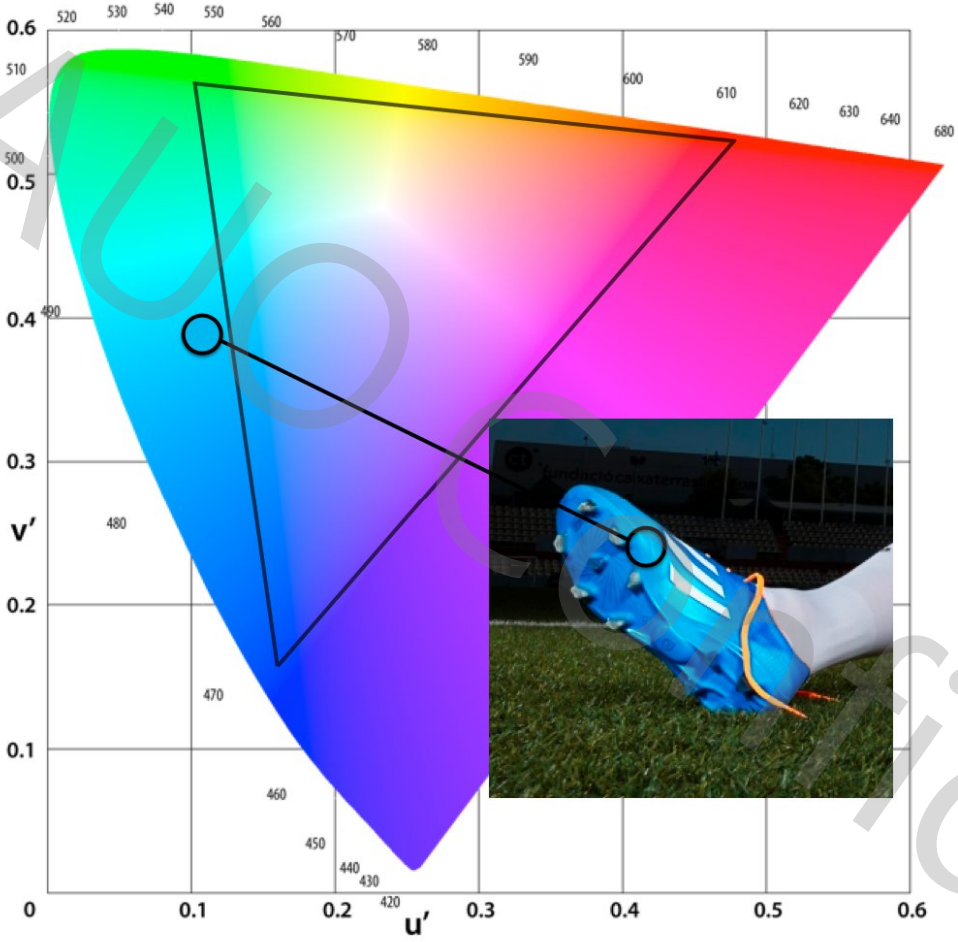
Trend of Wide Color Gamut Liquid Crystal Display

2016 ICC Meeting on Display and 3D Printing

Cheng Hsien Liao

Your HDTV probably can't show off Messi's boots in bright blue glory



— HDTV Color Gamut
Messi's Boot

Lionel Messi laces up some bright blue boots- designed for the FIFA World Cup 2014 (image source: Adidas)

Figure from : https://dot-color.com/

What is Wide Color Gamut Display?

Why should we need WCG Display?

How to approach WCG LCD ?

What is Wide Color Gamut Display?

Why should we need WCG Display?

How to approach WCG LCD ?

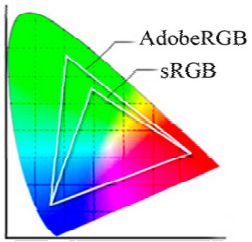
Broadcasting Planning Trend

Color Gamut Specification Trend

1953 — NTSC

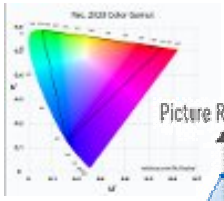
1996 — sRGB

1998 — Adobe RGB



2012 — DCI-P3

Rec 2020



UHD ALLIANCE

DIRECTV technicolor The Walt Disney Studios NETFLIX SAMSUNG LG Panasonic SHARP SONY make.believe

Broadcasting Planning

2014	2015	2016	2017	2018	2019	2020
Sochi winter Olympic	Rio Olympic			Pyeongchang winter Olympic		Tokyo Olympic

