High Efficiency LCDs using Quantum Dots

Jian Chen, Nanosys

NCCAVS Thin Film Users Group (TFUG), July 15 2014

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

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Nanosys Today

- 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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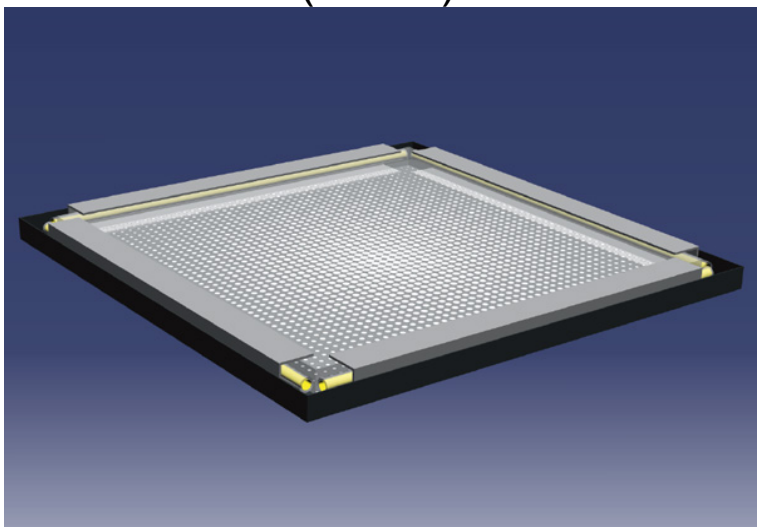
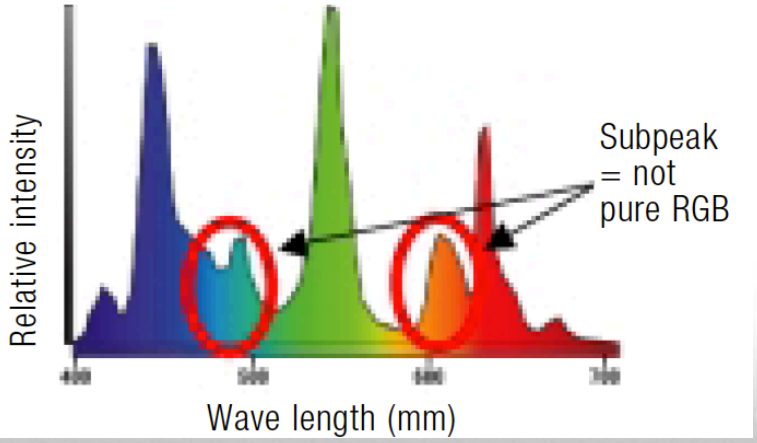
Back Lights for Flat Panel Displays
From CCFL to LEDs

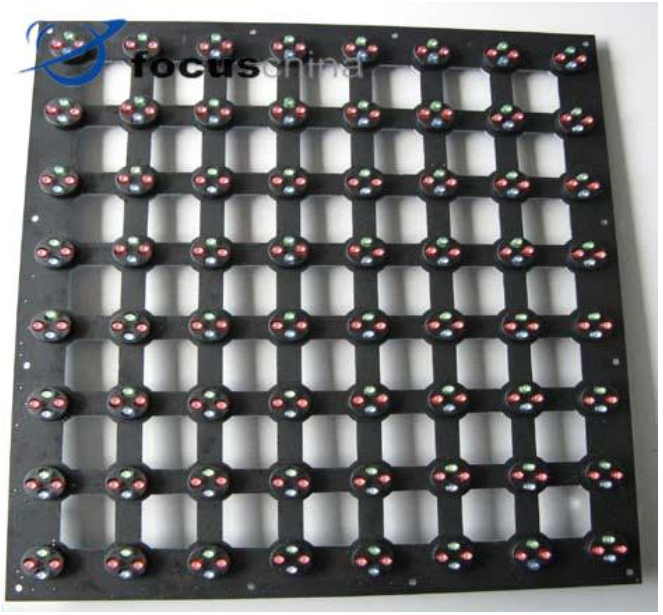
Cold Compact Fluorescent Lamp

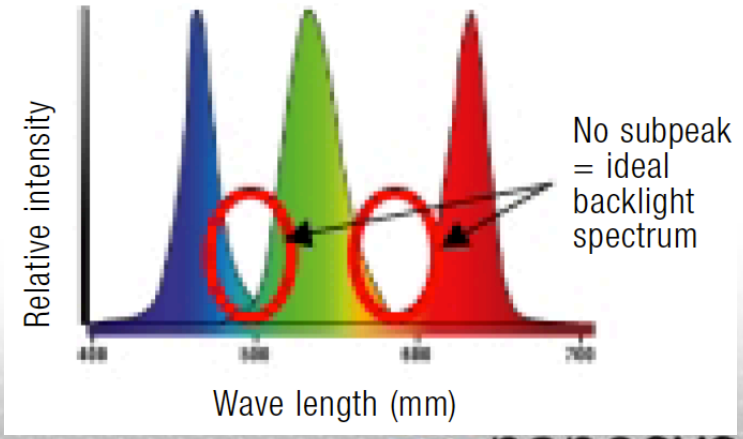
(CCFL)





LEDs





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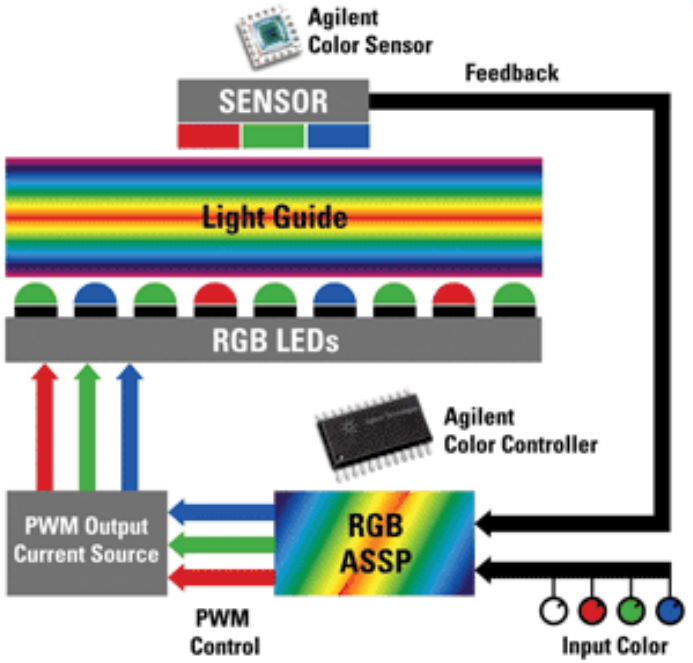
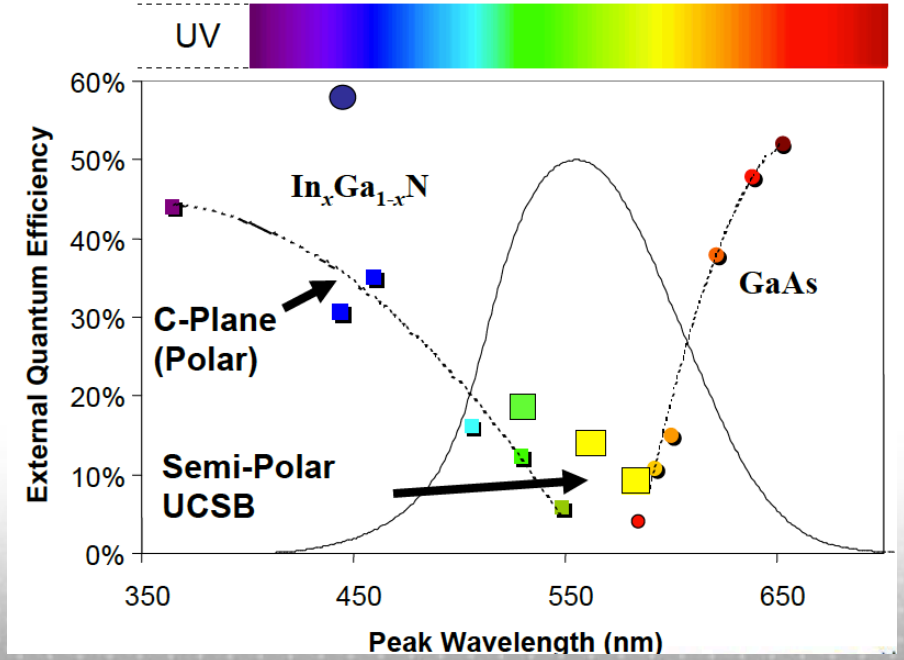
Backlights with RGB LEDs





