Quantum Dot Color for Motion Pictures and Television

Presenter: Seth Coe-Sullivan, Co-Founder and CTO
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Your Host

Joel E. Welch
Director of Education
SMPTE

Today’s Guest Speaker

Seth Coe-Sullivan
Co-founder and
Chief Technology Officer
QD VISION, INC.
Outline

• Quantum Dots Background
• Products for Displays
• Color Gamut, Accuracy, Content Delivery and Standards
• Comparisons to Competing Technology
• Roadmap and Conclusions

About QD Vision

- Founded in May 2005 - MIT roots
- First QD Products to market in Display and LED Lighting
- World’s largest QD Mfg. facilities
- Global footprint
- Color IQ™ optics shipping in high volume since Q1-2013
- Multiple MP lines qualified, operating
- High yield production processes for both QDs and final optic assembly
- ISO9000/14001, Green Partner status
Introduction to QDs

Shell
Core
Ligands

Introduction to QDs

Shell
Core
Ligands
Principle of Quantum Confinement

Size of QD provides lever for fine tuning color of emission

Introduction: QD Core Synthesis

Temperature sensor
Precursors
High boiling point Solvent mixture

Heating Mantle >200 C

Particle in a Box Description of Electronic States

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Controlling Size Distribution – La Mer 1950’s

Quantum Yield:
<5% before to >90% after overcoating
QD Manufacturing - Color

Rapid-Injection Method:
- Batch-by-batch approach
- Fast: can run >1 reaction per shift
- Reproducible
- Scaleable model

Color Control:
- ± 1nm of center wavelength
- Corresponds to less than 1Å (Angstrom = 1/10th of 1nm) of diameter
- Corresponds to less than 1/5th of one bond length

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Quantum Dot Optical Component

Quantum Dot Optics deliver OLED color at LCD cost

- Optical components containing light-emitting semiconductor nanocrystal Quantum Dots (QDs).
- Improves typical LCD TV color performance by 50%
- Best available Color-Efficiency combination
- QDs are tuned for optimized spectra, narrowband light emission
- Highly efficient, scalable manufacturing process

Current White LED Solution

Quantum Dots

Consumer Electronics Products

2013 introduction of QD components in consumer electronic devices:

- To improve color and efficiency
- From 7” – 65”
- Tablets and TVs
- FHD to UHD
- Worldwide
Form Factors for all Sized Displays

<table>
<thead>
<tr>
<th>Edge Optic</th>
<th>Film</th>
<th>On-chip</th>
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</thead>
<tbody>
<tr>
<td>QD Optic</td>
<td>QD Film</td>
<td>LGP</td>
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<tr>
<td>LED</td>
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<td>QD LED</td>
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<tr>
<td>LGP</td>
<td>QD Film</td>
<td>Panel</td>
</tr>
<tr>
<td>QD Optic</td>
<td>LGP</td>
<td>LGP</td>
</tr>
</tbody>
</table>

Source: Nanosys Online Media Kit
Source: LumenMax Optoelectronics

White LED Spectrum for LCD Systems

This blue line depicts the typical white LED spectrum after the Color Filter Array (CFA).

In a typical LCD TV, you only want the blue, green and red portions of this spectrum. Most of the other light contributes to desaturation.
Quantum Dot Optics-Optimal for LCD Systems

- Narrow band blue, green and red delivers highly saturated colors
- Saturated colors significantly expand color gamut

Quantum Dot Optics provide narrow band QD light emission optimized for LCD

Typical white LED spectrum after CFA

30-35nm FWHM typical

- Precise tunable spectrums

WAVELENGTH (nm)

Quantum Dot Optimizes LCD Color Gamut

Quantum Dot optics offer the only LCD full gamut (FG) solution:

- FG is >100% NTSC, Adobe RGB, or DCI gamut area
- Maximizes LCD color performance with existing color filter array
- Cost-effective color gamut enhancement
Visualizing Wide Color Gamut

Radiant Reds  Gorgeous Greens  Beautiful Blues

But you have to see it to believe it...

