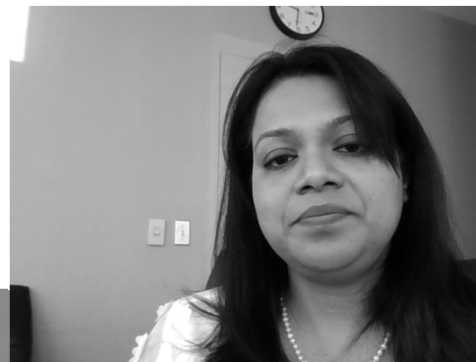
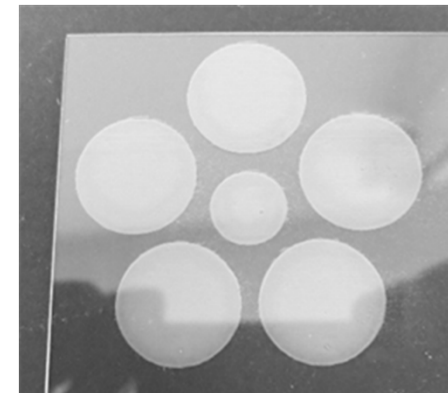
- Curable liquid with capped nanocrystals + polymer/monomer + additives
- Solvent free or solvent containing
- UV or thermally curable
- Transparent or with scatterers
- Meets wide range of application requirements – viscosity, shelf life, cure conditions, surface tension, uniformity, repeatability



# Nanocomposite Deposition

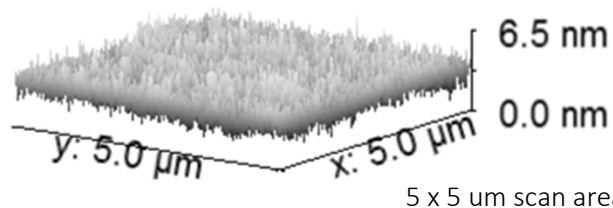
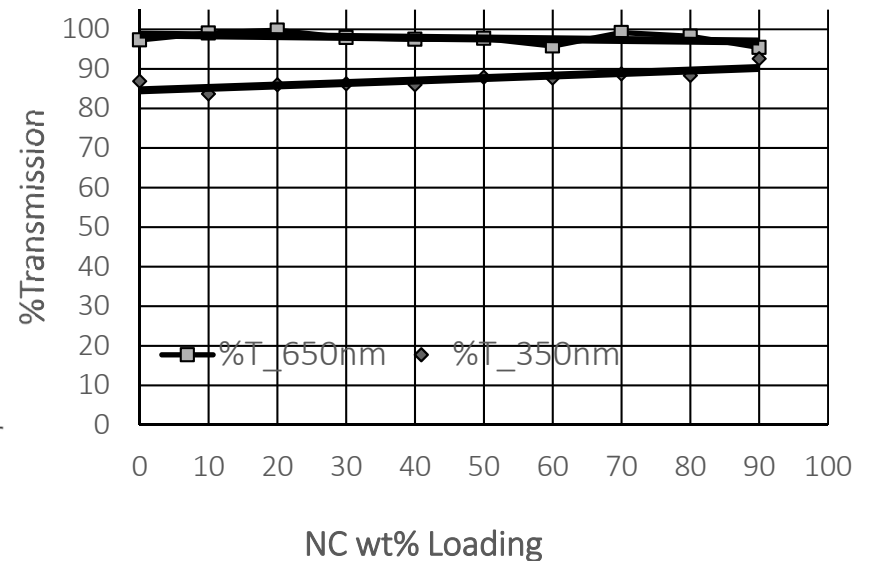
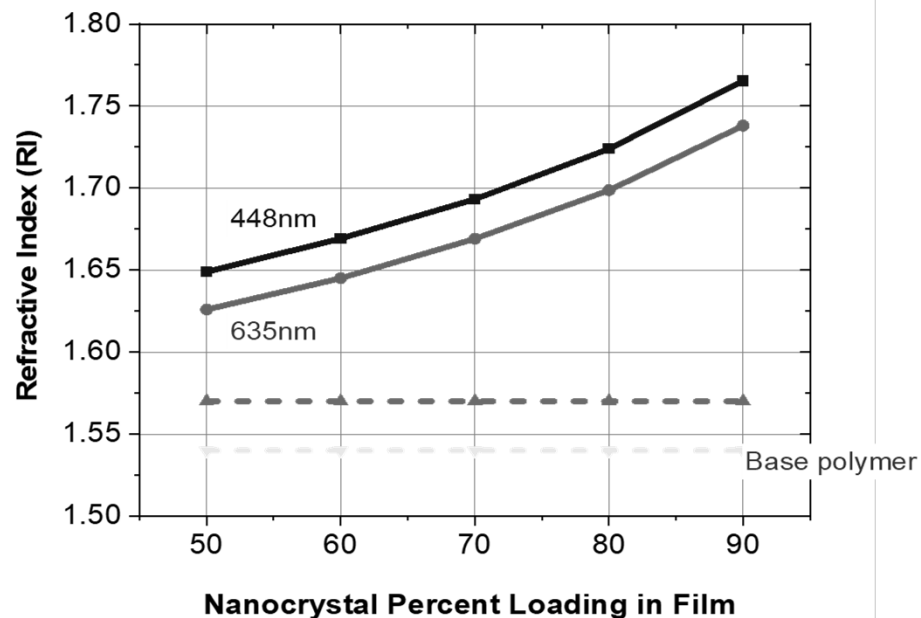


