High Efficiency LCDs using Quantum Dots

Jian Chen, Nanosys
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About Nanosys

- Founded in 2001 in the Silicon Valley, California
- First company to focus on Quantum Dots for Electronics
- #1 Quantum Dot IP Position
  - 211 world-wide granted patents, 73 pending
  - Technology from MIT, LBL, Life Technologies, Philips-Lumileds
• Nanosys operates a 60,000 sq ft state-of-the-art nano-material fab in Milpitas, CA

• Installed capacity equivalent to more than 100M tablet displays per year
  
  • >20,000kg QD Concentrate/year, expanding to >50,000kg/year in 2014

• More than 2000 kg of QD concentrate delivered to market in 2013
Outline

- Background Information
  - Evolution of LCD Color Performance
  - Quantum Dot (QD) and QD Film for LCDs

- High Efficiency sRGB Display using QD Film

- High Efficiency High Color Gamut Display – DCI-P3 Enabled by QD Film

- Conclusions
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Back Lights for Flat Panel Displays
From CCFL to LEDs

Cold Compact Fluorescent Lamp (CCFL)

LEDs

Relative intensity vs. Wave length (mm)

Subpeak ≠ not pure RGB

Relative intensity vs. Wave length (mm)

No subpeak = ideal backlight spectrum
Backlights with **RGB** LEDs

- **RGGB** used due to **lower efficiency** of green LEDs
- Real-time feedback needed to keep the correct white point due to color drifts mostly in green & red LEDs
- High system cost
White LEDs – sRGB ~ 70% NTSC

- White LEDs with high efficiency blue LED chips combined with yellow phosphor have become industry standard
- Compromise on color: sRGB ~70% NTSC
New Generation Phosphor: Quantum Dots

- Core/shell quantum dots
- High QY: ~90%
- Long-term stability
- Narrow FWHM, 30-40nm, highly saturated colors
Quantum Dot Enhancement Film – QDEF

- QDs embedded in organic polymer
- Continuous roll-printed sheet
- Replaces bottom diffuser

[Image of a diagram showing layers including QDEF, back plate, reflector sheet, blue LEDs, and light guide.]
Backlight Unit with **White** LEDs

- Liquid crystal module
- Top diffuser
- Horizontal BEF
- Vertical BEF
- Bottom diffuser
- Light Guide Plate
- Reflector
Liquid crystal module

Top diffuser

Horizontal BEF

Vertical BEF

QDEF

Light Guide Plate

Reflector

- Blue LEDs replaces white LEDs
- QD Film replaces bottom diffuser
Roll-to-Roll Process for QDEF

- QDEF manufactured by roll-to-roll processing
- Gold Award, 2012 SID display component of the year
- QDEF supplied by
  - 3M
  - LMS
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In LCD, each pixel consists of R, G, and B sub-pixels. By using white backlights and color filters, R/G/B primary colors are created.
Creating Primary Colors using White LEDs for Standard & High Color Gamut. Example Green

- Narrow band-pass color filters need to be used to carve out the primary color from a broad white light source.
- For high color gamut displays, even narrower-band color filters need to be used. More light is thrown away.
Creating Primary Colors using QDs
Color Filters Only Need to Filter Out Other Peaks – Example Green

Backlight Spectrum
White LED

Green Color Filter

Green Spectrum on Display for white LED

High gamut

Backlight Spectrum
Blue LED + QD

Green Color Filter

Green Spectrum on Display for blue LED + QD

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Higher Efficiency LCD using QDs for sRGB

- 1st QDEF product used in tablet for sRGB: 20% power efficiency improvement over white-LEDs
- QDs use higher transmission color filters
- Perfect sRGB for accurate color reproduction
  - Important for online merchandize
Power Saving for sRGB Display and Battery Life for Mobile Devices

20% higher efficiency in display translates to ~10% smaller battery pack for the same battery life.
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sRGB displays can only show about one third of the colors your eye can see, and far less than the artistic intent of content creators.

[Diagram showing CIE 1976 Chromaticity Diagram with sRGB and DCI-P3 regions highlighted.]

Missing: London Bus Red

Missing: Pacific Surf Cyan
High Color Gamut LCDs using QD Film
E.g., DCI-P3

By changing QD wavelengths (shorter $\lambda_{\text{green}}$ and longer $\lambda_{\text{red}}$) and combining with current CF72 color filters, DCI-P3 displays are obtained.
Demo: DCI-P3 LCD Display using QD Film

QD Film Demo

Control
Demo: LCD with DCI-P3 Gamut using QD Film

<table>
<thead>
<tr>
<th></th>
<th>White LED Control</th>
<th>Blue LED + QD Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>sRGB Coverage</td>
<td>90.3%</td>
<td>99.8%</td>
</tr>
<tr>
<td>DCI-P3 Coverage</td>
<td>73.1%</td>
<td>97.4%</td>
</tr>
<tr>
<td>Brightness (nits)</td>
<td>340</td>
<td>366</td>
</tr>
</tbody>
</table>
By combining QD film with high efficiency blue LEDs, high color gamut displays (e.g., DCI-P3) have become possible with comparable power efficiency as current sRGB LCDs using white LEDs.
High Gamut Display – Asus ZenBook NX500 15.6”
3840x2160 Resolution & 100% NTSC/108% Adobe-RGB
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• Quantum dots have already emerged from a novelty material to a commercial product. QDs and QD film have been manufactured on large scale with robust supply chain for the LCD industry.

• For sRGB displays, QD film offers 20% higher efficiency than existing LCDs using white LED backlights.

• QD film enables high efficiency high color gamut LCDs, e.g., DCI-P3, with comparable efficiency as current sRGB LCDs. The era of high gamut LCDs has come through the use of QD technology.
Thank You!