- 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**

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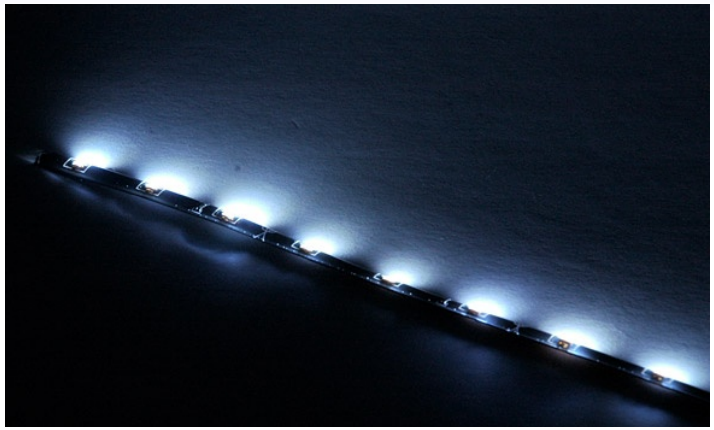
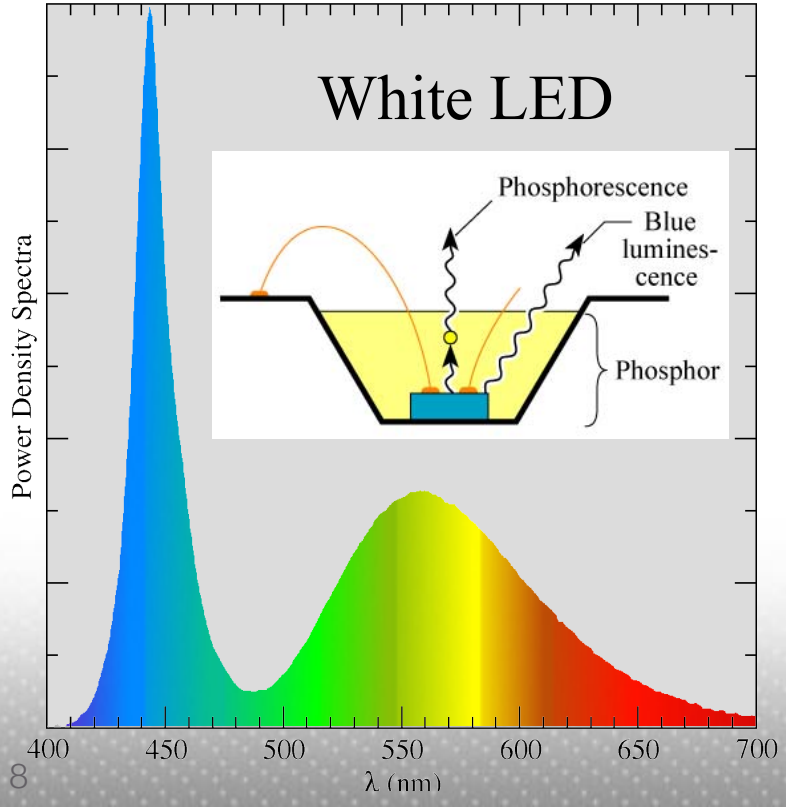
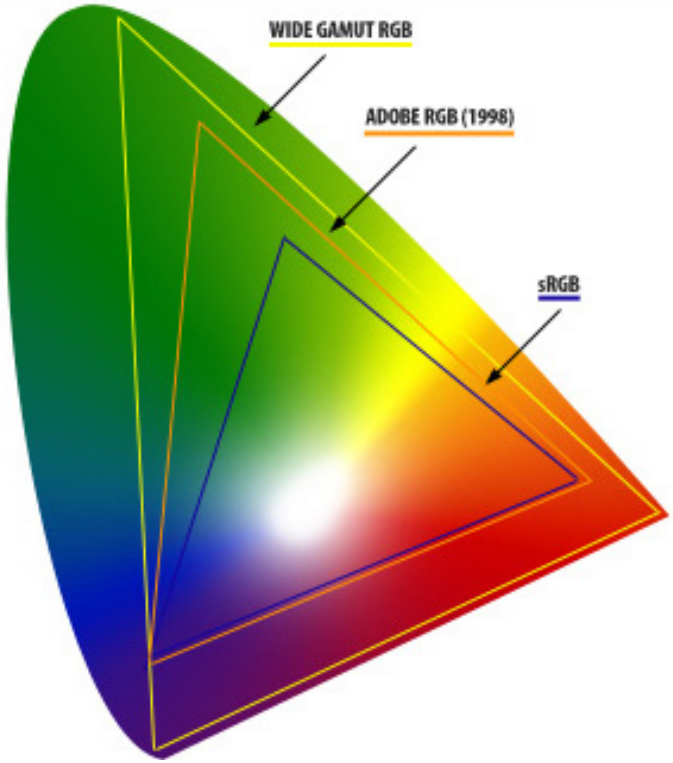
Steve DenBaars, DOE SSL Market Introduction Workshop 2008

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**

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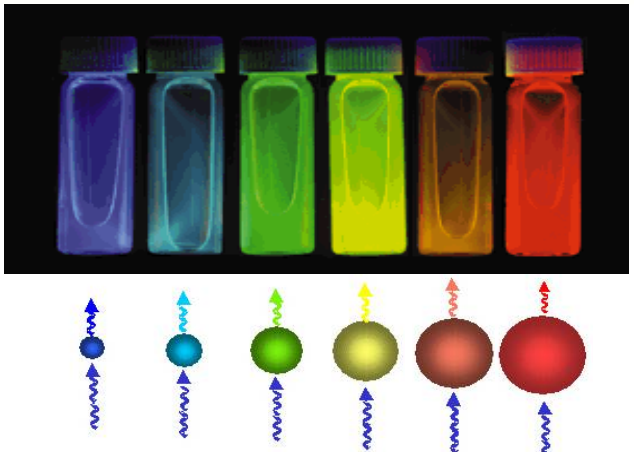
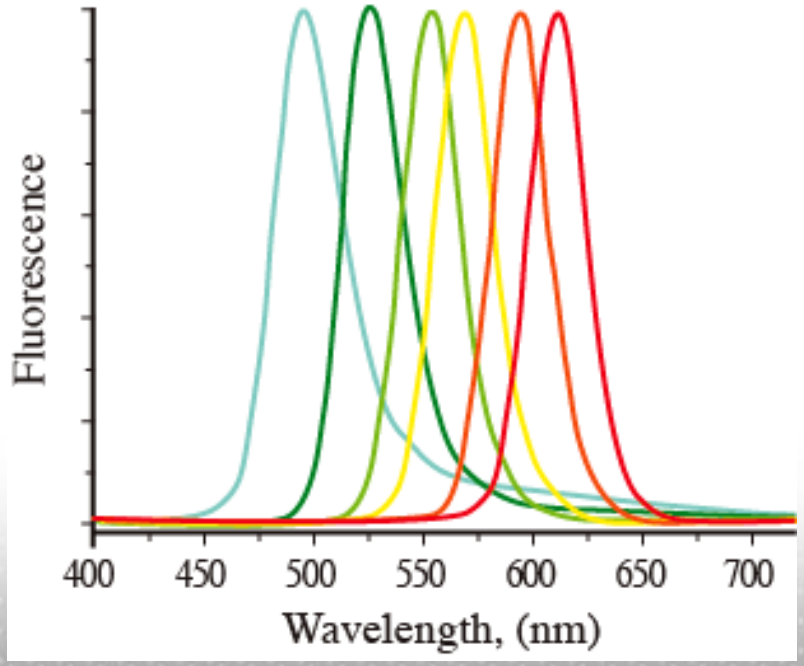
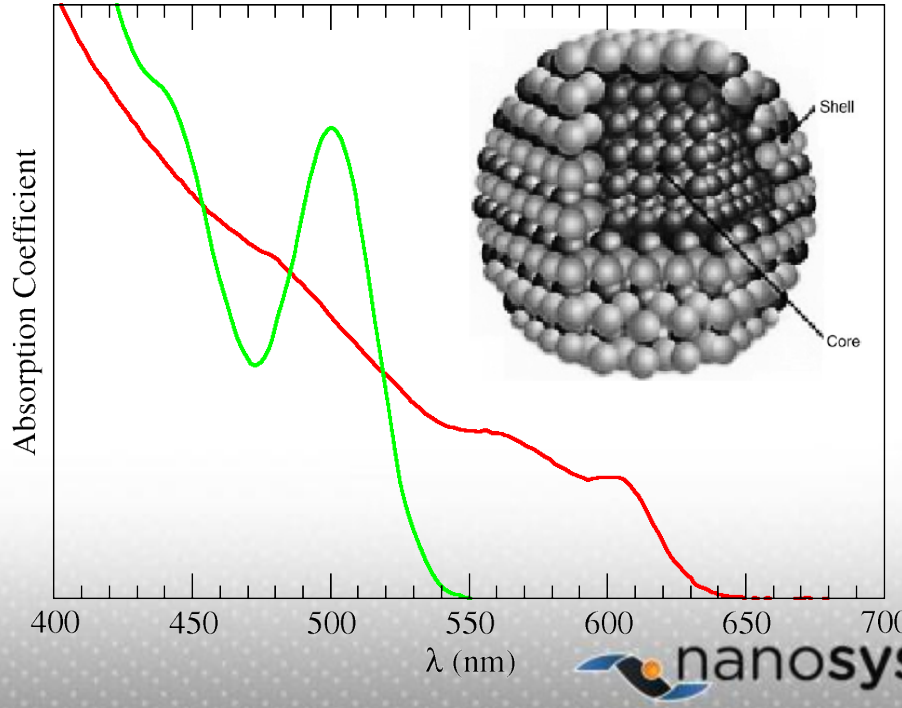
New Generation Phosphor: Quantum Dots