- Solution processable
- Compatible with formulation manufacturing processes
- Compatible with commonly used deposition methods
  - Inkjet printing
  - Slot die coating
  - Spin-coat
  - Screen printing
  - Dispense
  - Spray coating
  - Imprint lithography

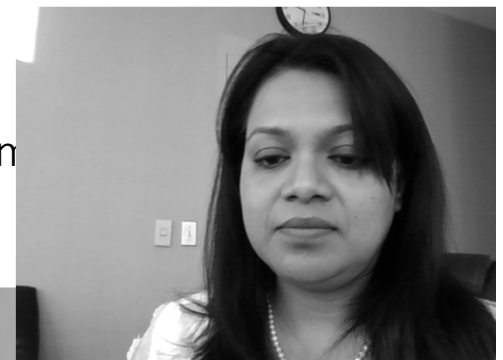


# PixClear® High Refractive Index Nanocomposite

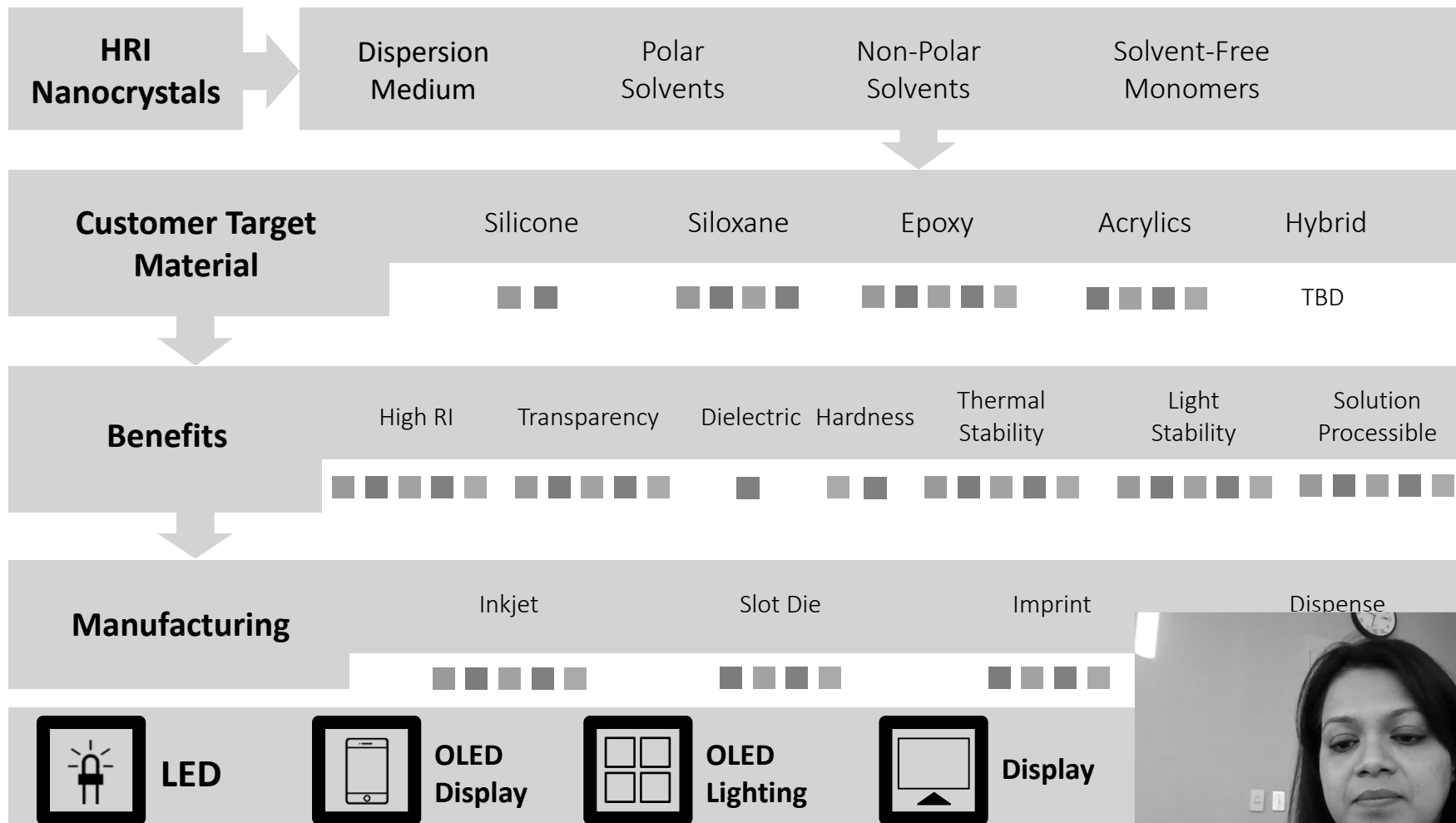
High RI, High Transmittance, and Smooth Surface



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



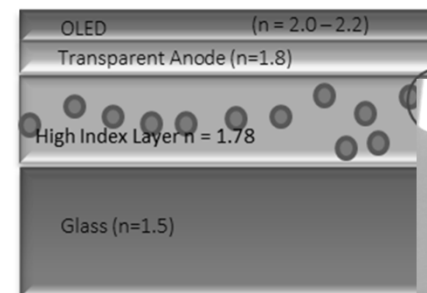
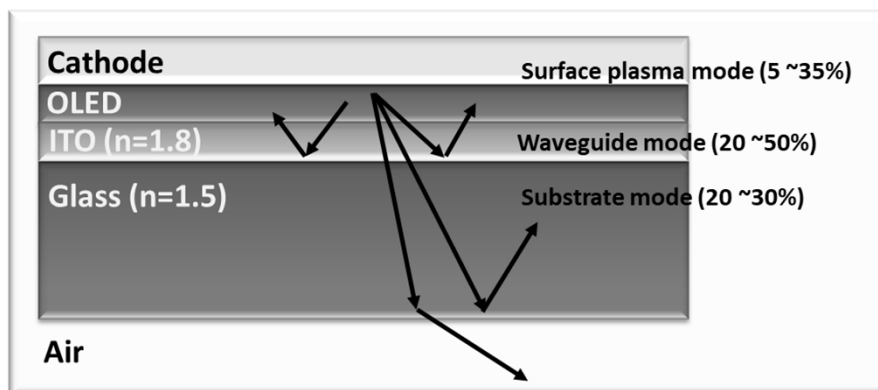
## Broad Compatibility



