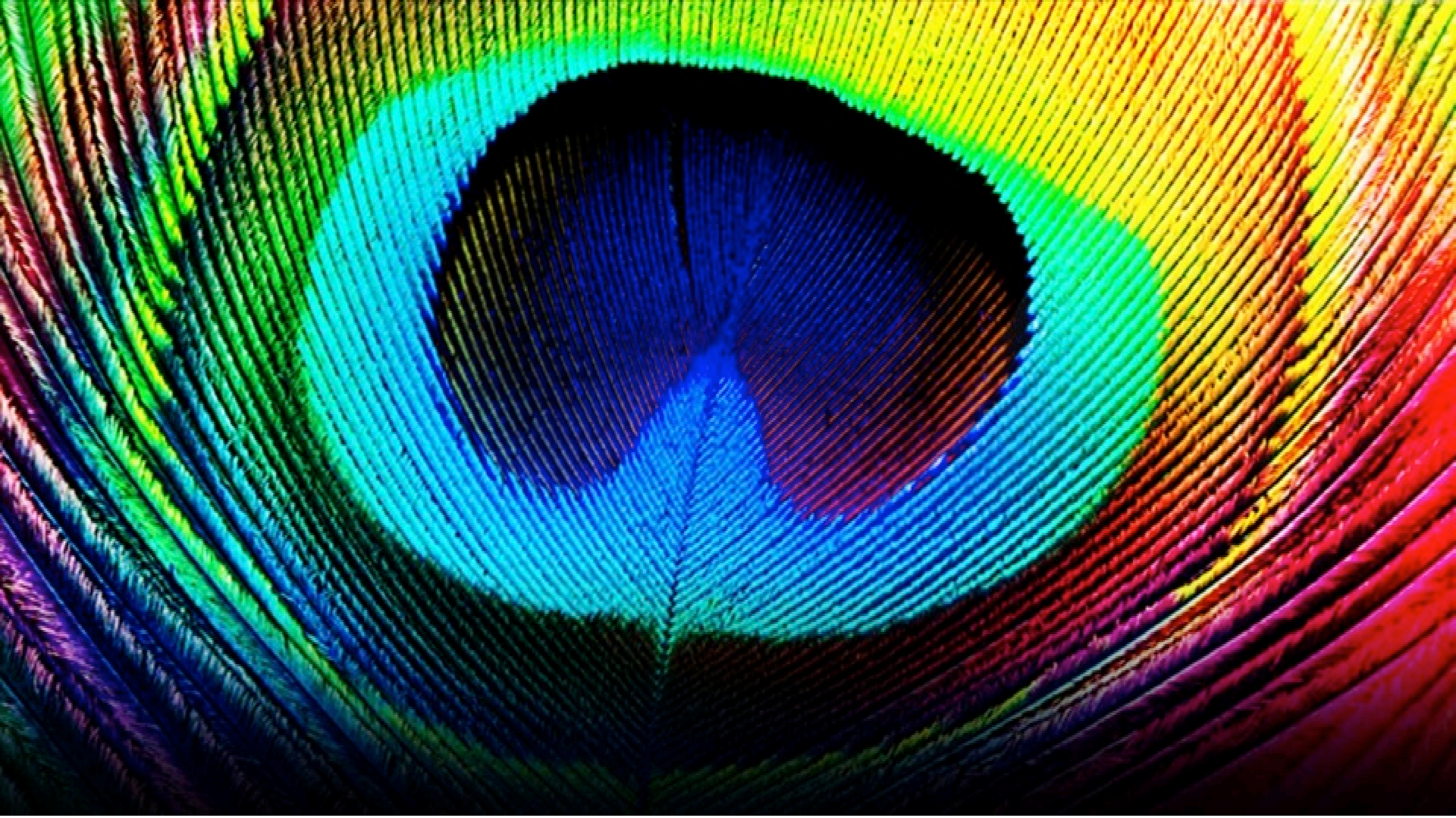


Introduction to Quantum Dot Display Technology

September, 2015
John Ho, jho@qdvision.com

QD VISION

Quantum Dot Adoption is Accelerating

Companies Demonstrating Quantum Dot Displays in 2015

KONKA

LG

SAMSUNG

TCL

Hisense

Skyworth

SHARP

PHILIPS

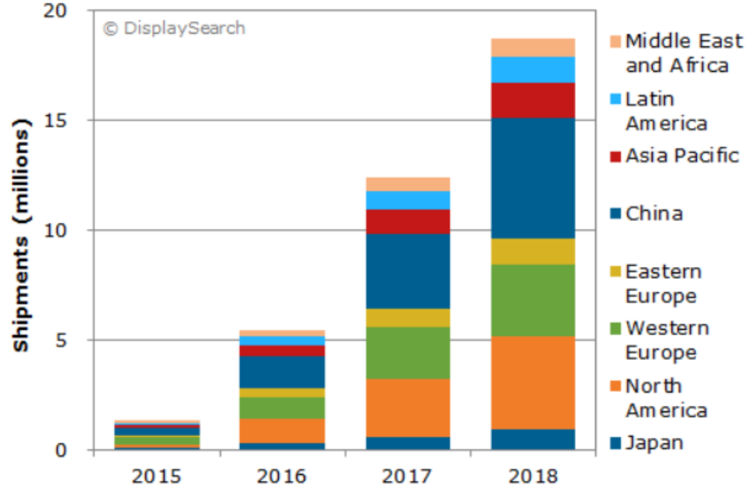
AOC

CHANGHONG 长虹

*"**We forecast by 2025, 60% of TVs will have quantum dots in them**; 51% of monitors will adopt quantum dot."*

- Dr. Jennifer Colegrove, CEO, Touch Display Research Inc.

Figure 1: Quantum Dot TV Shipment Forecast by Region

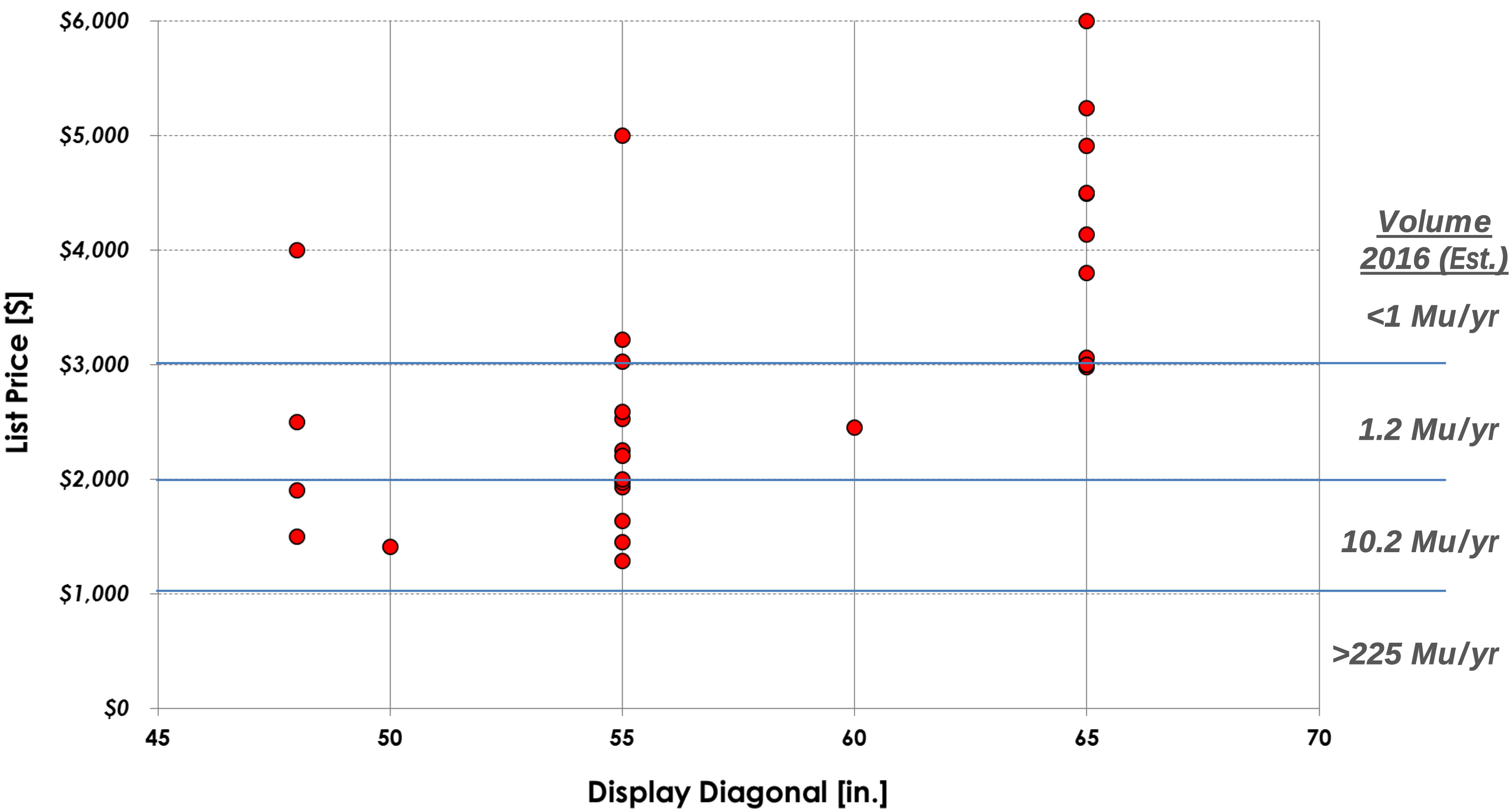


Source: DisplaySearch *Quarterly TV Design and Features Report*

*"TVs using QD technology will become available in 2015, with 1.3 million shipping worldwide. **Shipments of quantum dot TVs are expected to grow to 18.7 million in 2018.***