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





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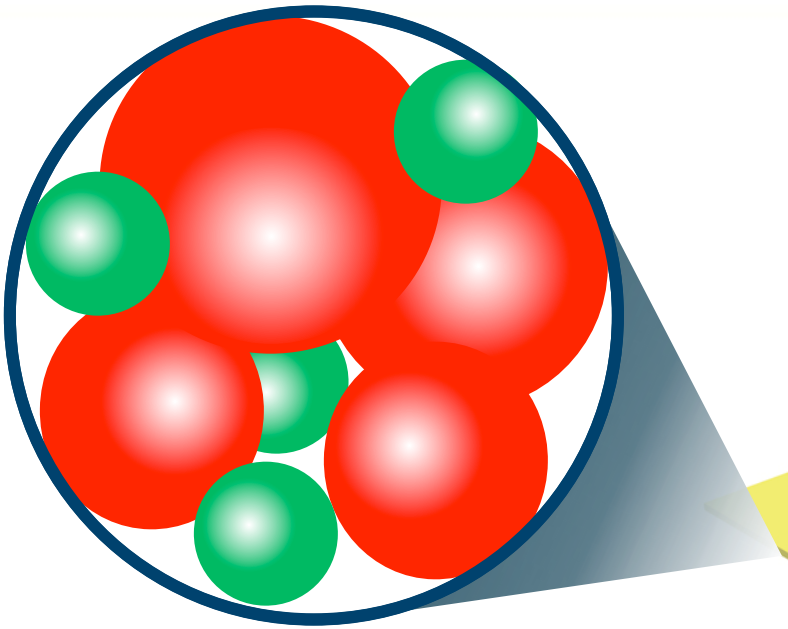
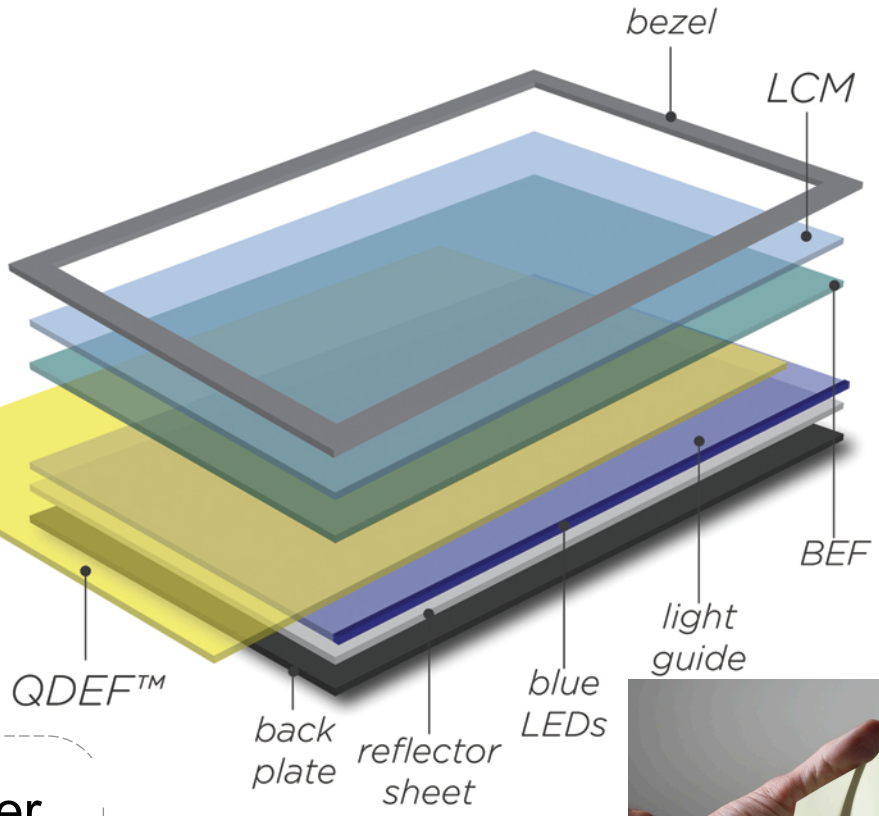
Quantum Dot Enhancement Film – QDEF





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

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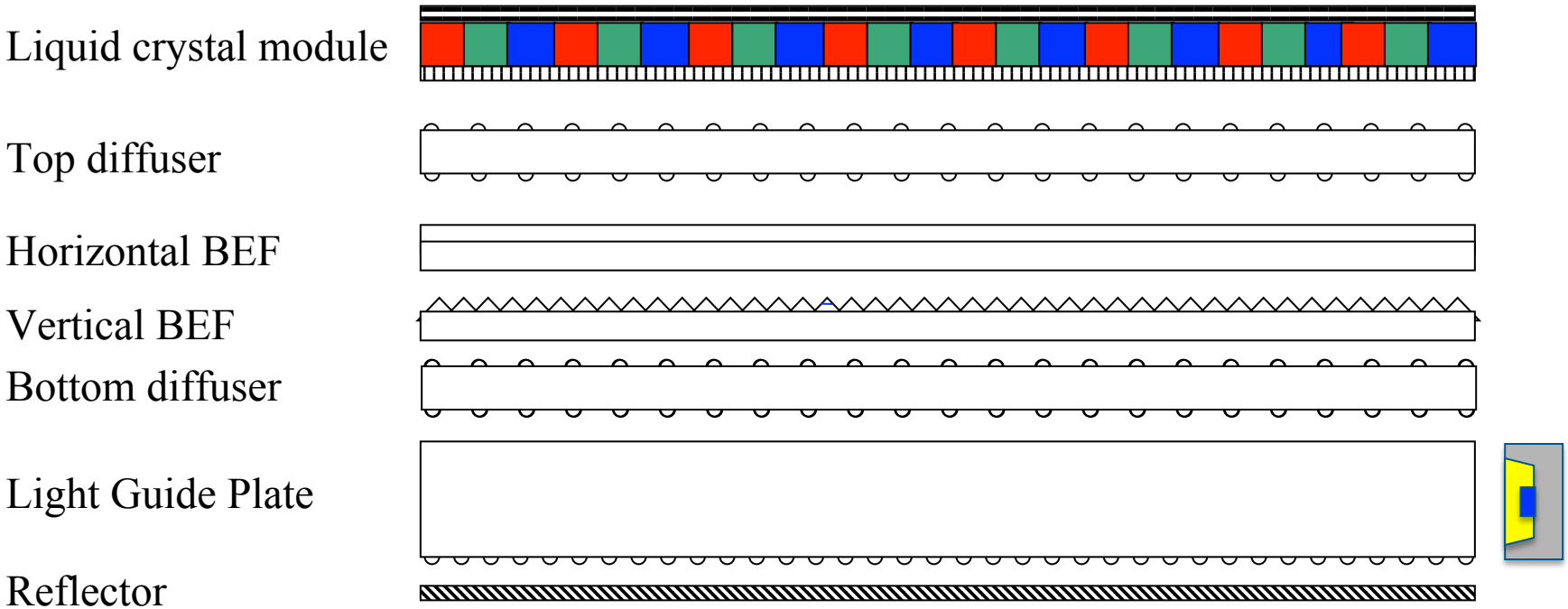
Backlight Unit with **White** LEDs



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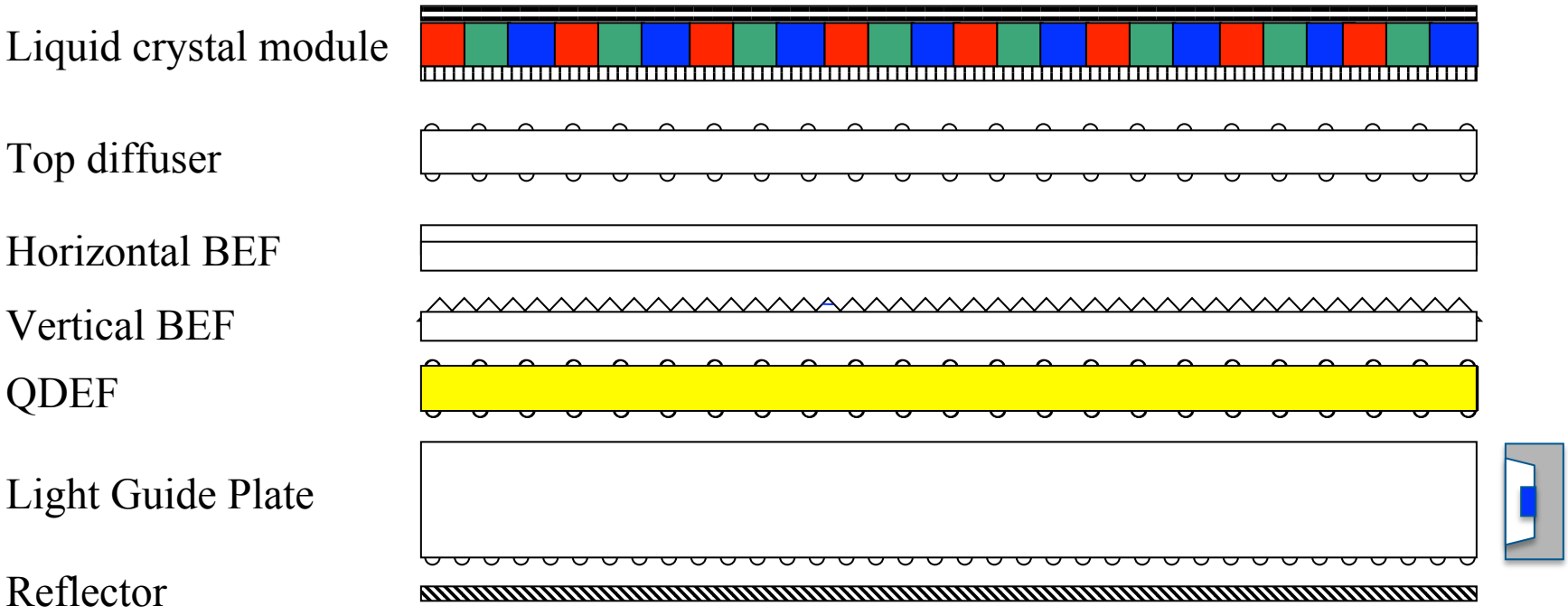
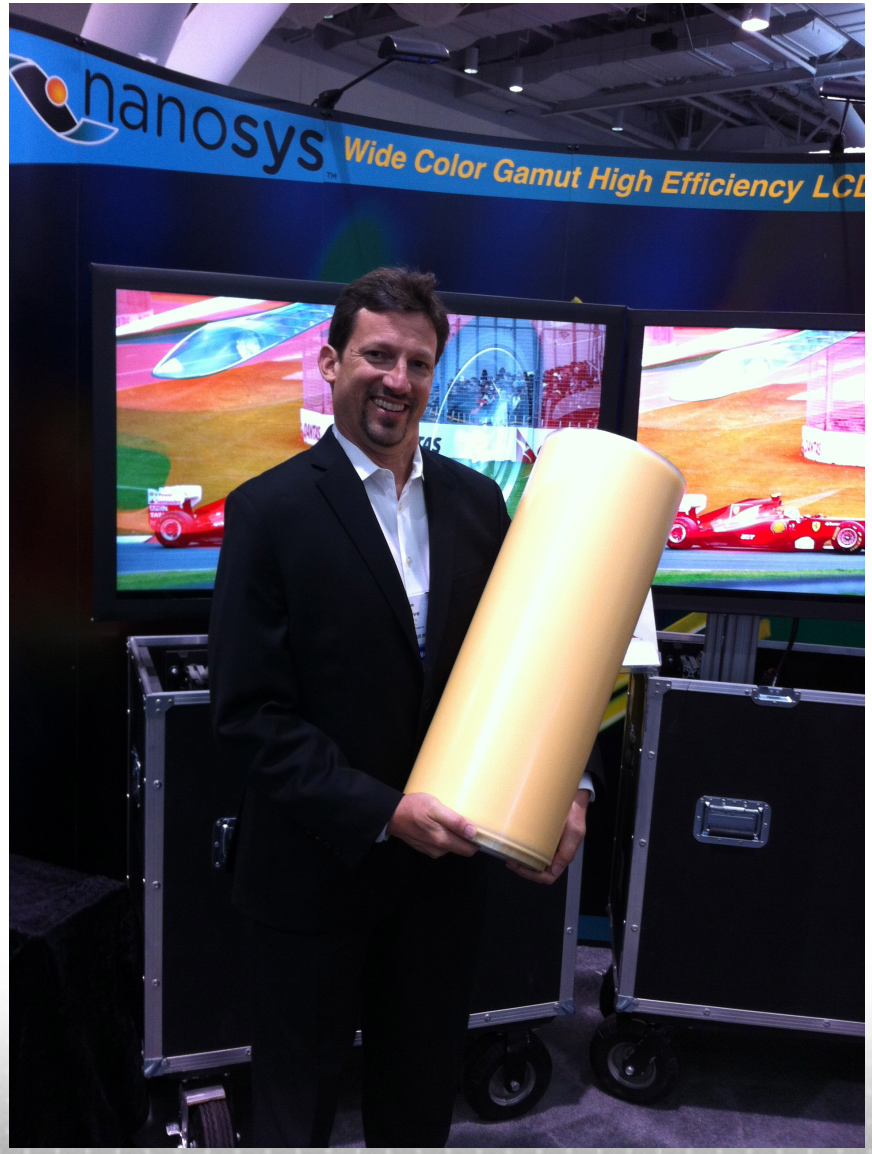
Backlight Unit with **Blue** LEDs **+ QD** Film