CES 2013: Sony Debuts Triluminos LCD TVs

- 10 Sony Triluminos LCD TVs include QD Vision Color IQ™ Optics
- TV models on the market now, worldwide
- 100% NTSC color gamut performance
- Sony won “Best in Show” Award from TechRadar for their new LCD TV with Color IQ Optics
- Sony also won a Blue Ribbon for best Home Theater product for their Triluminos TV with Color IQ Optics.
### Ten TV Models In the Market

<table>
<thead>
<tr>
<th>Four TV Series</th>
<th>N.America</th>
<th>S. America</th>
<th>Europe</th>
<th>Asia</th>
<th>RoW</th>
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<tr>
<td>XBR-65X900A</td>
<td>65</td>
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<tr>
<td>XBR-55X900A</td>
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<tr>
<td>55”, 65” (4K)</td>
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<td>KDL-55W905A</td>
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<td>KDL-40W905A</td>
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<td>46</td>
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<tr>
<td>46”, 55” FHD</td>
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<tr>
<td>KDL-55W950A</td>
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<tr>
<td>KDL-46W950A</td>
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<td>55</td>
<td>46</td>
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<tr>
<td>KDL-42W850A</td>
<td>42”, 47”, 55” FHD</td>
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</tbody>
</table>

- **Award winner**

### Outline

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**FG enables Accuracy and Colorfulness**

- 100% Accuracy in Rec.709
- DCI Colorfulness
- 100% Accuracy in AdobeRGB
- AdobeRGB Colorfulness
- Rec.709 signal + Gamut expansion
- DCI signal + Color Control
- Rec.709 signal + Color Control
- Adobe signal + Color Control

**Accurate sRGB Signal with Color Control**

- Image captured in sRGB/REC709
- Display with less than sRGB/REC709 gamut Inaccurate
- Display with sRGB/REC709 gamut Accurate
- Add Color Control Algorithm
- Display with wide gamut Inaccurate

Courtesy of: PORTRAIT DISPLAYS
Accurate and Colorful Full Gamut

Content captured in wide gamut; AdobeRGB, DCI-P3

Display with sRGB/REC709 gamut inaccurate

Displayed on a wide gamut display accurate

Courtesy of:

PORTRAIT DISPLAYS

Content Delivery of Today

Capture → Broadcast → Display

Courtesy of:
nanosys
Broadcast Bottleneck Gone

Capture  Deliver  Display

 Courtesy of: nanosys

Content Delivery of Tomorrow

Capture  Deliver  Display

Color Management

 Courtesy of: nanosys
### UHD Standardization

Current broadcaster thinking on UHD Services

<table>
<thead>
<tr>
<th></th>
<th>UHD-0</th>
<th>UHD-1</th>
<th>UHD-2</th>
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</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>3840x2160</td>
<td>3840x2160</td>
<td>7680x4320</td>
</tr>
<tr>
<td>Frame Rate</td>
<td>50 / 60p</td>
<td>100 / 120p</td>
<td>100 / 120p</td>
</tr>
<tr>
<td>Bit depth</td>
<td>10 (display; some services may be 8)</td>
<td>10</td>
<td>10/12/14</td>
</tr>
<tr>
<td>Color Gamut</td>
<td>BT.709</td>
<td>BT.2020 (subset)</td>
<td>BT.2020 (more)</td>
</tr>
<tr>
<td>Dynamic Range</td>
<td>Current</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Courtesy of: [DISPLAY SEARCH](http://www.display-search.com)

### Towards Rec 2020 with QDs

Graph showing color gamut and dynamic range comparisons. The graph illustrates the current Rec 2020 standard, QD technology, and potential improvements with Quantum Dot (QD) technology. The graph also shows the potential for a broader color gamut and improved dynamic range compared to traditional phosphor lighting systems.
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2012 View of TV Technologies

“OLED TV is here, will QDs ever really arrive?”

Why OLED?

- I started a PhD at MIT in 2000 with a leading OLED scientist from Princeton and UDC – we knew ‘why OLED’:
  - 50% boost in color gamut
  - 10x boost in power efficiency
  - 25x thickness reduction - inches to millimeters
  - 1000x response speed increase
  - 1000x boost in contrast
  - 50% reduction in BoM costs
  - 2x increase in viewing angle
  - Low cost manufacturing modes (R2R, additive)
  - New display modes (transparent, flexible)

We just needed to solve, blue, lifetime, ink-jet, etc.