UHD-phase I	UHD-phase II	UHD-phase III
4K2K 60Hz Rec709 (sRGB) 8bit/10bit	4K2K 120Hz Rec2020 10bit & 12bit/14bit(optional) HDR	8K4K 120Hz Rec2020 10bit/12bit/14bit HDR

Wide Color Gamut Display of CES

Curved OLED


Ultra-slim UHD LCD

Curved QDEF UHD LCD

→ Wide Color Gamut ←

Curved

Bendable

Ultra-large

8K

Ultra-slim

Curved UHD LCD

UHD LCD

110" Curved UHD LCD

4K UHD LCD

Wide Color Gamut play an important role of CES show!

Figure from : 2015/2016 CES

Wide Color Gamut Display of CES

Wide Color Gamut (Brands Summary)

LG	~100% NTSC	OLED
	~ 95% NTSC	KR "QD Film"
SAMSUNG	~ 95% NTSC	KR "QD Film"
Hisense	~ 100% NTSC	3M QDEF
TCL	~ 100% NTSC	3M QDEF
CHANGHONG	~ 100% NTSC	3M QDEF
SHARP	~ 100% NTSC	3M QDEF

Not only OLED, but also LCD shall reach the 100% NTSC

Figure from : 2015/2016 CES

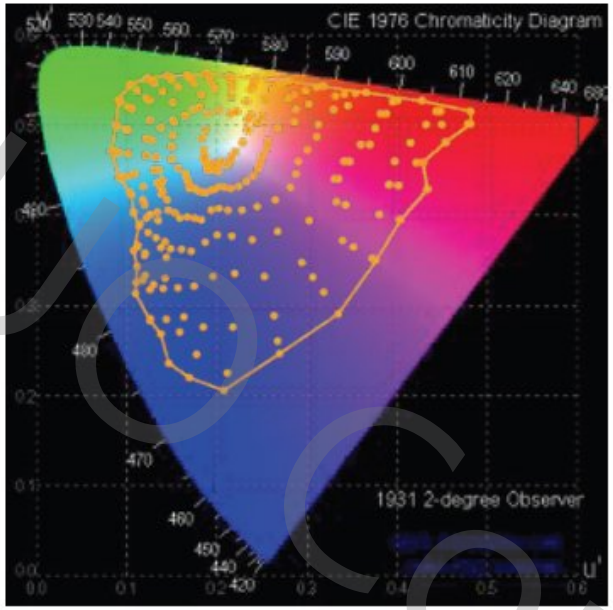
What is Wide Color Gamut Display?

Why should we need WCG Display?

How to approach WCG LCD ?

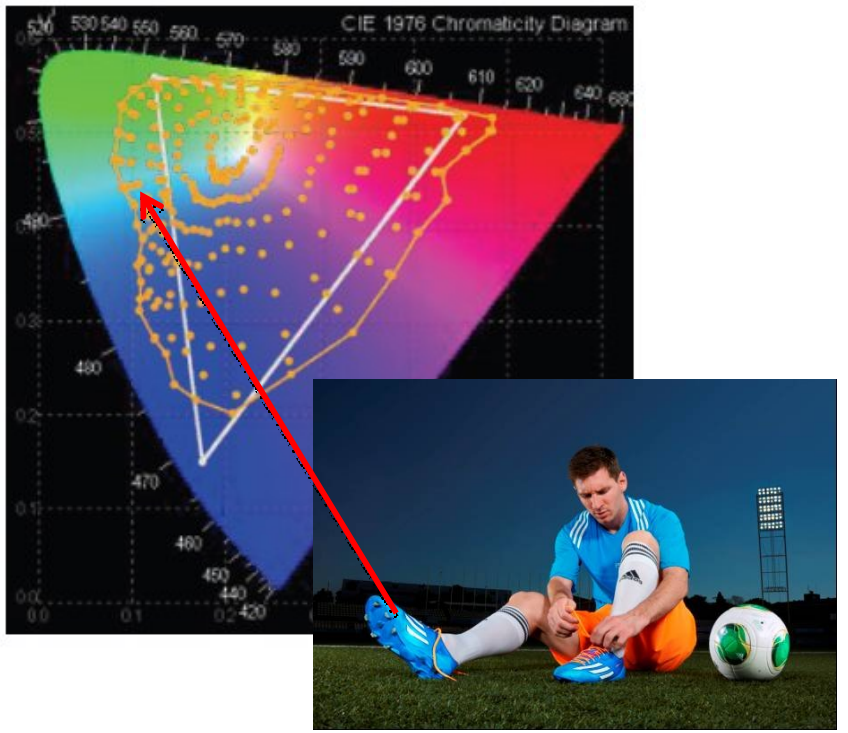
HDTV (Rec.709) is Not for WCG

Pointer's Color Gamut:



"The Gamut of Real Surface Colors", M.R.Pointer, Color Research and Application 5 (1980).