- DisplaySearch *Quarterly TV Design and Features Report*

Quantum Dot TV Products by Retail ASP



Source: IHS/Displaysearch, JD.com, Gome.com.cn, Samsung.com, Amazon.com, Retail Stores

Overview

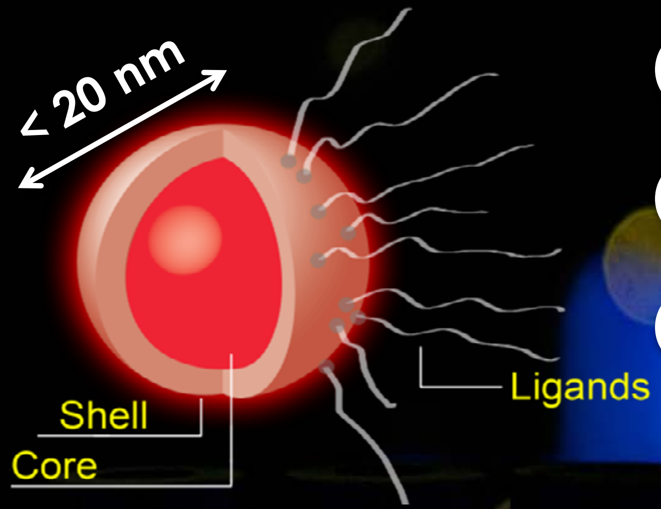
- QDV Introduction
- What are quantum dots (QDs)?
- How are QDs used in displays?
- How do QDs work?
- Impacts on image quality
- Path to BT. 2020

About QD Vision

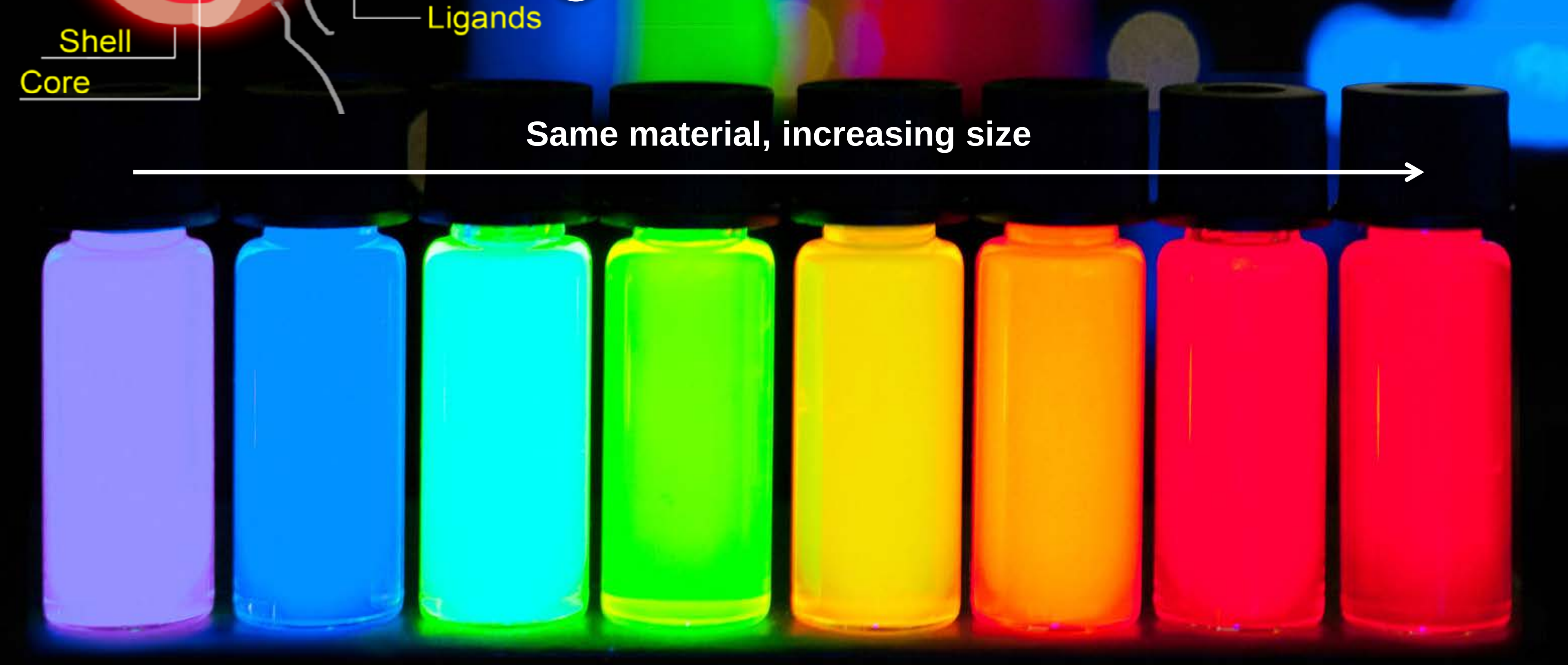
- Founded in 2005, operations in Lexington, Massachusetts, USA
- MIT roots with many staff from MIT
- Over 250 patents and patents pending
- Launched the world's first Color IQ™ quantum dot displays in 2013
- World's largest quantum dot manufacturing facilities
- Currently developing products with the top Chinese TV and Monitor manufacturers

What are Quantum Dots?

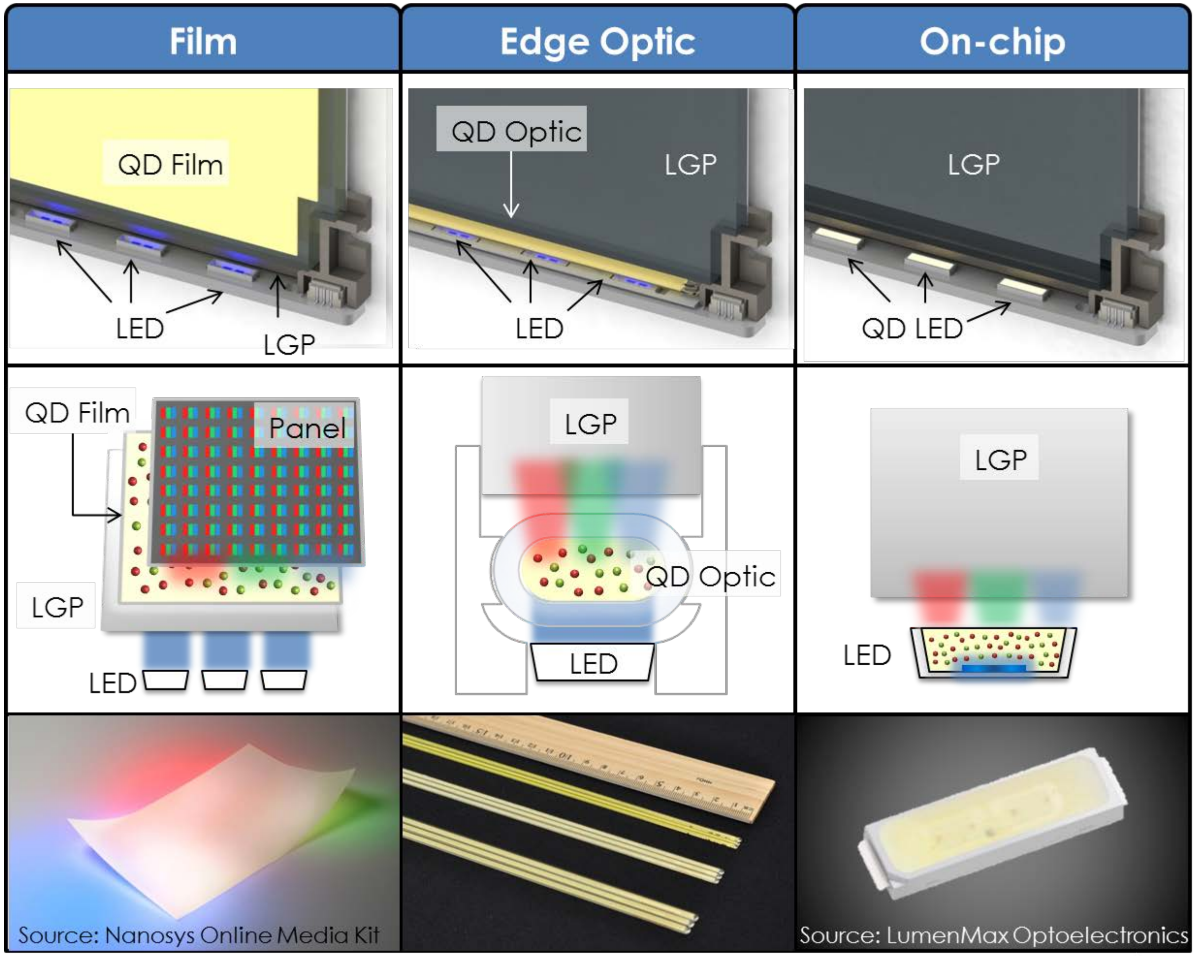
- Quantum *from Quantum Mechanics (physics on a nanoscale)*
- Dot *from the spherical shape*



1. Spectrally pure, light-emitting nanocrystals
2. Color determined by size and core elements
3. World's most efficient color conversion material



How Are QDs Used in Displays?