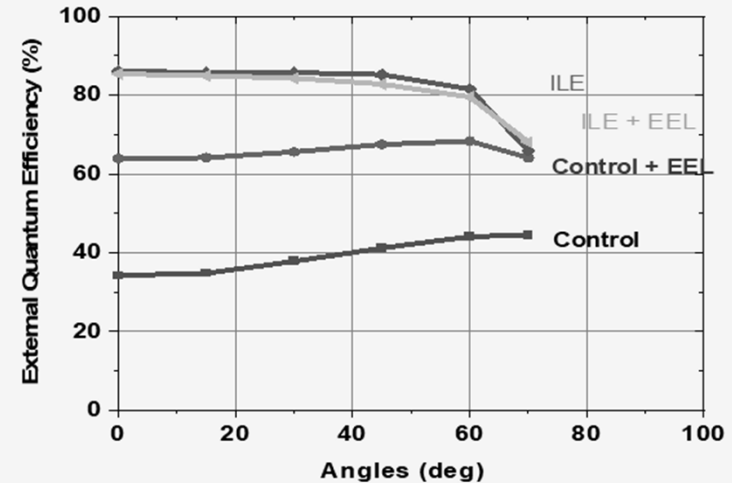
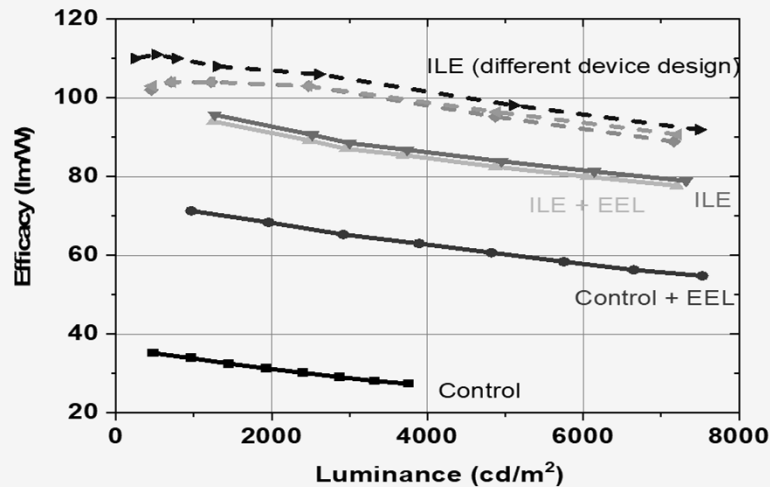


## PixClear® Solution for OLED Lighting

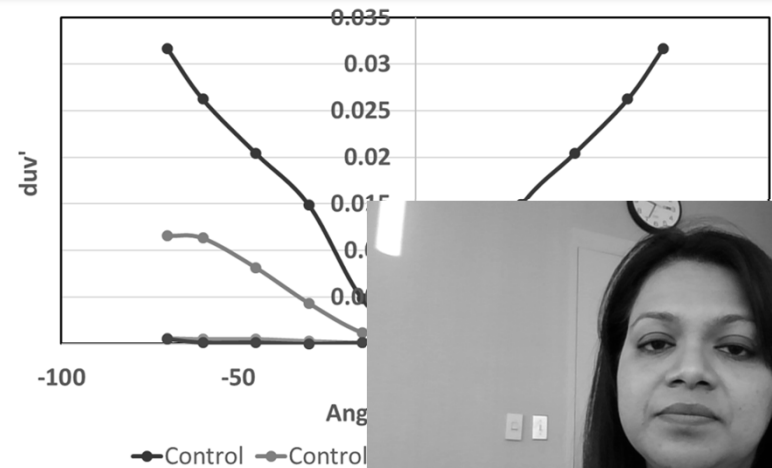
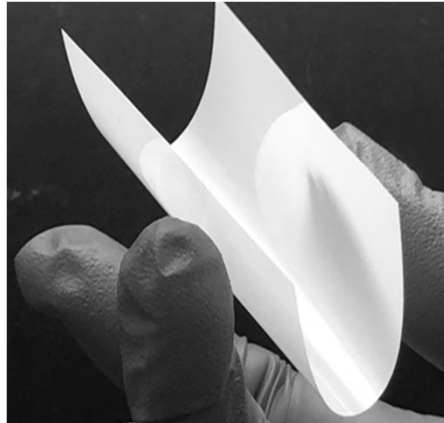
- Total Internal Reflection traps most of the light in the device
- Different light extraction schemes vary in how and where light is redirected
- Most effective light extraction benefit is when the light at the ITO-substrate interface is re-directed
- PixClear High Refractive Index (HRI) Formulation ( $n \sim 1.77$ ) as an Internal Extraction Layer (IEL)
- Reduces index mis-match between the ITO and the substrate
- Compatible with scatterers such as  $\text{TiO}_2$  for internal light extraction



