Novel Metal Oxide Nanocrystals and Nanocomposites Enabling Next Generation Opto-Electronic Devices

Strategic Materials Conference, San Jose
Sept. 2017
Presentation Overview

I. Introduction

II. Leading challenges in commercializing advanced materials and Pixelligent Technologies approach:
   - Value proposition related challenges
   - Value/supply chain related challenges
   - Uncertainty Due To Scaling challenges

III. Products & Technology enabling next generation optoelectronic devices

IV. Conclusions
I. Introduction
**Company Overview**

**Disruptive Technology**
- Technology leader in Next Generation High-RI Nanocomposites
- IP: 43 Active & Pending

**Key Markets Served**
- OLED Display, HD Display, OLED Lighting, LED Lighting

**Customers & Partners**
- Leading Device, Advanced Materials, & Consumer Electronics Companies

**Manufacturing**
- 5 MT Pilot Baltimore, MD
- 40 MT Full-scale, PA, Q4 2017

**Locations**
- Baltimore, MD - HQ
- Midwest Sales Office
- Taipei, Taiwan Sales Office

**Distributors**
- Korea, Japan, Taiwan
Disruptive Technology Platform

• Technology leader in high RI nanocomposites:
  – 5nm-10nm ZrO$_2$ spheres
  – Fully uniform (monodisperse)
  – High loadings (>80wt%)
  – 95% transmittance
  – High RI >1.8
  – Broad compatibility

• Significant customer benefits:
  – Highest possible light extraction
  – Low Haze <0.5%
  – Increased mechanical strength
  – Dramatic improvements in overall operating efficiencies
II. Challenges In Commercializing Advanced Materials* and Pixelligent Approach

Challenge of Long Timeline To Peak Revenue For New Materials Products:

Long time to peak revenue for new materials products a function of many factors:

- Lack of focus by materials companies, Technology scaling risk
- Value chain complexity, Value proposition not clear, Adoption cycle, etc.

**Diagram:**

- 15-20 Yrs. Rev. growth starts
- 0-10 Yrs. For finding apps. & acceptance
- Adaption approaches the limit/ market is saturated
- Major technical obstacles are overcome
Challenges In Commercialization of Advanced Materials:

Value Proposition Related Challenges

• Market Segmentation: Finding the Best Match
  • Older products will be completely replaced by my new product:
  • “Why wouldn’t every consumer (every market segment) want a more energy efficient light bulb enabled by my new product”

• Utopian Illusion
  • Companies think that materials developed based on a distinct set of properties in early R&D can be a “panacea”
  • Fact: Customers value only 1 or 2 properties of the new material in their applications

Value Chain Related Challenges

• Stifled By The Loser:
  • Upstream position in the value chain
  • Benefits to end-user do not equate to benefits to value chain players

• “Drop-in Solution”:
  • Integration and reliability
  • Need for complementary innovation

Technology Uncertainty For End Users and Value Chain Partners

• Lab to full scale manufacturing
Value Proposition Related Challenges:

- **Market Segmentation**
  - Belief that “older products will be completely replaced by my new product”
  - “Why wouldn’t every consumer want a more energy efficient light bulb enabled by my new product”

- **Utopian Illusion:**
  - Companies think new materials developed based on a distinct set of properties in early R&D can be a “panacea”
  - Fact is customers value only 1 or 2 properties of the new material in their applications

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**Pixelligent Approach and Timeline**

- **2013**
  - LED Lighting
  - OLED Lighting
  - Displays

- **2014**
  - OLED Lighting
  - LED Lighting
  - Displays
  - OCF

- **2015**
  - OLED Lighting
  - LED Lighting
  - HD Displays
  - OCF

- **2016**
  - OLED Displays
  - OLED Lighting
  - LED Lighting

- **2012**
  - Metal Coatings
  - Optically Components & Films (OCF)
  - OLED Displays
  - Dielectric Coatings
  - Lubricants & Greases
  - Paints & Coatings
  - Dental Composites
  - Lithography Hard Mask
  - Gradient Index Lenses

- **Q1 Pilot mfg. began**
- **Q2: Standard PixClear™ products launched**
- **Value proposition understood in light extraction**
- **Focus market segments identified**
- **Q1: First JDA engagement in SSL**
- **Q2: First POR Win in SSL Lighting**
- **Prioritized focus**
  - High Priority Segments: OLED Displays
  - OLED Lighting
  - LED Lighting
Pixelligent Approach: Key Take Away

- Engaged with customers early: Do not wait to have a perfect product to go to market.

- Helped understand the value of PixClear™ in customer applications and determine target market segments early:
  - Segments that value materials with combination of high R.I., high %T, and low haze.