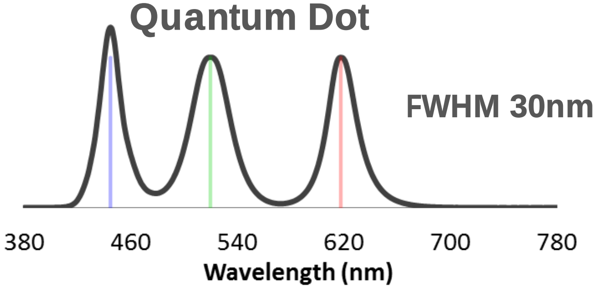


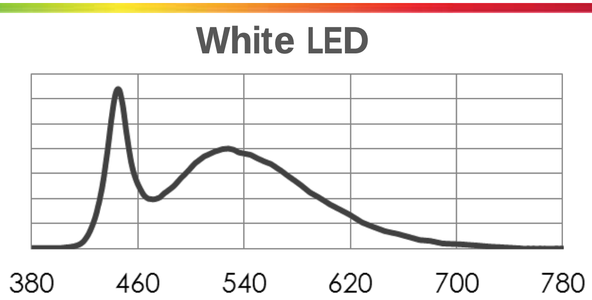
Operating Flux, Temperature

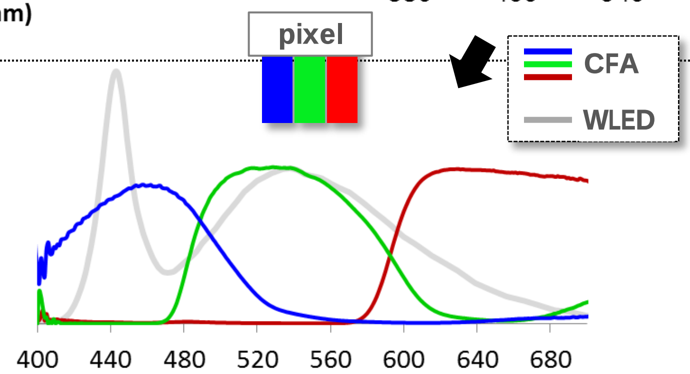
How Do QDs Work?