# OLED Lighting Device with PixClear® HRI IEL



- ✓ >30,000 hours projected lifetime based on accelerated tests
- ✓ Flexible
- ✓ Lower driving voltage - Less waste heat and longer lifetime



(Source from

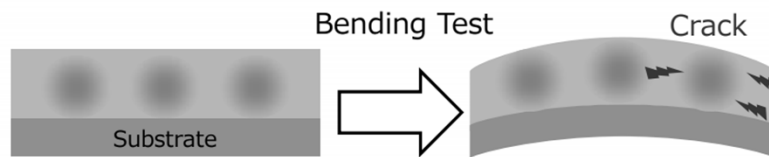


## PixClear® High Index Photo-Patternable Material

- High Refractive Index: 1.7
- High Transparency: 96.4%
- Excellent Flexibility

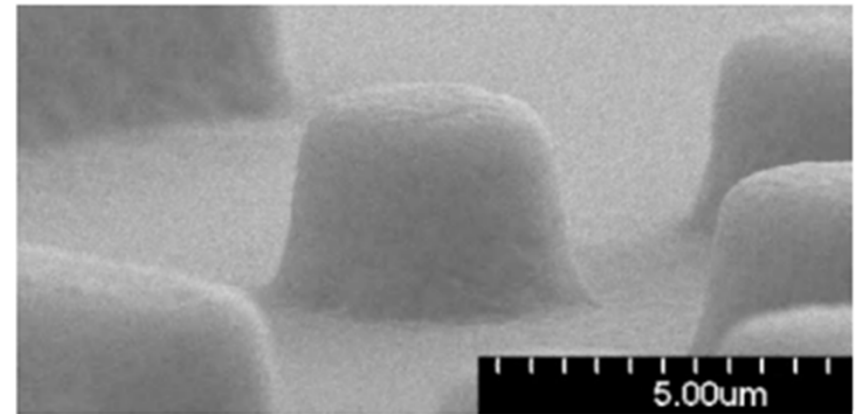
### Conventional Filler

Filler Size: 50 nm ~



**Pixelligent Ink (PixClear®)**  
Filler Size: 5 ~ 10 nm

**Smaller filler leads to suppression of cracking**



Result

### Flexibility Data

#### Conditions

Substrate	: Kapton Film
Coating	: Spin coat
FT	: 50 nm (after post-bake)
Prebake	: 100 °C - 2 min
Exposure	: 1 J/cm² (Broad band)
Post-bake	: 230 °C - 20 min