- 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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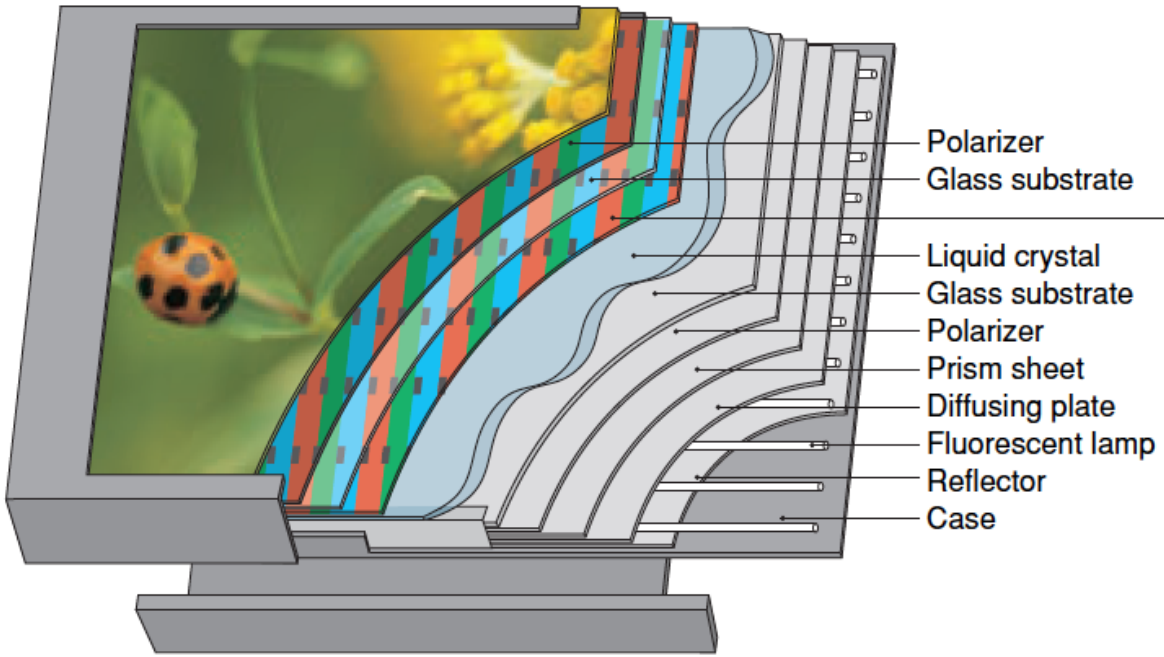
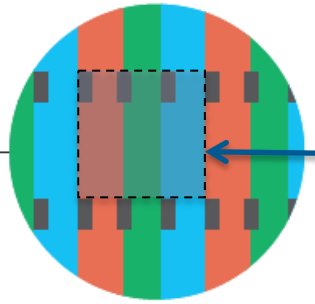
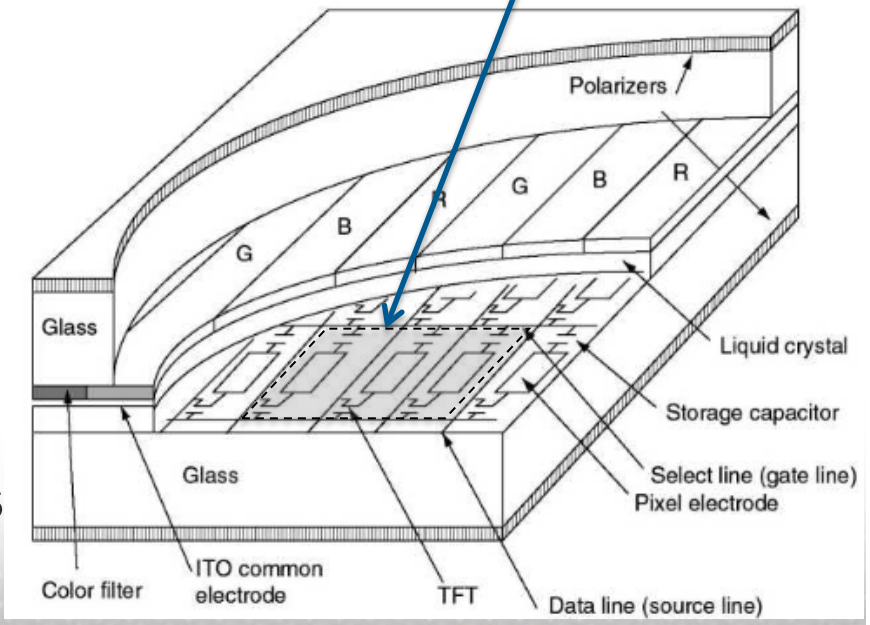
Creation of Primary Colors in LCD

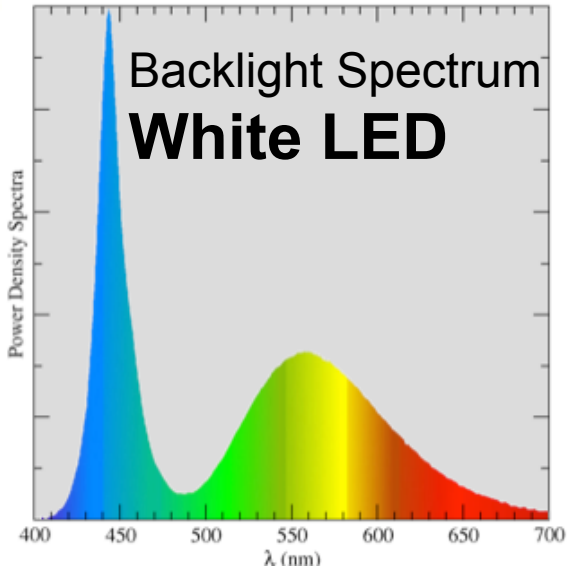


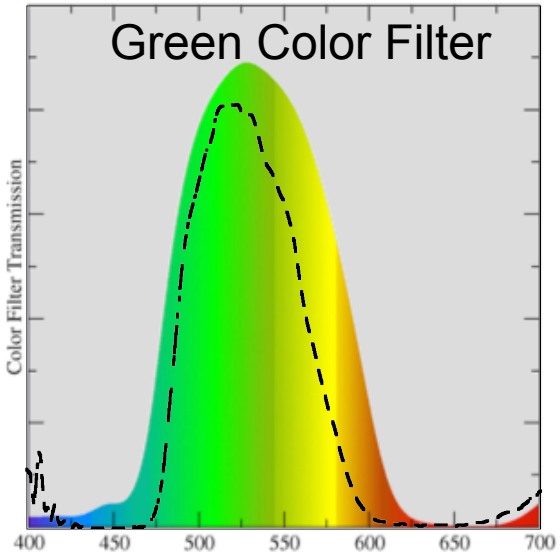


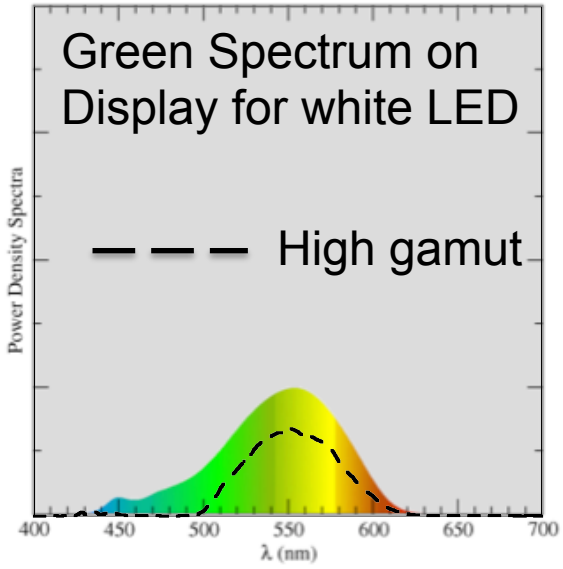


- In LCD, each pixel consists of R, G, and B sub-pixels
- By using white backlights and color filters, R/G/B primary colors are created