Light Source + Color Filters = Display Spectrum

BLU Level

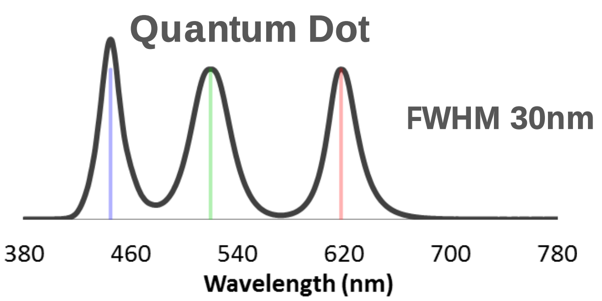


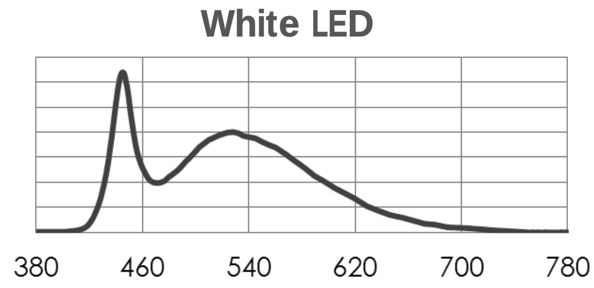


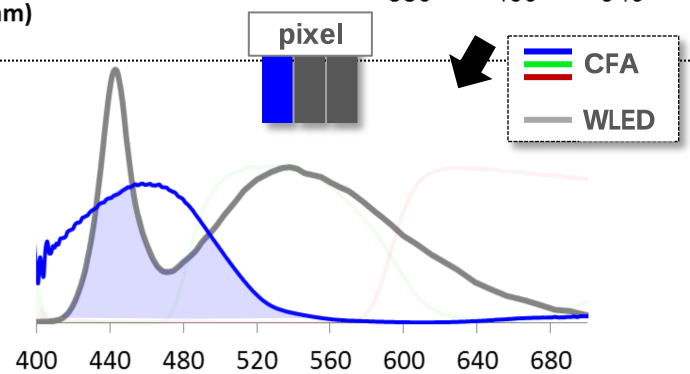


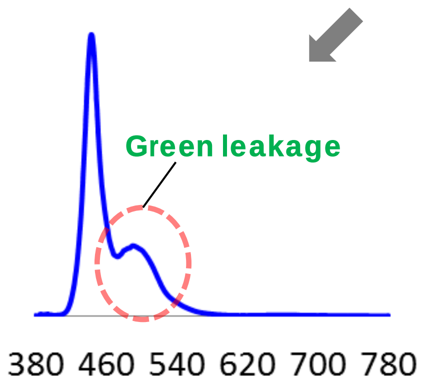
BLU + CFA Spectra: WLED

BLU Level



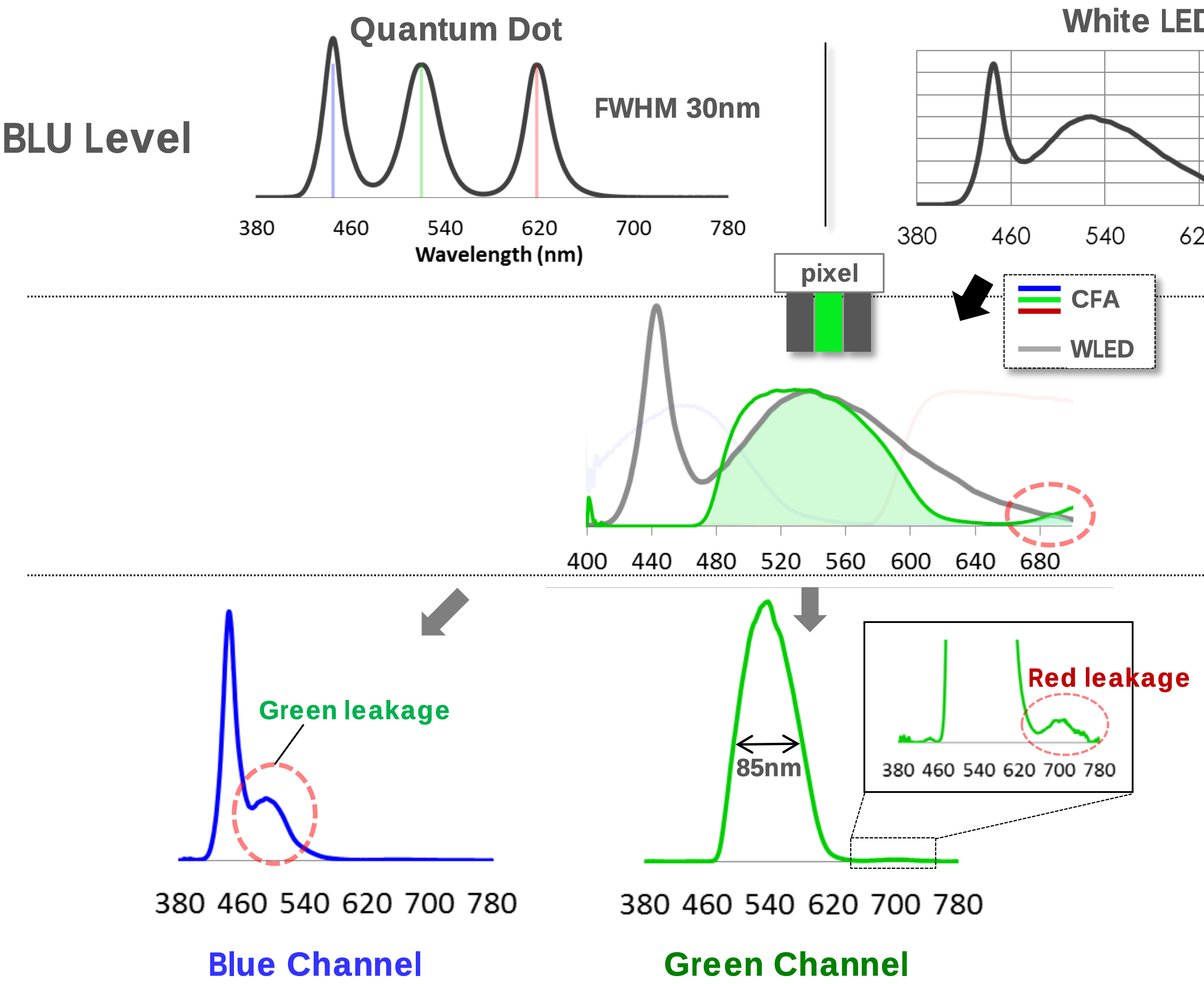






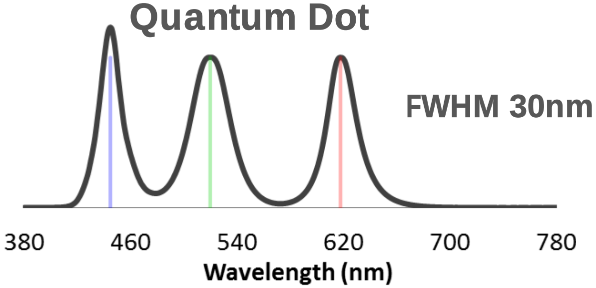
Blue Channel

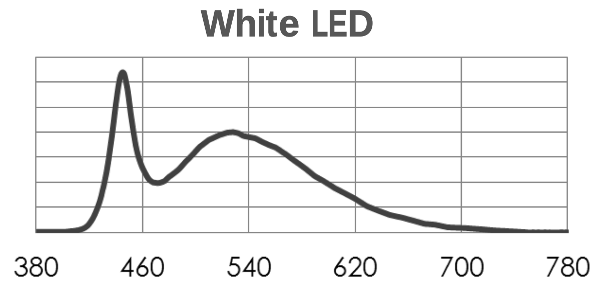
BLU + CFA Spectra: WLED

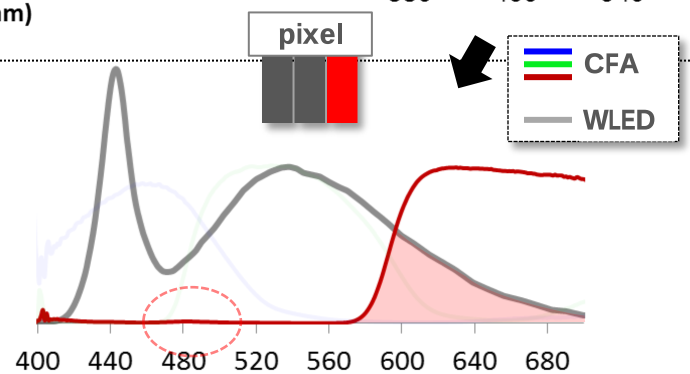


BLU + CFA Spectra: WLED

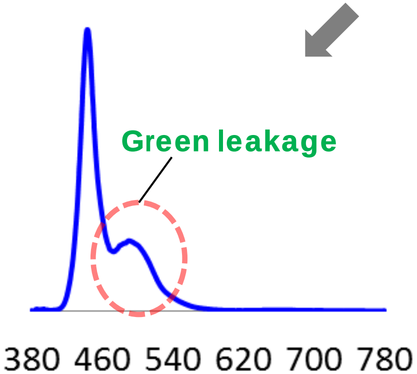
BLU Level



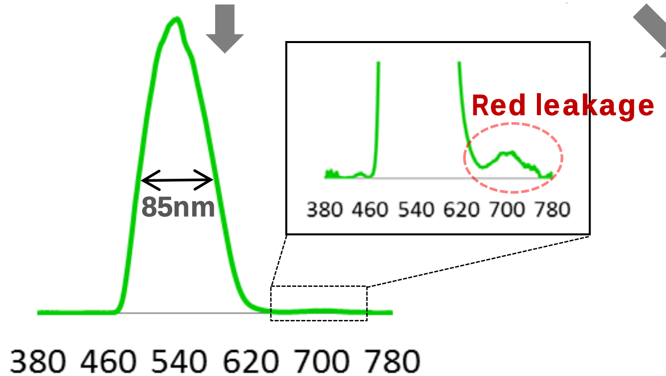




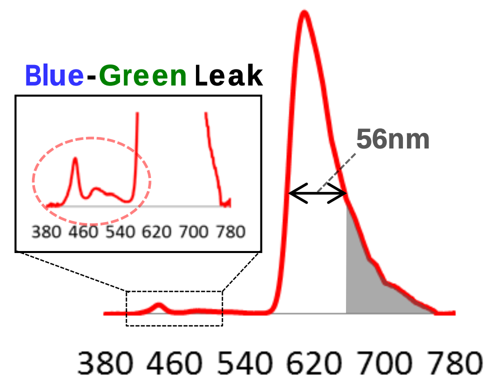
WLED Technology
- Wide FWHM reduces gamut
- CFA channel leak reduces gamut