Benchmarking OLED TVs

<table>
<thead>
<tr>
<th>Samsung KN55S9C</th>
<th>LG 55EA9800</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TV Size</strong></td>
<td>55”</td>
</tr>
<tr>
<td>Panel Resolution</td>
<td>1920x1080</td>
</tr>
<tr>
<td>Max Brightness</td>
<td>452 nits</td>
</tr>
<tr>
<td>White Point (CIEx,CIEy)</td>
<td>(0.313,0.329)</td>
</tr>
<tr>
<td>% NTSC (Coverage-CIE1976)</td>
<td>98%</td>
</tr>
<tr>
<td>% DCI (Coverage-CIE1976)</td>
<td>94%</td>
</tr>
<tr>
<td>Max Power Consumption (W)</td>
<td>300</td>
</tr>
<tr>
<td>Efficiency (nits/W)</td>
<td>1.5</td>
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<tr>
<td><strong>TV Size</strong></td>
<td>55”</td>
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<tr>
<td>Panel Resolution</td>
<td>1920x1080</td>
</tr>
<tr>
<td>Max Brightness</td>
<td>372 nits</td>
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<tr>
<td>White Point (CIEx,CIEy)</td>
<td>(0.279,0.287)</td>
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<tr>
<td>% NTSC (Coverage-CIE1976)</td>
<td>89%</td>
</tr>
<tr>
<td>% DCI (Coverage-CIE1976)</td>
<td>92%</td>
</tr>
<tr>
<td>Max Power Consumption (W)</td>
<td>215</td>
</tr>
<tr>
<td>Efficiency (nits/W)</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Due to OLED technology, brightness & power consumption are dependent on picture content.

Sources: DisplayMate, CNET Review, AVSForum, Crutchfield
QD TVs Have Better Color and Efficiency Than OLED

### KDL-55W900A (2K)
- **TV Size**: 55"
- **Panel Resolution**: 1920x1080
- **Max Brightness**: 366 nits
- **White Point (CIE, CIE)**: (0.294, 0.294)
- **% NTSC (Coverage-CIE1976)**: 90%
- **% DCI (Coverage-CIE1976)**: 95%
- **Max LED Power Consumption (W)**: 90
- **Efficiency (Watts/W)**: 4.0

### XBR-55X900A (4K)
- **TV Size**: 55"
- **Panel Resolution**: 4K (3840x2160)
- **Max Brightness**: 399 nits
- **White Point (CIE, CIE)**: (0.287, 0.293)
- **% NTSC (Coverage-CIE1976)**: 100%
- **% DCI (Coverage-CIE1976)**: 98%
- **Max LED Power Consumption (W)**: 150
- **Efficiency (Watts/W)**: 2.6

#### Comparing The Products

**Color IQ™ 55” LCD TV**
- 100% NTSC, Full Gamut
- Thin Design
- Available in FHD and UHD
- $1,529 for FHD (UHD $3,000)
- High yield, in high volume production and on market today

**55” OLED TV**
- <100% NTSC Color
- Thin Design
- Only available in FHD
- $6,000 to 15,000
- Production yield is a key issue. Reports on production readiness vary
Why OLED? 2014 View

- 50% boost in color gamut
- 10x boost in power efficiency
- 25x thickness reduction—_inches to millimeters
- 1000x response speed increase
- 1000x boost in contrast (with the lights out)
- 50% reduction in BoM costs
- 2x increase in viewing angle
- Low cost manufacturing modes (R2R, additive)
- New display modes (transparent, flexible)

Problems with blue, lifetime, ink-jet, manufacturing, etc.

2014 View of TV Technologies

QD TV is here, will OLEDs ever really arrive?

And by then, won’t OLEDs do the same thing but better?
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QD Product Evolution

The Past:
- Biology
- Remote Lighting Plates
- On-edge TV BLUs

The Present:
- MORE On-edge TV BLUs
- On-edge Monitor BLUs
- On-edge All-in-one Computer BLUs

The Future:
- Laptop BLUs
- Tablet BLUs
- Cellphone BLUs
- Lighting Re-entry
- Cellphone QLEDs
Conclusions

Quantum Dots are a nanomaterial technology bringing color accuracy and gamut expansion to LCDs, and are commercially available today.

QD Vision’s Quantum Dots:
- Best color-efficiency combination available
- Color gamut expansion
- Increased color accuracy
- Without waiting for “tomorrow’s technology”

Q & A

Seth Coe-Sullivan
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QD VISION, INC.