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

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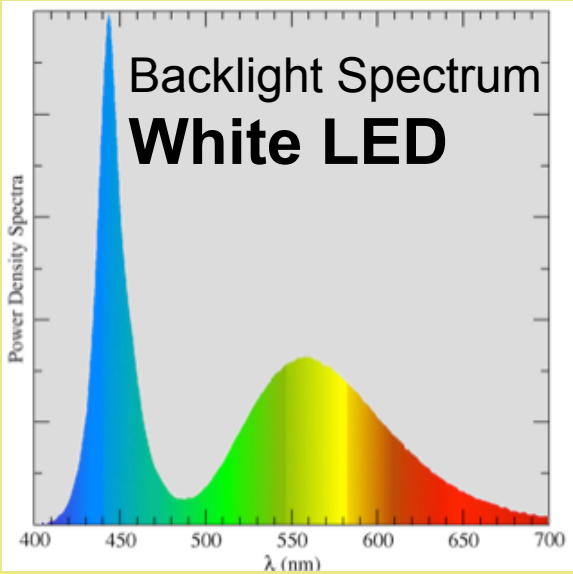
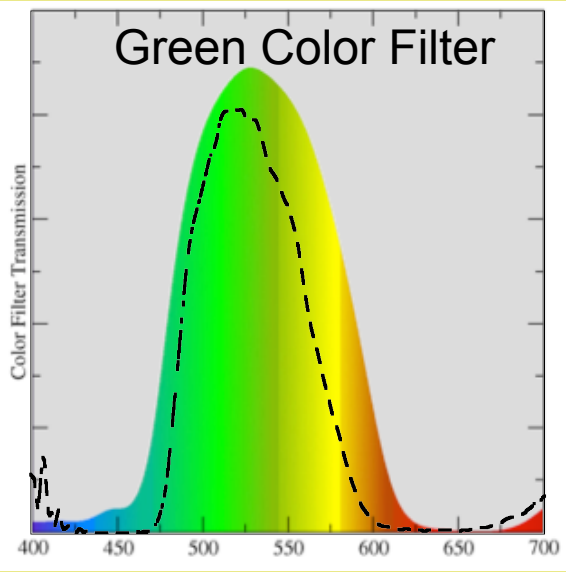
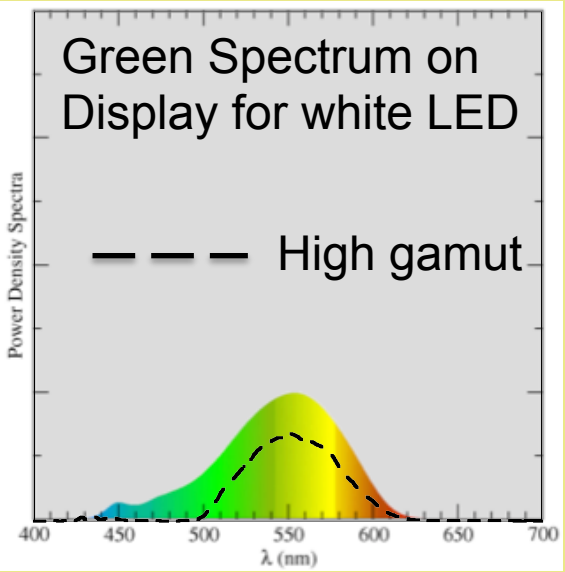
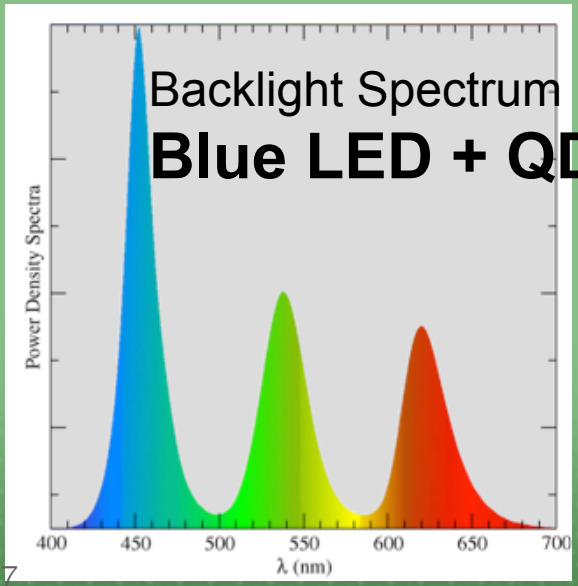
Creating Primary Colors using QDs

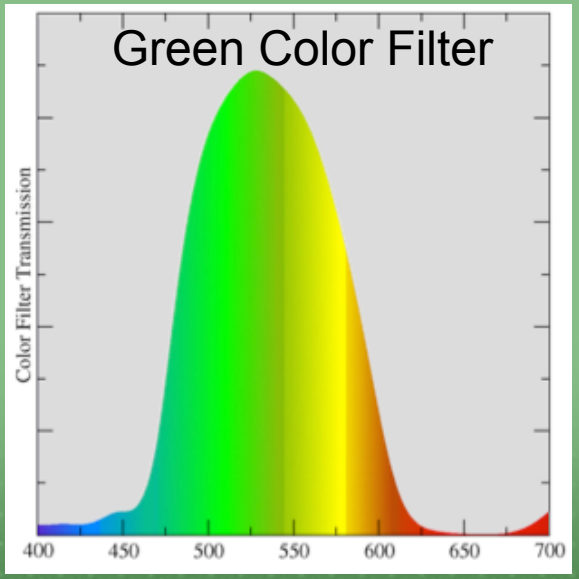
Color Filters Only Need to Filter Out Other Peaks – Example Green