Blue Channel

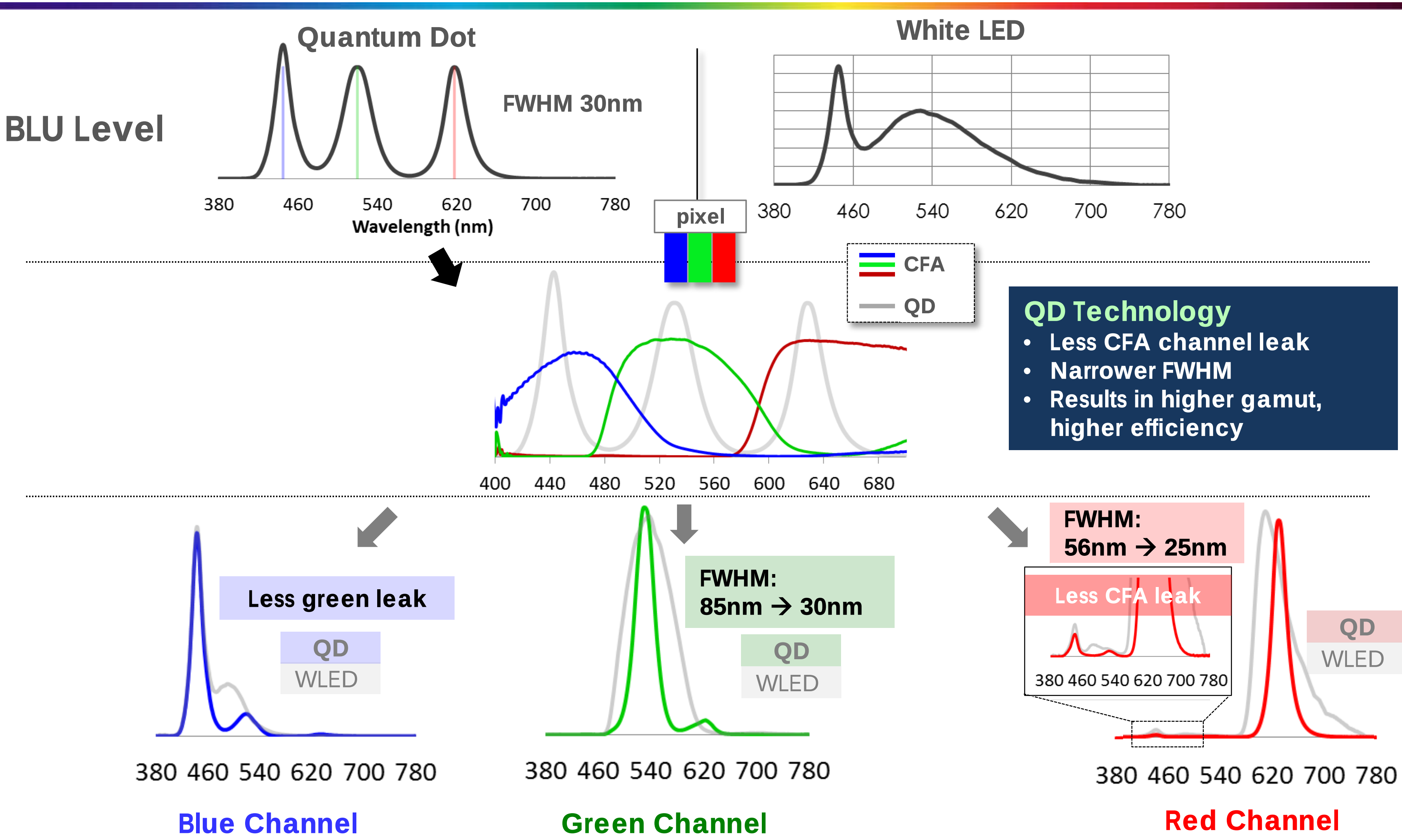


Green Channel

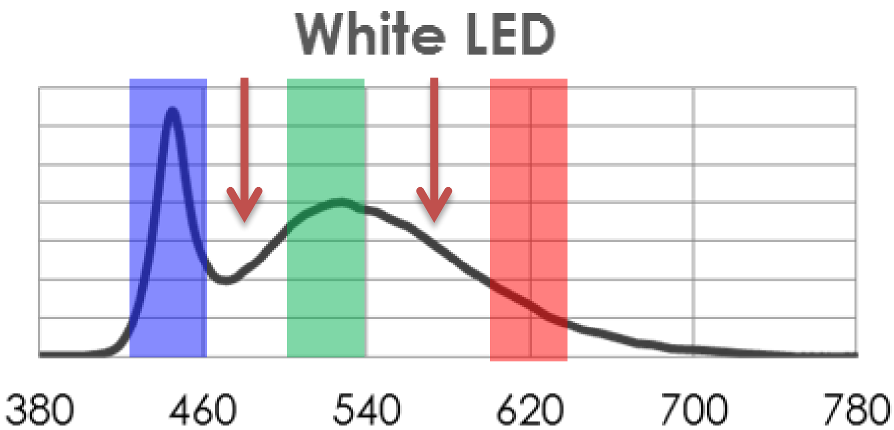


Red Channel

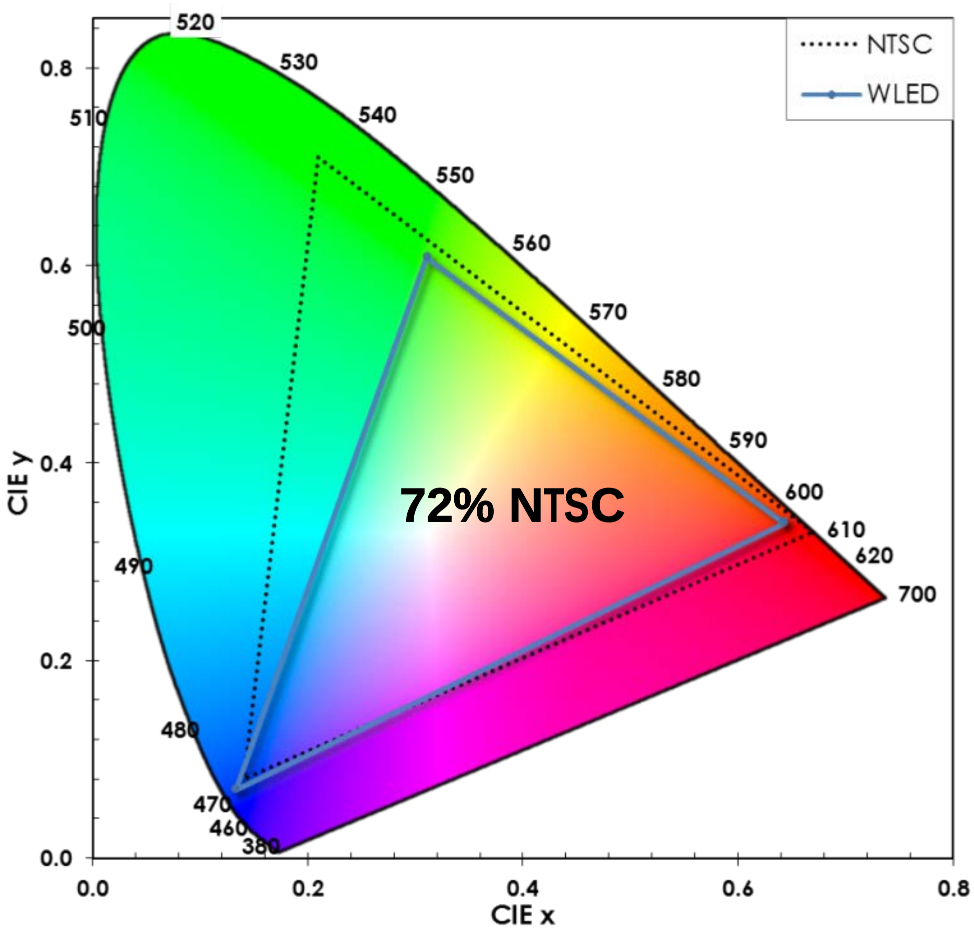
BLU + CFA Spectra: QDs



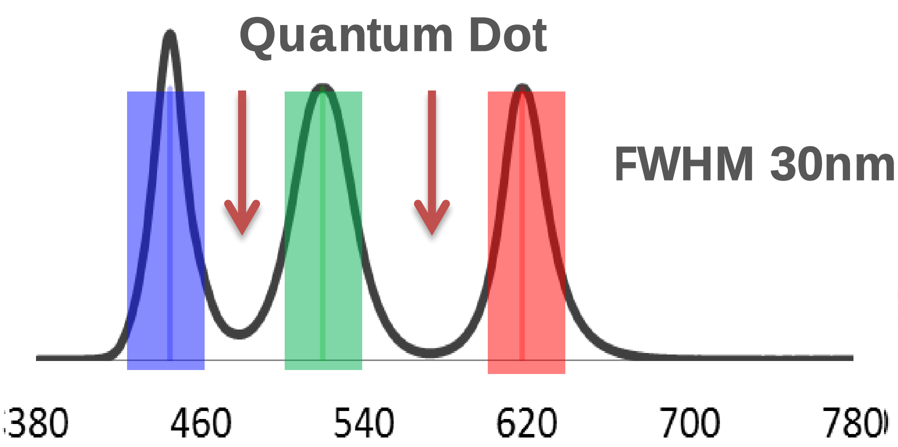
Color Gamut Is Determined By Spectral Distribution

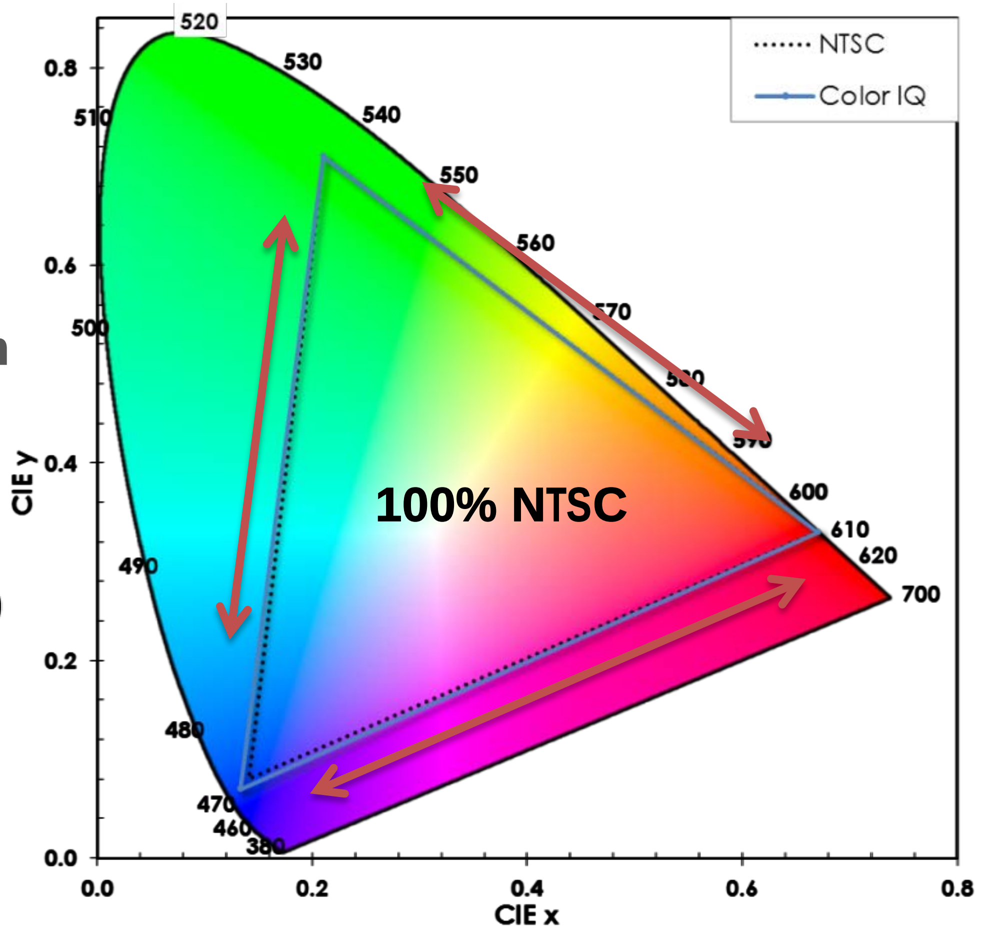


Leakage between RGB channels limits gamut area



Color Gamut Is Determined By Spectral Distribution

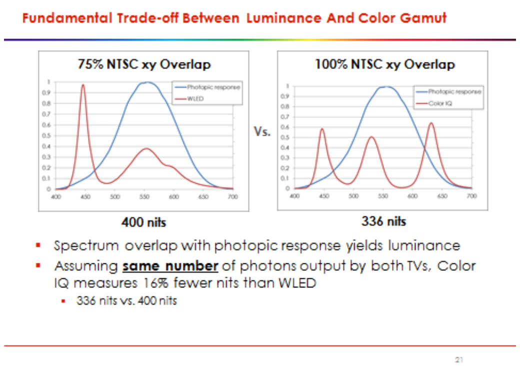




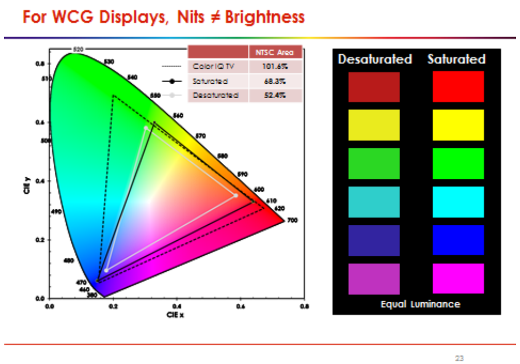
Tunable, pure QD emission separates RGB channels achieving full gamut