#### Bending Test



#### w/ PixClear® Filler

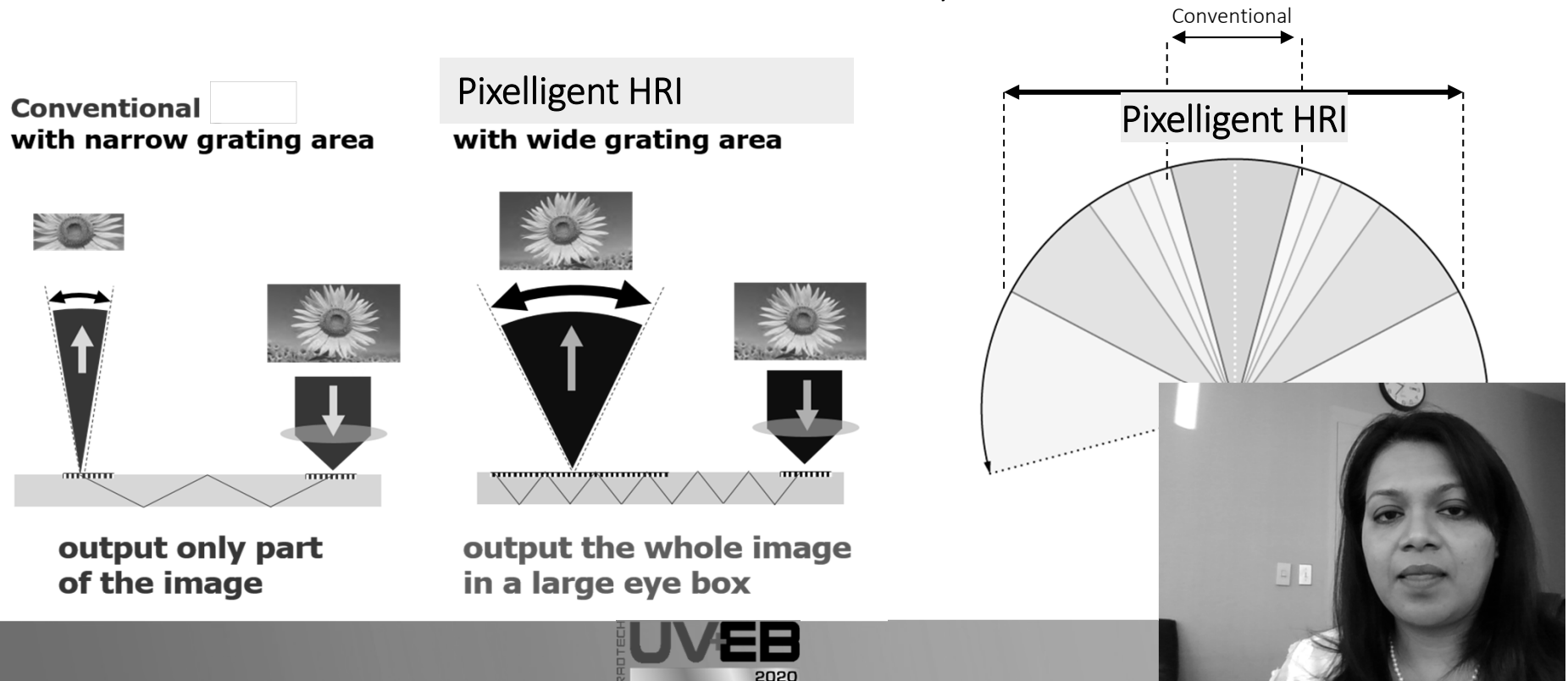
No Crack



Source: TOK

## PixClear® Technology for AR Glasses

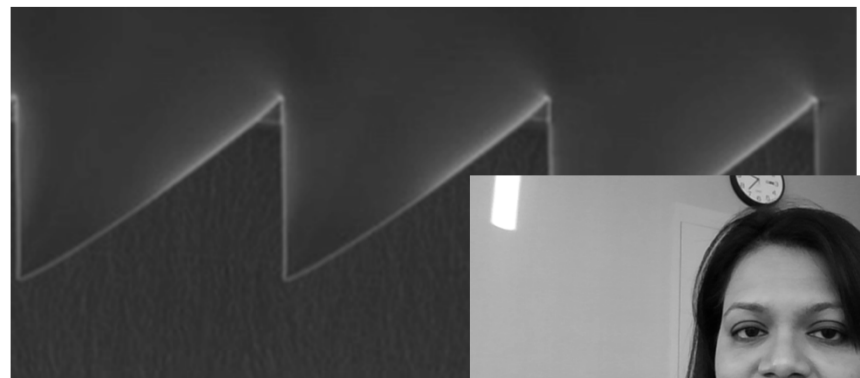
- Largest covering for all visible wavelength
  - Large FoV and highly immersive
- Reducing eyestrain and weight: Extending wearability
  - Light weight with HRI nano patterned single lens
- AR market to total \$50B-\$60B and 2.5B users by 2023.....



## PixClear® Solution for 3D Sensor Application

### Benefits

- High RI: 1.7-1.8RI
- Solvent-free
- Reduced lens size/thickness with wider light diffraction angle
- Increased flexibility of lens design
- >95% transmittance at 100um thickness
- Better imprinting process control: UV curable for thick films
- No particle precipitation under 150C - major issue for competitors
- High thermal stability
- Forecasted \$3.5B - \$5.5B market 2022