- Understanding market segments helps in prioritization & resource allocation to accelerate high potential commercial opportunities.
Value Chain Related Challenges:

- Stifled By The Loser:
  - Upstream position in the value chain
  - Benefits to end user do not equate to benefits to value chain players

Pixelligent Approach:

- **End Users**: Engage with leading end users and key stakeholders in value chain to demonstrate benefits and value of PixClear® and create a market pull
  - End users help drive engagement with leading material suppliers in the market
  - Engagement with end device mfrs. led to JDAs with material suppliers
- **Materials Suppliers**: Engage with key formulators and materials suppliers to develop a finished product for end users
- **Equipment Suppliers**: Engage with key equipment suppliers to lower barriers to integration & adoption
• Many advanced materials/nanomaterials companies fall into “Valley of Death”:

  • Tried to scale too many materials platforms/products without understanding the real market pull
  • Scaling from lab to large scale manufacturing proved to be very challenging, expensive, etc.
Technology Uncertainty For End-Users and Value Chain Partners Going From Lab to Full Scale Manufacturing

Pixelligent Approach: PixClearProcess™ for fully scaled ZrO2 Nanocomposites

- **ZrO2 Nanoparticle**: Same ZrO2 nanoparticle for all products
- **Capped ZrO2 Nanoparticle**: Application specific surface modification, Same equipment and process for all products
- **Nanodispersions and Formulations**: Broad materials compatibility, Wide range of applications
PixClearProcess™ *Frost & Sullivan 2017 Manufacturer of the Year*

**Volume**
- 5 MT pilot line today
- >40 MT on line 4Q17
- Further scaling without constraints

**Quality**
- Quality maintained during scaling
- Consistent Lot to lot quality, over multiple years

**Compliance**
- Fully compliant with all US and International EH&S and standards.

**Cost**
- >95% Mfg cost reduction from lab to MP
- Driving compelling value propositions

PixClearProcess™
ZrO₂

**Focused on one core material system**
**Experts in nanoparticle synthesis and surface chemistry**

**Developed large portfolio of proven surface modifiers**
**Fully integrated PD and manufacturing processes**
III. Products and Technology Enabling Next Generation Optoelectronic Devices
PixClear® Drives Significant Customer Benefits in Rapidly Growing Markets

- **OLED Display**
  - Increases OLED display brightness 50% to 200%

- **LED, LCD, QD, and Reflective Displays**
  - Provides substantial operating efficiencies across all display technologies

- **Total Available Market ($B)**
  - 2016:
    - Non-OLED Display: $103
    - OLED Display: $16
    - OLED Lighting: $16
  - 2020:
    - Non-OLED Display: $110
    - LED Lighting: $42
    - OLED Lighting: $56

- **OLED Lighting**
  - Releases up to 35% of trapped light in LEDs
  - Increases OLED lighting efficiency by >100%
Extending the PixClearProcess™
# Broad Compatibility

## Zirconia Nanocrystals
- Dispersion Medium
- Polar Solvents
- Non-Polar Solvents
- Solvent-Free Monomers

## Customer Target Material
<table>
<thead>
<tr>
<th>Material</th>
<th>Silicone</th>
<th>Siloxane</th>
<th>Epoxy</th>
<th>Acrylics</th>
<th>Future</th>
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## Benefits
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<tr>
<th>Feature</th>
<th>High RI</th>
<th>Transparency</th>
<th>Dielectric</th>
<th>Hardness</th>
<th>Thermal Stability</th>
<th>Light Stability</th>
<th>Solution Processible</th>
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## Manufacturing
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<thead>
<tr>
<th>Method</th>
<th>Inkjet</th>
<th>Slot Die</th>
<th>Imprint</th>
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### Products
- **LED**
- **OLED Display**
- **OLED Lighting**
- **Display**
- **OC&F**
PixClear® delivers:

- 1.75+ RI
- 95% transparency
- Flexible or rigid
- 100%+ light efficiency improvement
- Improved scratch resistance

PixClear® Display Applications

- Anti-reflective hard coating
- Optically clear adhesive
- ITO index matching
- Optically clear adhesive
- Light extraction microlenses
- HRI-enabled LED backlight
PixClear® Gen 1 internal light extraction ("ILE") materials provide a smoothing layer; Gen 2 will include scatters; part of 4 generation product roadmap

PixClear® Gen 1 ILE materials provide more than 100% increase in light output compared to control
PixClear® LED Applications

PixClear® silicone nanodispersions increase refractive index of silicones from 1.4 to 1.65, improving performance by releasing 15% - 35% of the trapped light.
IV. Conclusion
PixClear® Disruptive Product & Process Technology

Performance / Value Offering

- Birth
- Growth
- Maturity
- Discontinuity
- Decline
- Breakthrough
- Innovation
- New growth

50 Year Old Chemical Composite Technology

PixClear® Nanocomposites

PixClearProcess™ Scaled Manufacturing & Applications
Summary

• PixClear® delivers dramatic cost and performance improvements in OLED Display, OLED Lighting, Non-OLED Display, and LED Lighting markets:

  – Improves OLED displays by increasing display brightness, improving operating efficiencies and extending battery life – features critical to both the mobile computing and TV markets

  – Increases OLED light output by 100%+, accelerating the adoption of OLED lighting

  – Delivers significant performance improvements and cost reductions in LED chips by releasing 15% - 35% of the trapped light in each chip

  – Built on proprietary PixClearProcess™ for Mass Production

  – Supported by one of the most experienced and sophisticated nanocomposite teams in the world
Thank You!!

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Meet us @ 2017 OLED World Summit, San Francisco Sept. 21, 22
Pixelligent Presentation on OLED Technology