Summary of QD Impacts on Image Quality Perception

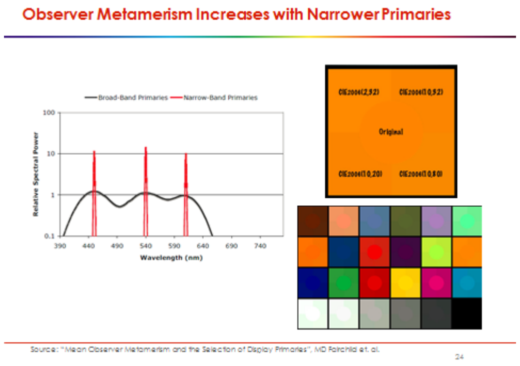
- Luminance vs. Gamut tradeoff



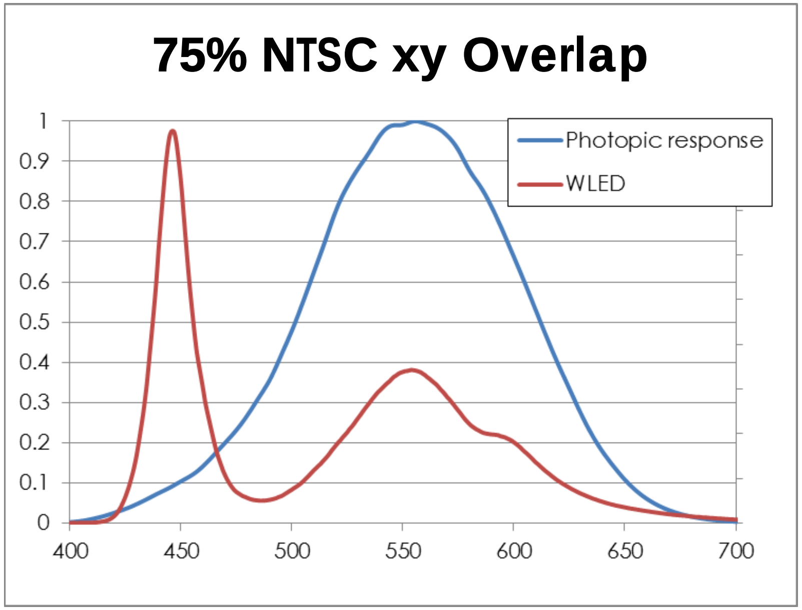
- H-K effect



- Observer Metamerism

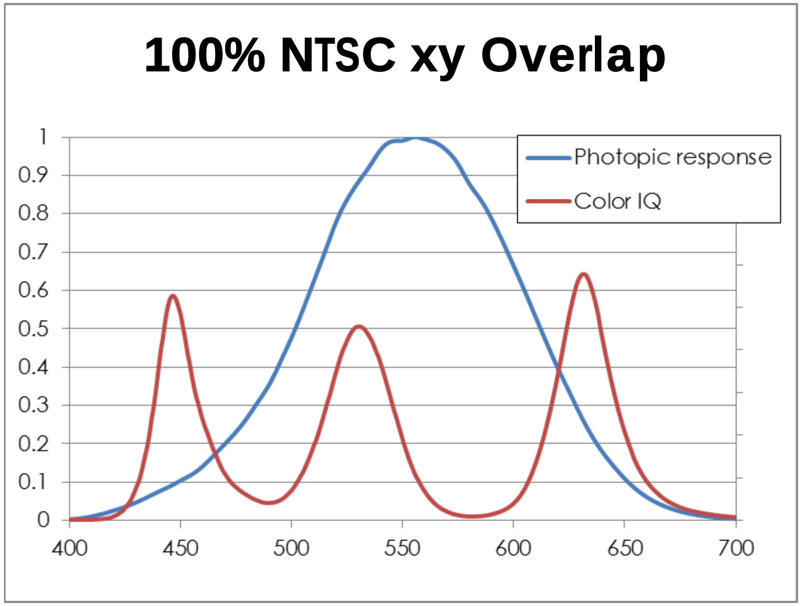


Fundamental Trade-off Between Luminance And Color Gamut



400 nits

Vs.

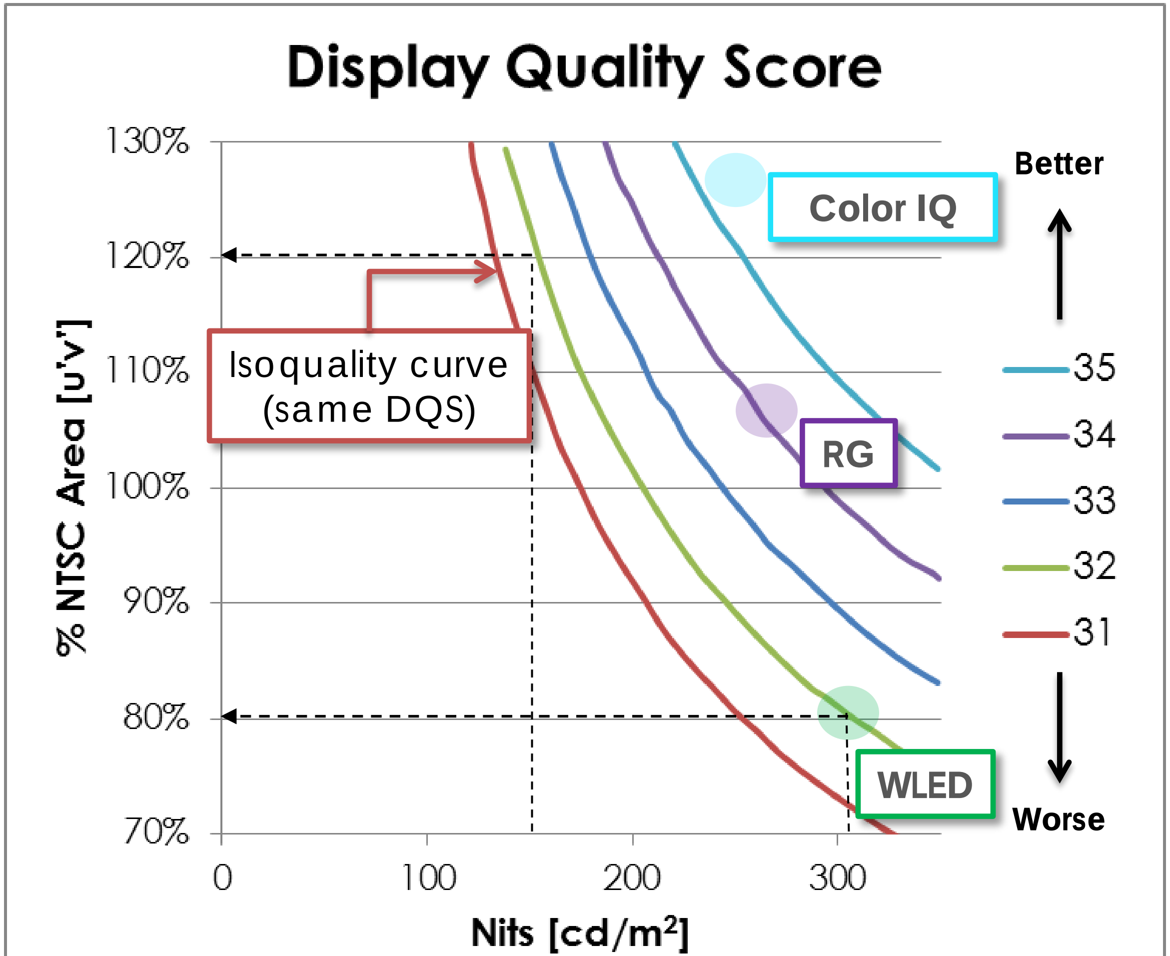


336 nits

- Spectrum overlap with photopic response yields luminance
- Assuming **<u>same number</u>** of photons output by both TVs, Color IQ measures 16% fewer nits than WLED
    - 336 nits vs. 400 nits

QDs Can Improve Display Quality Score (DQS)

*3M's global study includes 6 countries (US, Japan, China, Korea, Poland, and Spain), over 200 participants, and >110K data points



48" diagonal, viewing distance of 275 cm, black point of 0.5 cd/m², FHD resolution

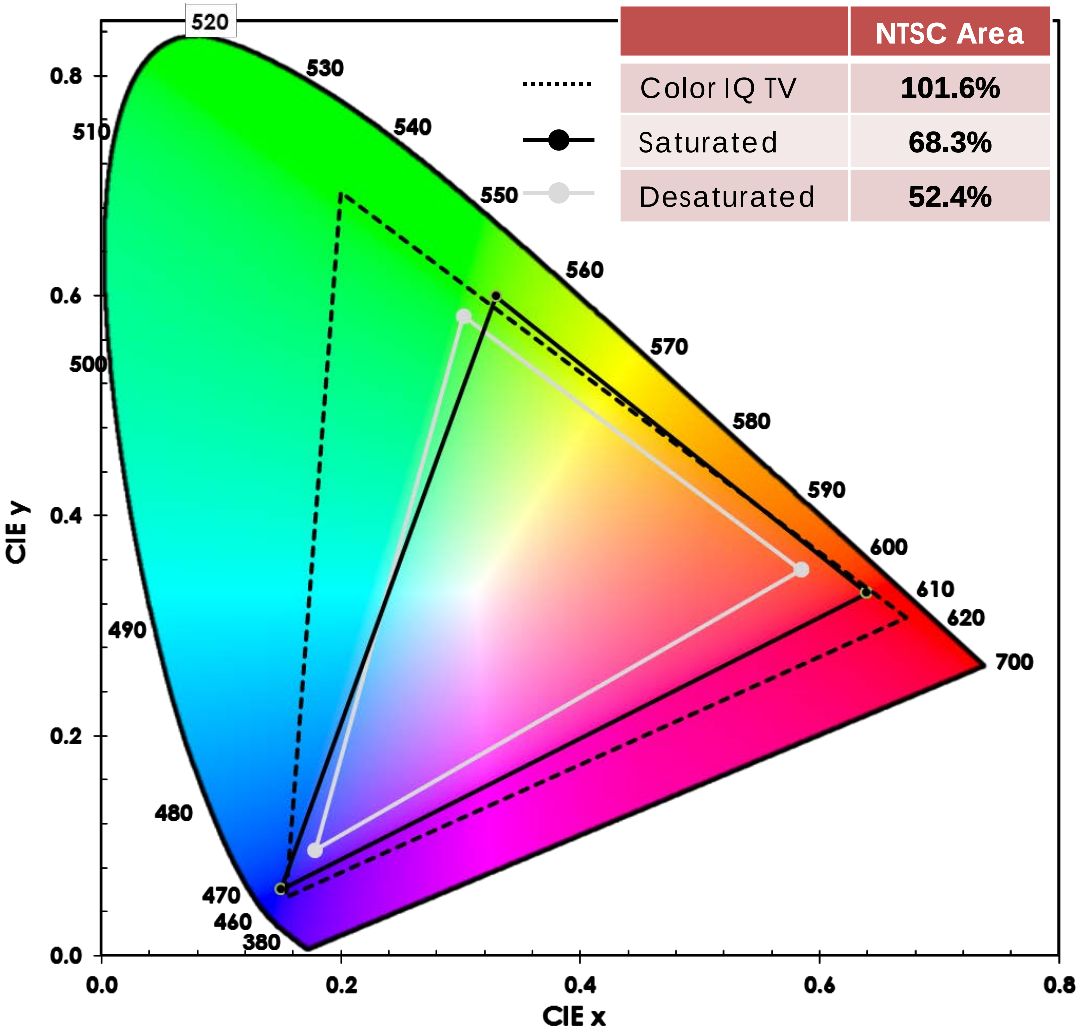
Source: 3M's Display Quality Score Whitepaper