## PixClearProcess® Fully Scalable

ZrO<sub>2</sub> Nanoparticle Synthesis Reactors



ZrO<sub>2</sub> Capping Reactor



Same ZrO<sub>2</sub> nanoparticle for all products

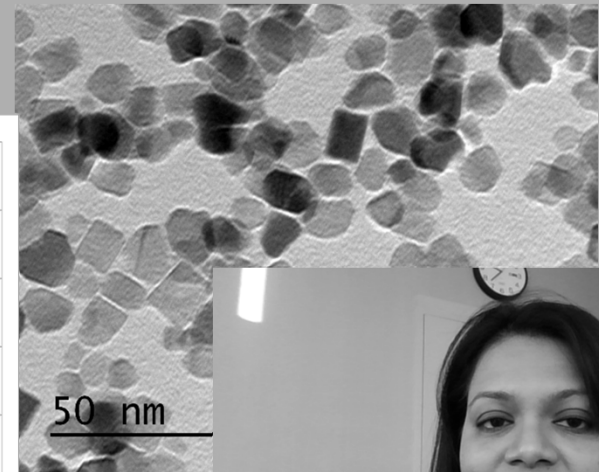
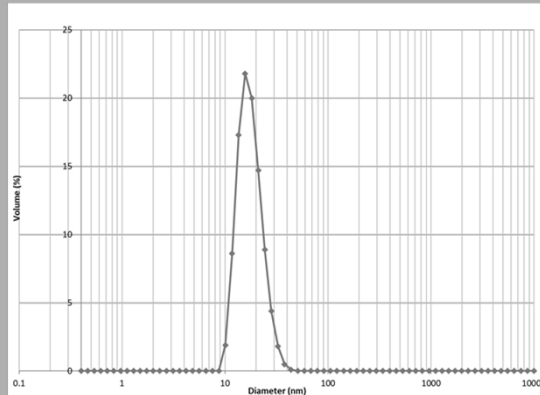
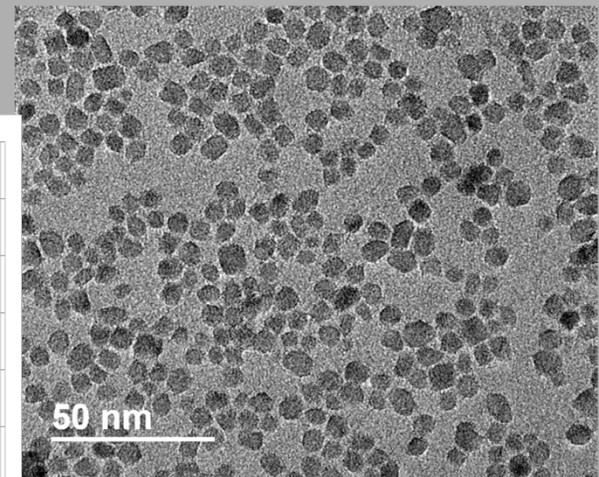
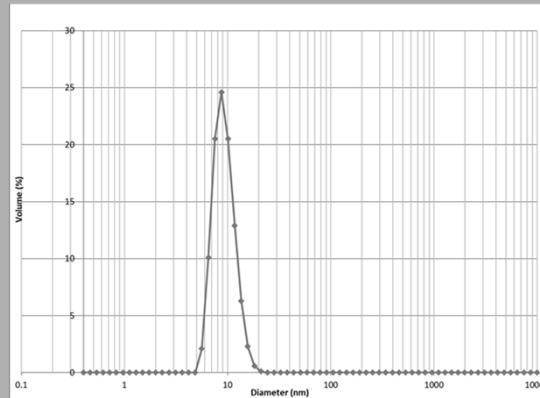
Same capping process for all

## Pixelligent is ISO9001 Certified



## Preview - Extending the PixClearProcess®

- $\text{TiO}_2$  nanocrystals
- Two distinct sizes: 5 nm core and 15 nm core
- RI of 1.8+
- Product-release planned in April 2020



PixClear® HRI Nanocomposites can deliver  
unmatched RI, transparency, and compatibility  
to yield

Brighter – Higher Efficiency – Longer Life  
Products





## 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
- FROST & SULLIVAN Manufacturing Award
- OLEDWorks LLC



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



**SBIR·STTR**  
America's Seed Fund

**MANUFACTURING  
LEADERSHIP AWARDS**  
FROST & SULLIVAN  
**WINNER 2017**



# Thank you

For more technical details, read our white paper:

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

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