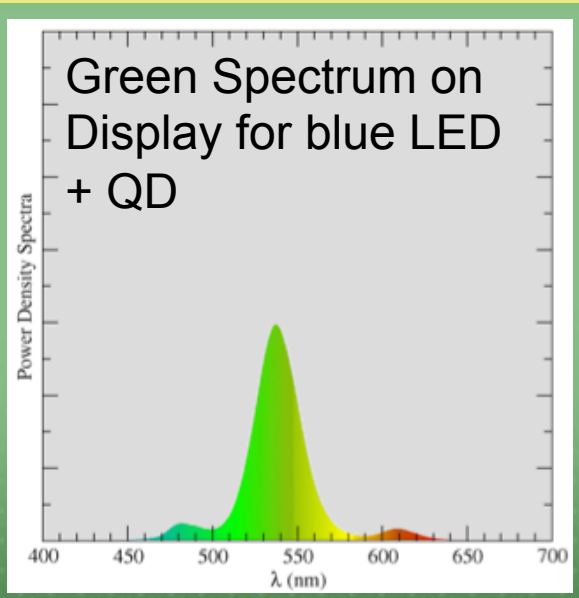






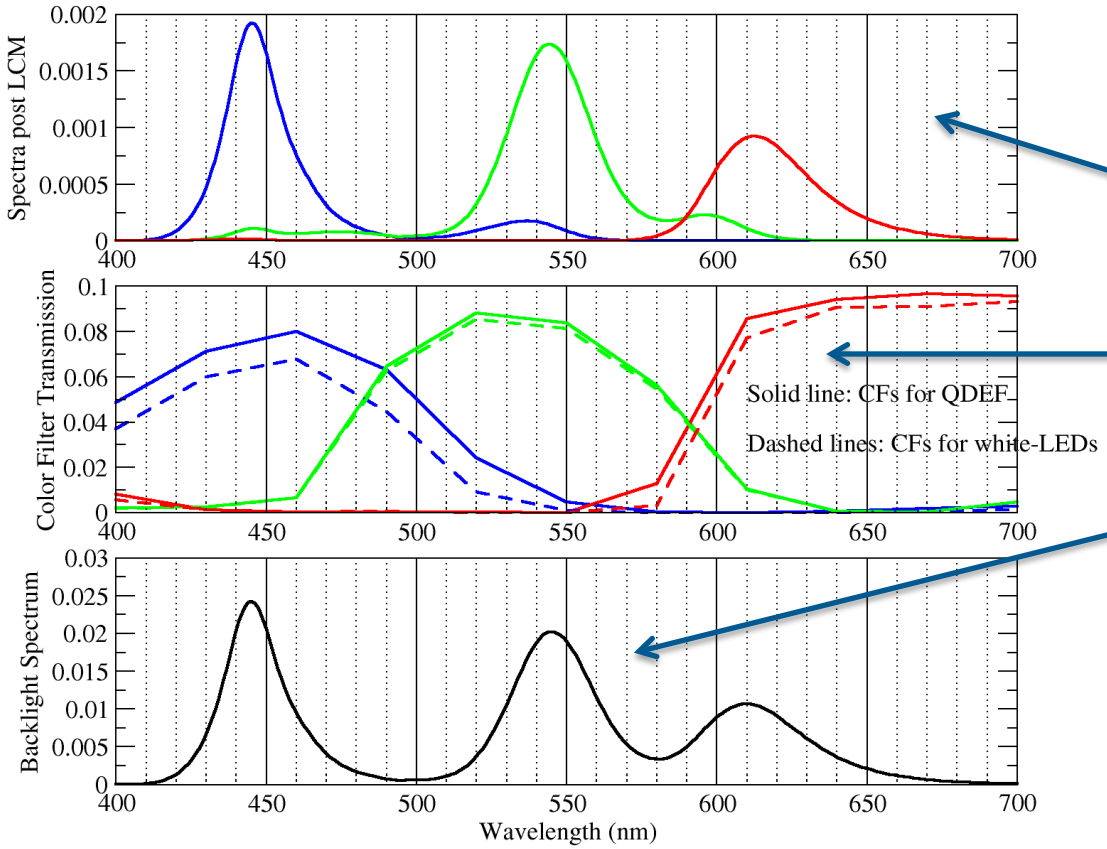


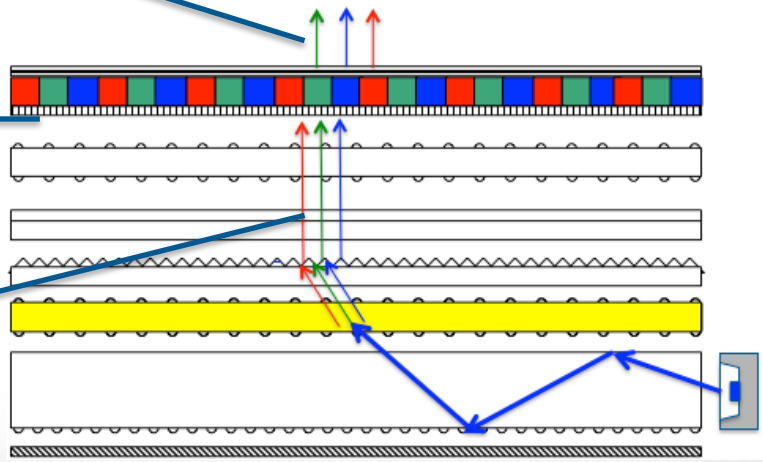




Higher Efficiency LCD using QDs for sRGB

- 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





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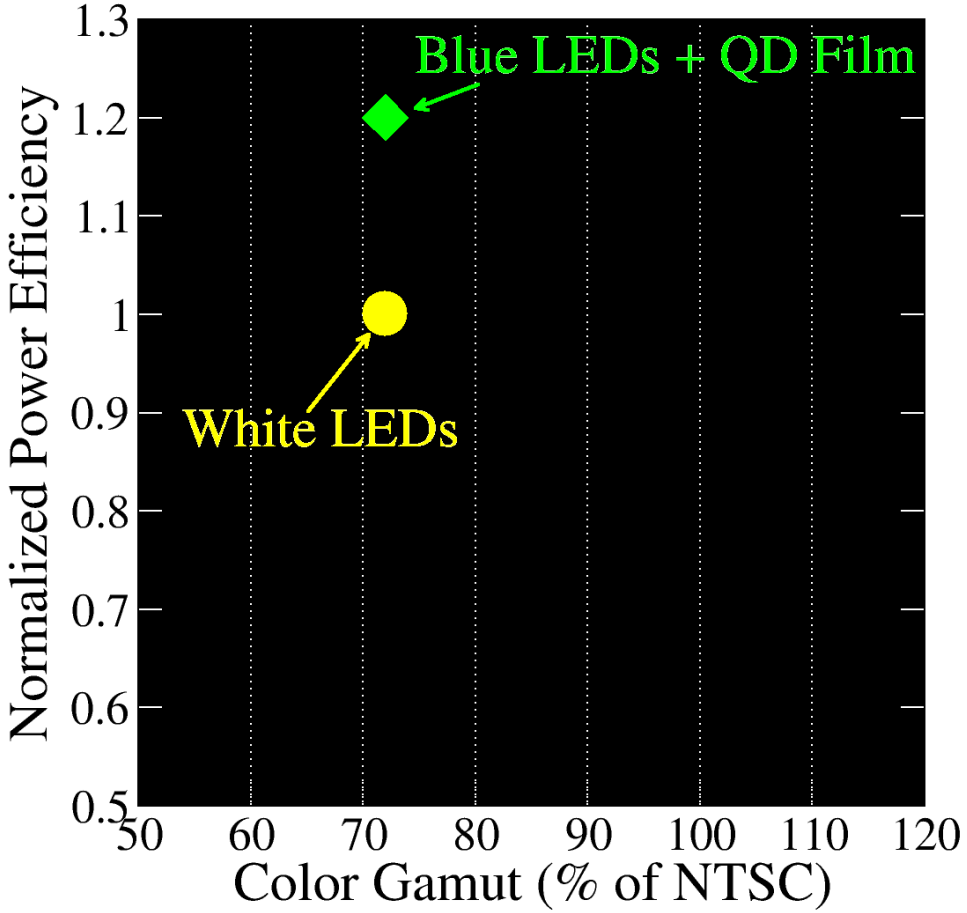
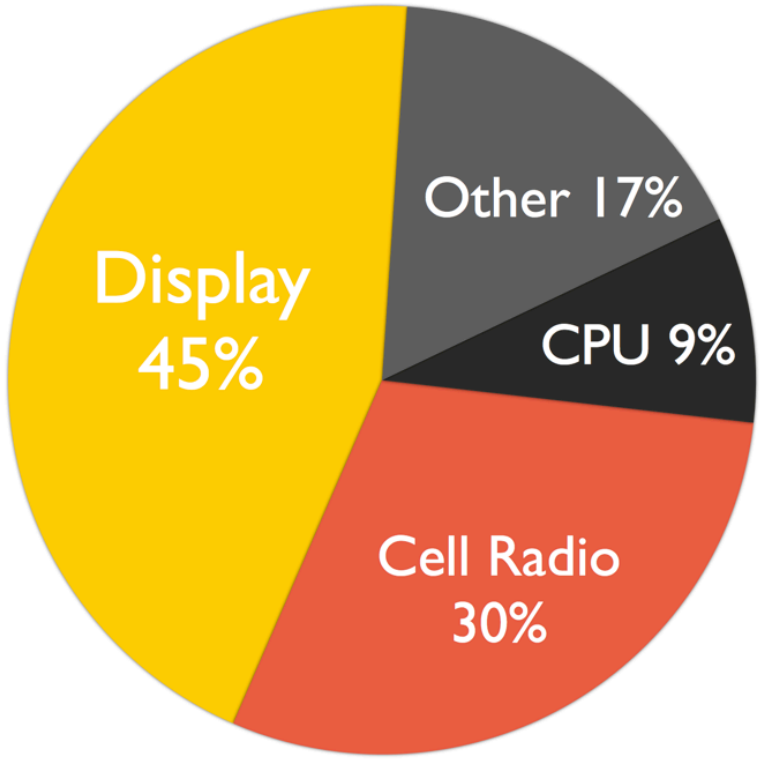
Power Saving for sRGB Display and Battery Life for Mobile Devices





Source: DisplaySearch

20% higher efficiency in display translates to ~10% smaller battery pack for the same battery life

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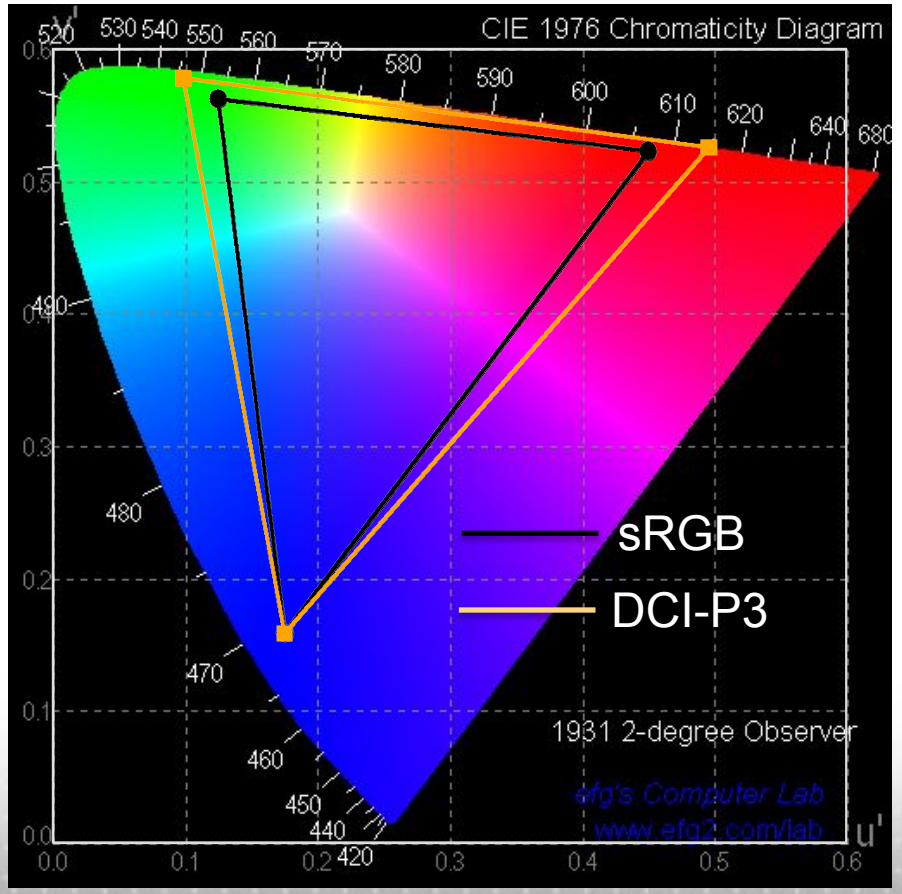
More Compelling and Realistic Images and Video