- **Relative DQS scores indicate viewer preference**

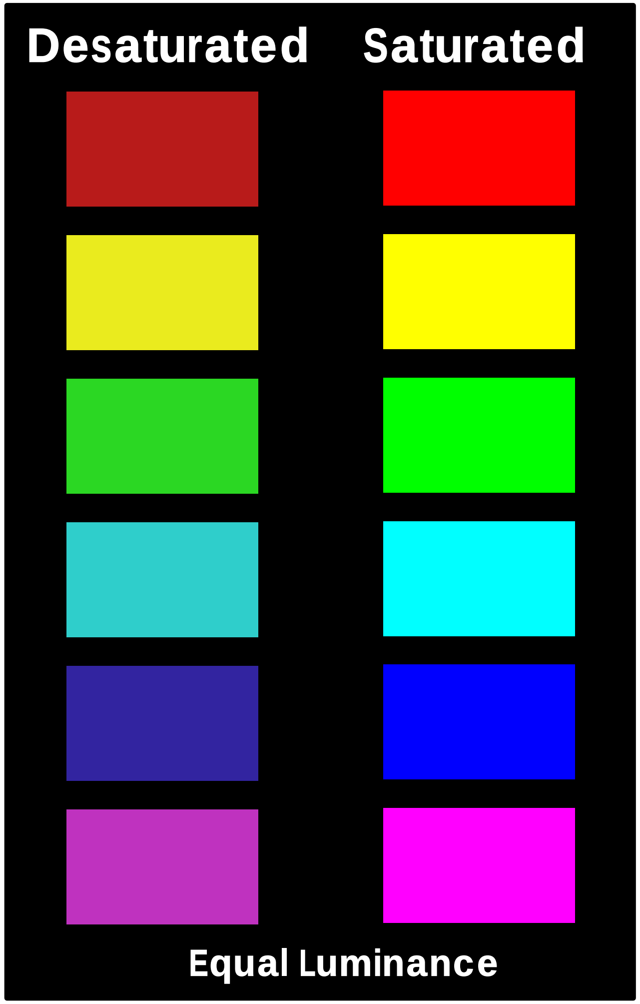
	% population preferring higher DQS display
0	50%
1	75%
≥2	≥86%

- **9 out of 10 people would prefer Color IQ over WLED**
- **3 out 4 people prefer Color IQ to RGph**
- **At 120% NTSC area, Color IQ TV could be 50% luminance of WLED TV and maintain DQS**

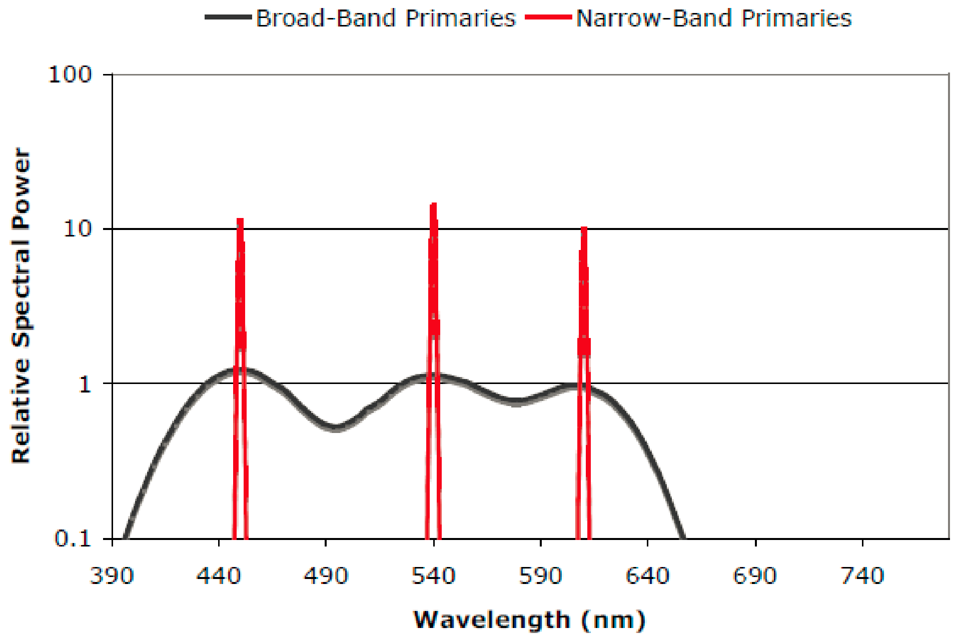
For WCG Displays, Nits ≠ Brightness

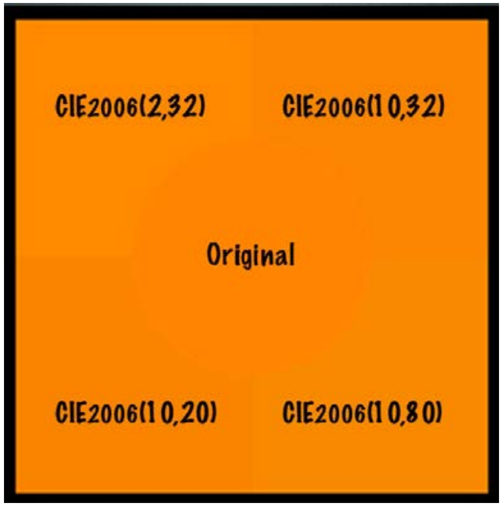


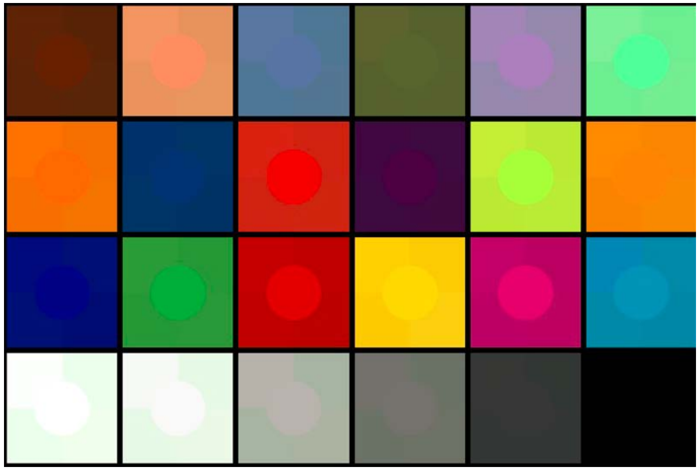
	NTSC Area
Color IQ TV	101.6%
Saturated	68.3%
Desaturated	52.4%



Observer Metamerism Increases with Narrower Primaries





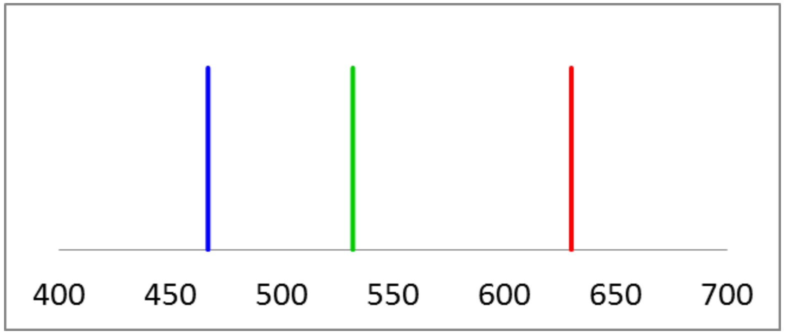


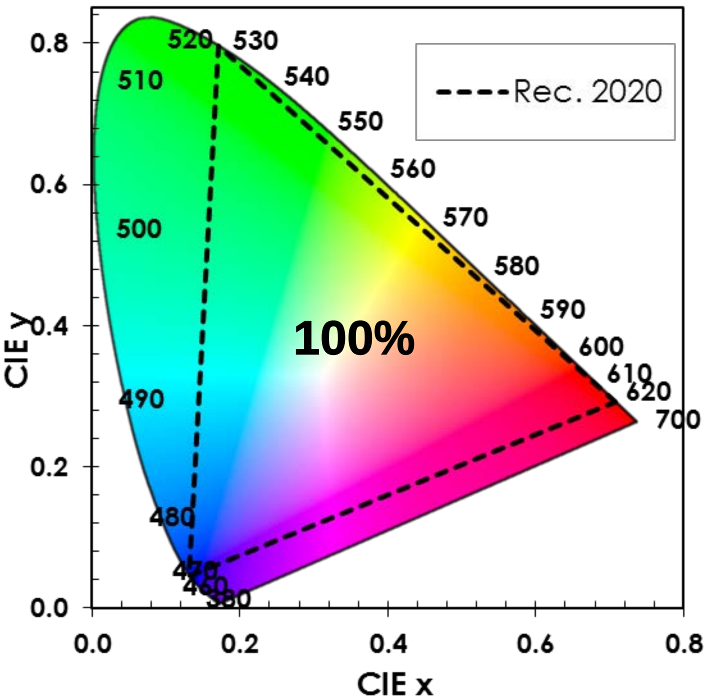
Source: “Mean Observer Metamerism and the Selection of Display Primaries”, MD Fairchild et. al.

How to Achieve Maximum Overlap of Rec. 2020?

- Full gamut can only be achieved in theory
- Primaries originally developed by NHK:
  - Covers all existing gamut standards and real object colors
  - Compatible with potential laser wavelengths
  - Located on loci of constant hue

Theoretical Maximum

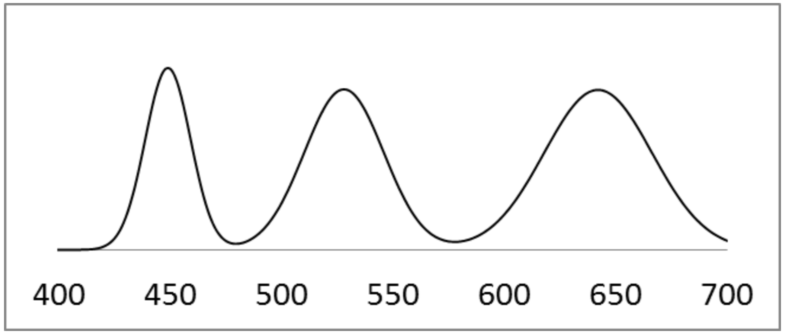


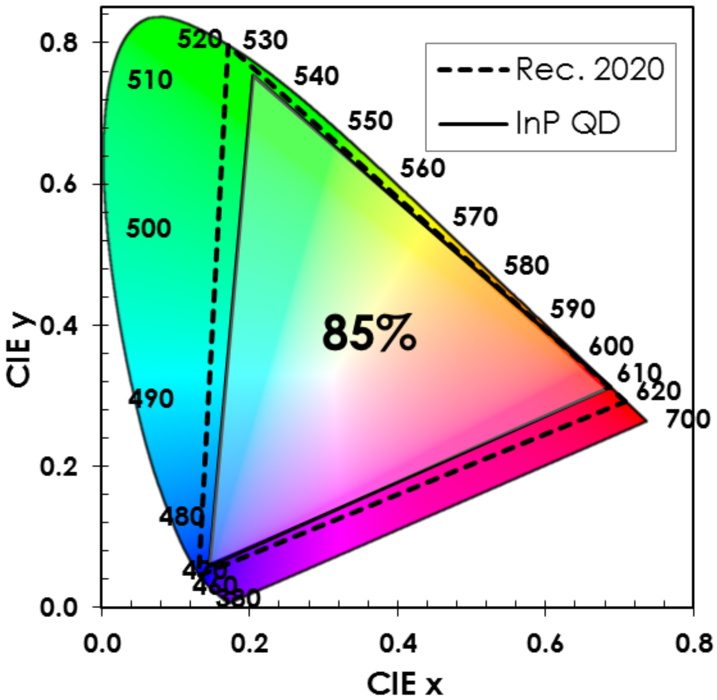


How to Achieve Maximum Overlap of Rec. 2020?

- Red and green phosphor primaries are too wide
- Addition of thicker color filter material will dramatically reduce system efficiency
- Large FWHM of primaries limits RGph to ~85%

RGph red and green primaries too wide

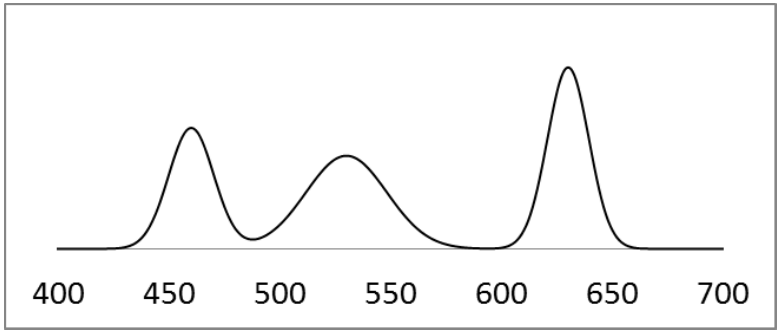


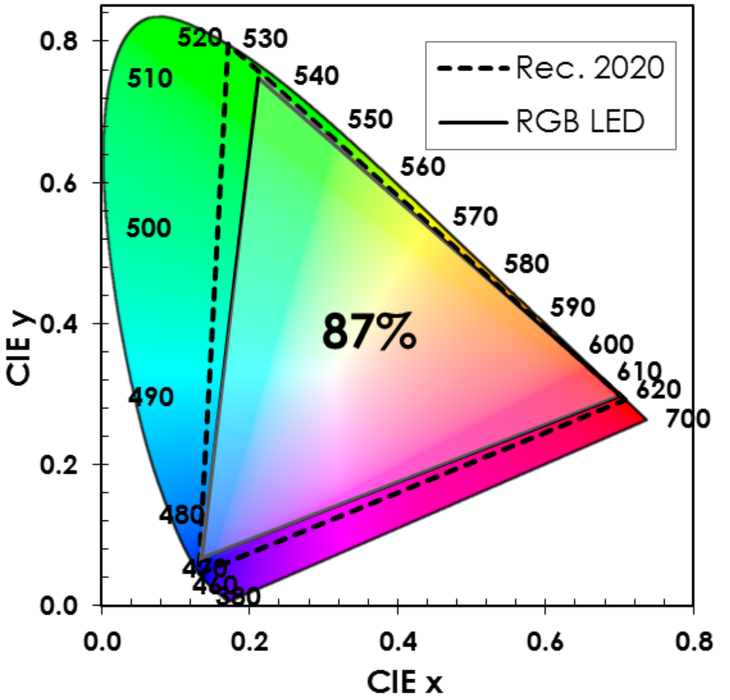


How to Achieve Maximum Overlap of Rec. 2020?

- Low Green LED efficiency, and differential aging, and temperature performance remain key challenges
- Large FWHM of green primary limits gamut to < 90%
- Prohibitive cost/complexity

RGB LED green primary too wide

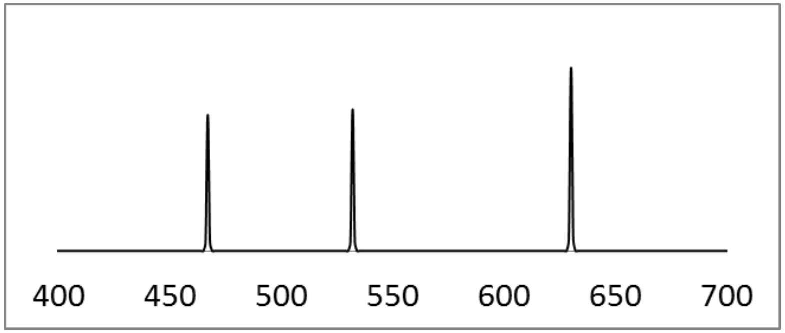


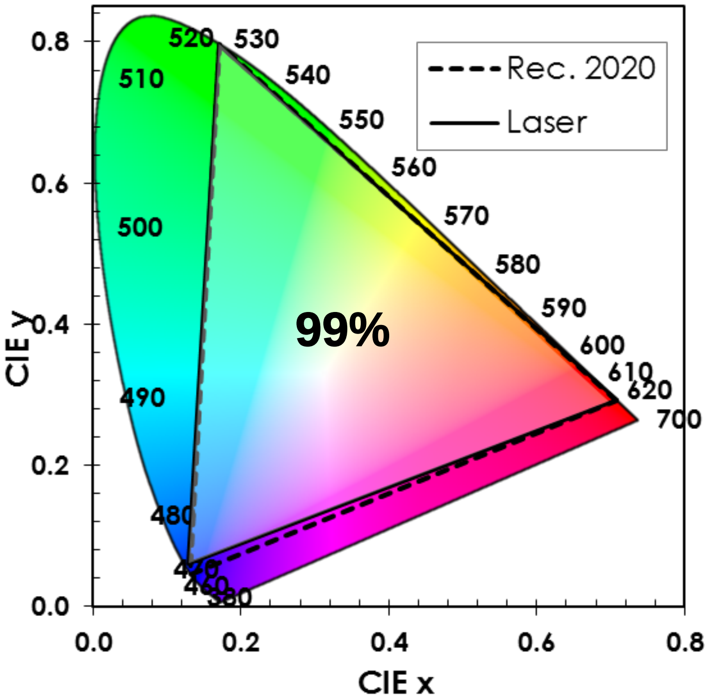


How to Achieve Maximum Overlap of Rec. 2020?

Lasers provide best performance, but are not practical

- Full gamut nearly achieved
- Speckle and observer metamerism remain key technical challenges
- Prohibitive cost/complexity





How to Achieve Maximum Overlap of Rec. 2020?

- Assumes Ideal Color Filters and 25 nm FWHM QDs
- In practice, only ~93% gamut coverage achieved due to blue and green color filter leakage
- Getting to visually indistinguishable coverage of BT. 2020 requires adding tolerance to RGB primaries

CdSe QD primaries yield best path to Rec. 2020 overlap