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



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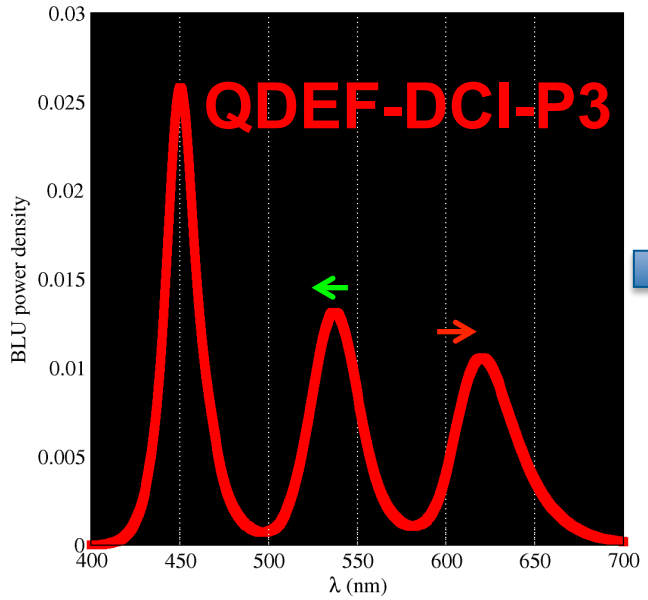
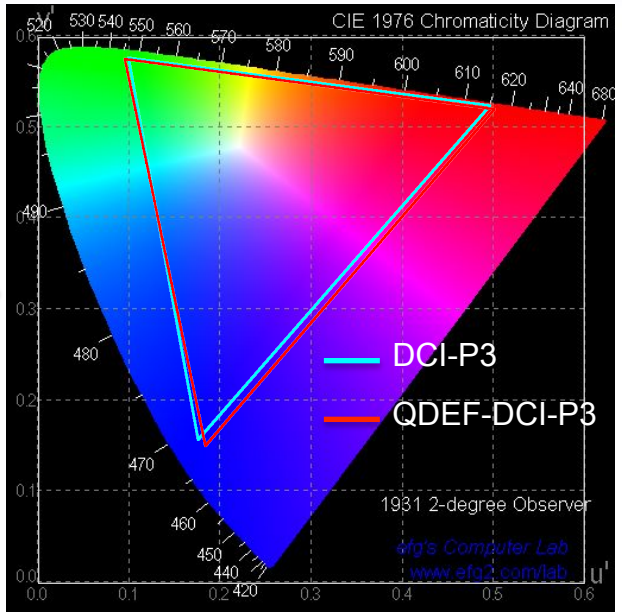
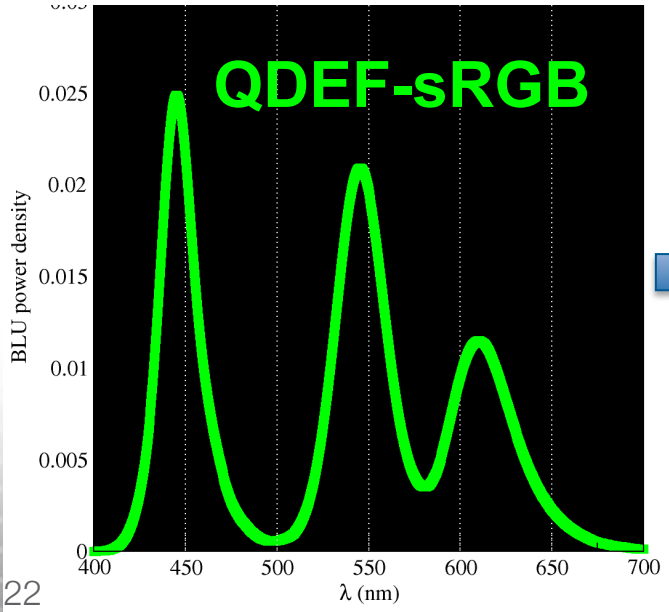
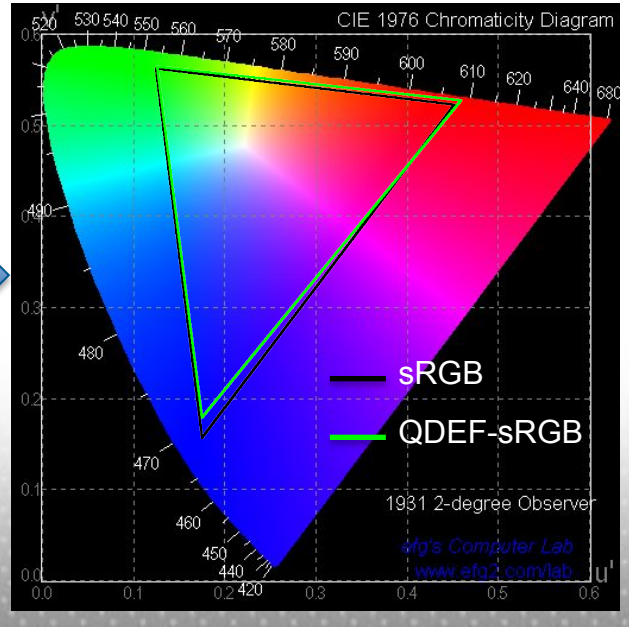
High Color Gamut LCDs using QD Film
E.g., DCI-P3









By changing QD wavelengths (shorter λ_{green} and longer λ_{red}) and combining with current CF72 color filters, DCI-P3 displays are obtained

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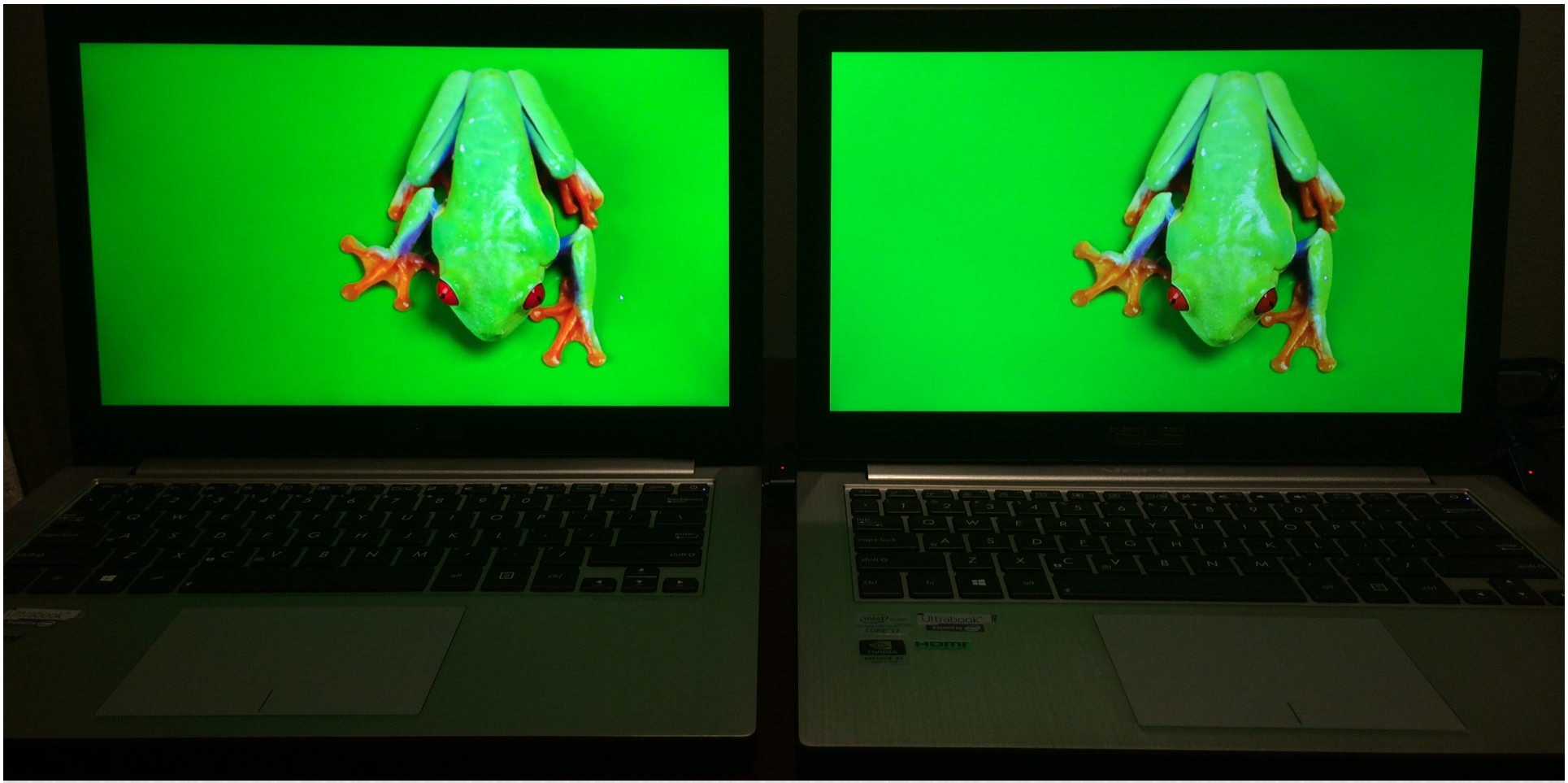
Demo: DCI-P3 LCD Display using QD Film

QD Film Demo

Control



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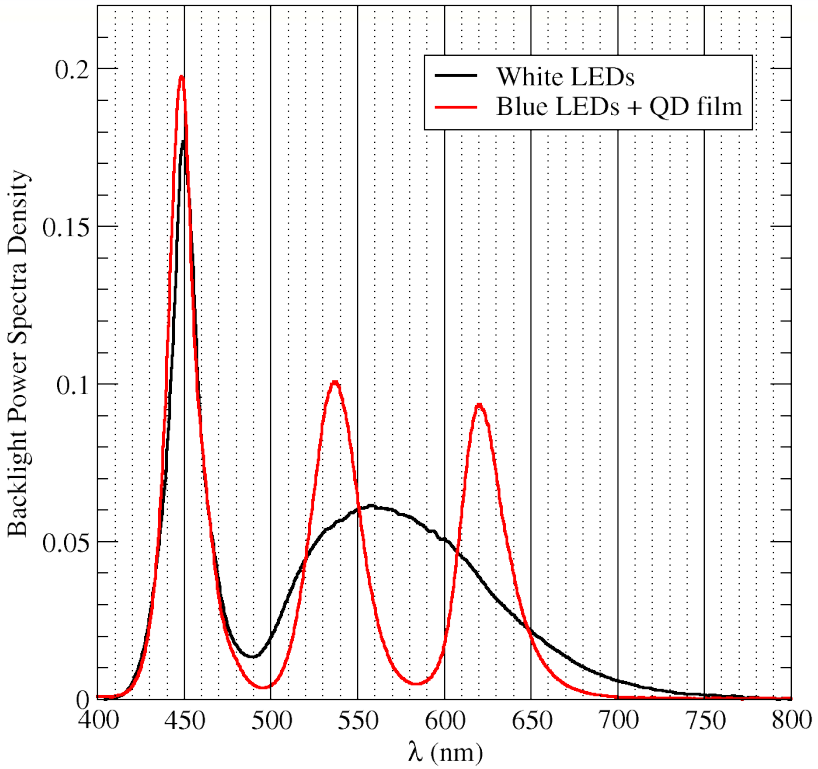
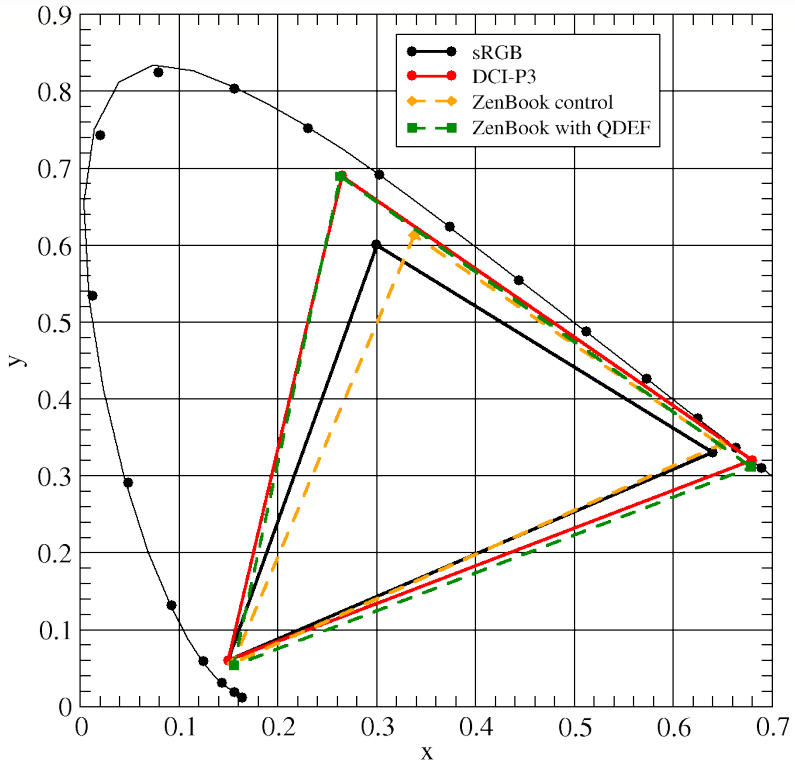
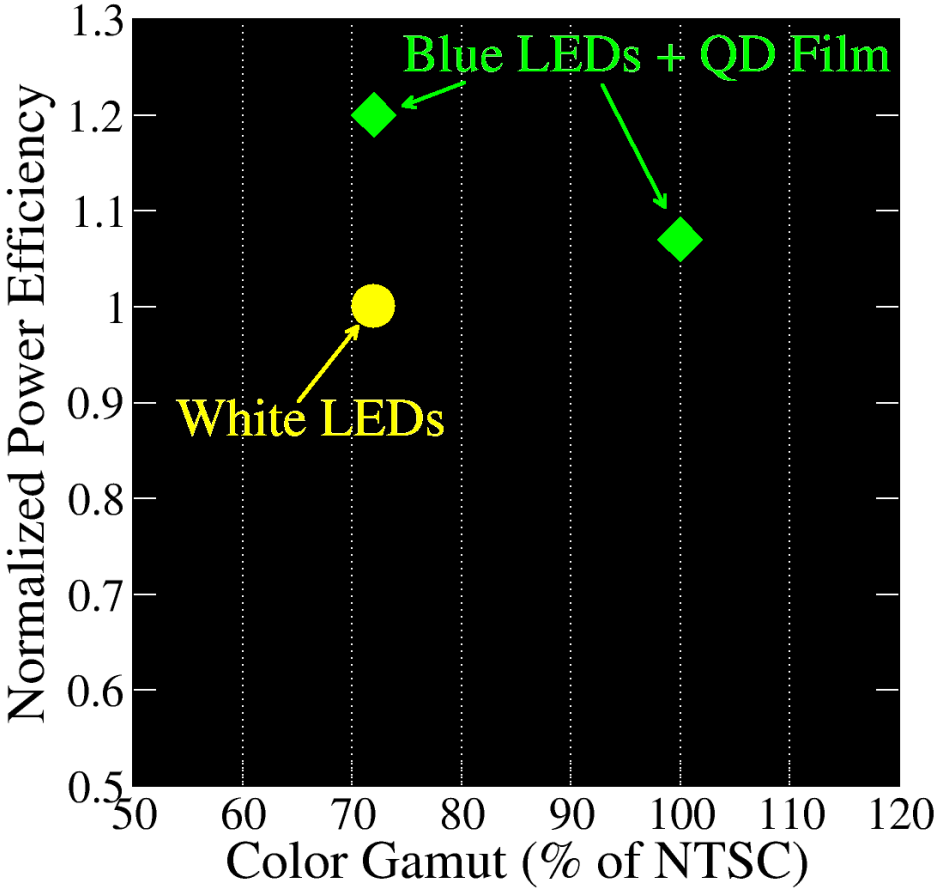
Demo: LCD with DCI-P3 Gamut using QD Film

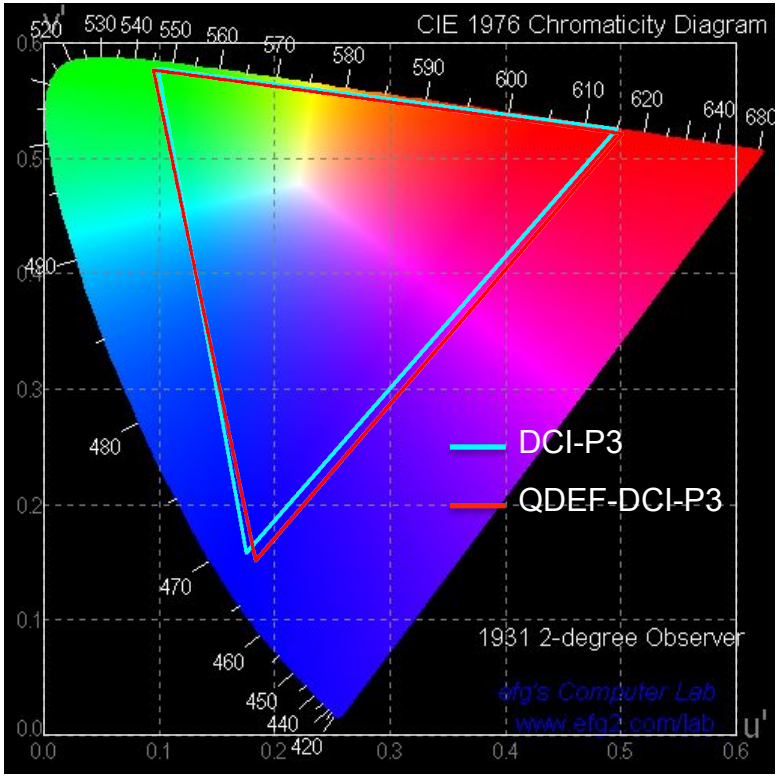




	White LED Control	Blue LED + QD Film
sRGB Coverage	**90.3%**	**99.8%**
DCI-P3 Coverage	**73.1%**	**97.4%**
Brightness (nits)	**340**	**366**

Efficiency of High Gamut Displays using QD Film Example: DCI-P3





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

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High Gamut Display – Asus ZenBook NX500 15.6”
3840x2160 Resolution & 100% NTSC/108% Adobe-RGB

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Conclusions

- 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

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Thank You!

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