Rec709 / sRGB



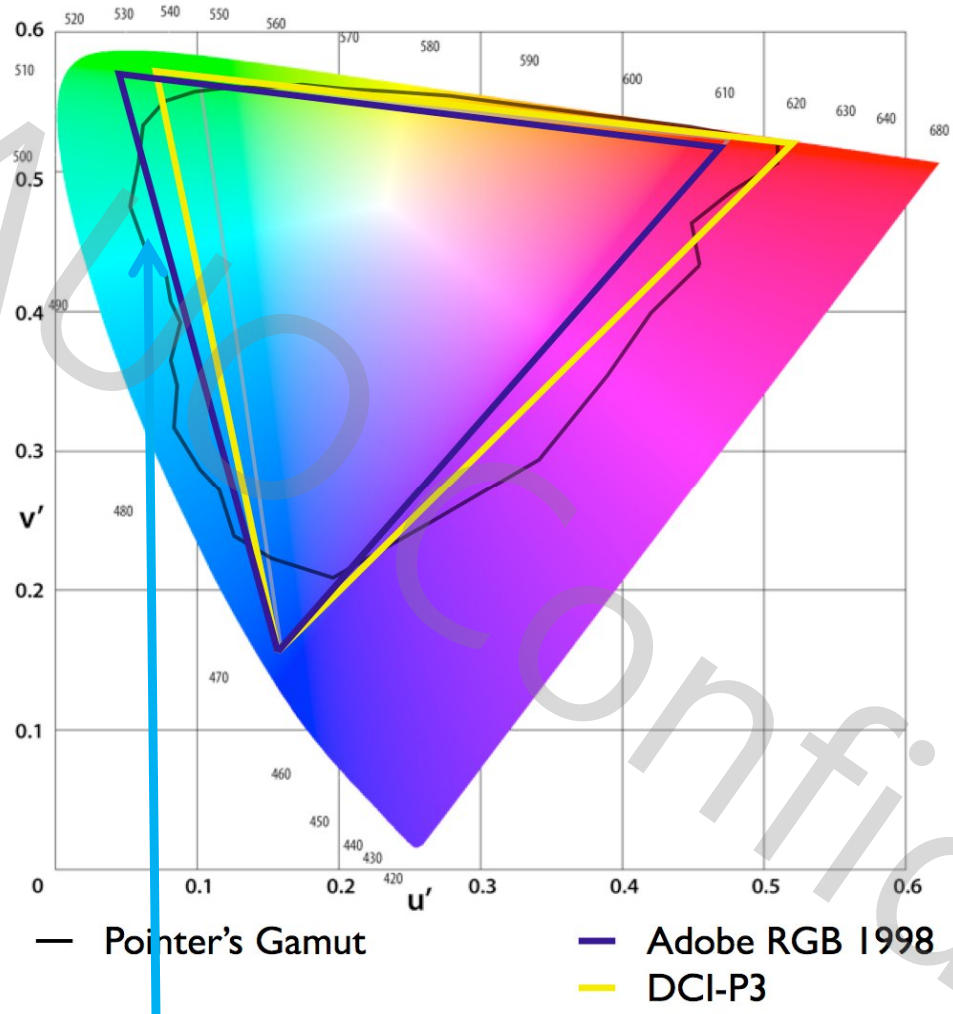
Colors measured from reflections of real objects
→46% of color space that can be seen by the human eye
by Dr. Michael Pointer (1980)
Color Research and Application 5

Rec.709 - ITU-R Recommendation for HDTV

- **→ sRGB covers 33% of color space for the human eye**
- **→ only covers 70% of Pointer's gamut**
- **→ 1990s, HP、Microsoft...etc establish for standard spec corresponding NTSC 70%.**

ITU :International Telecommunication Union

Are Adobe and DCI-P3 Wide Enough?



DCI-P3 – US-American film industry

1. **2010s, US American film industry established for digital movie projection → all of colors from movies are covered.**

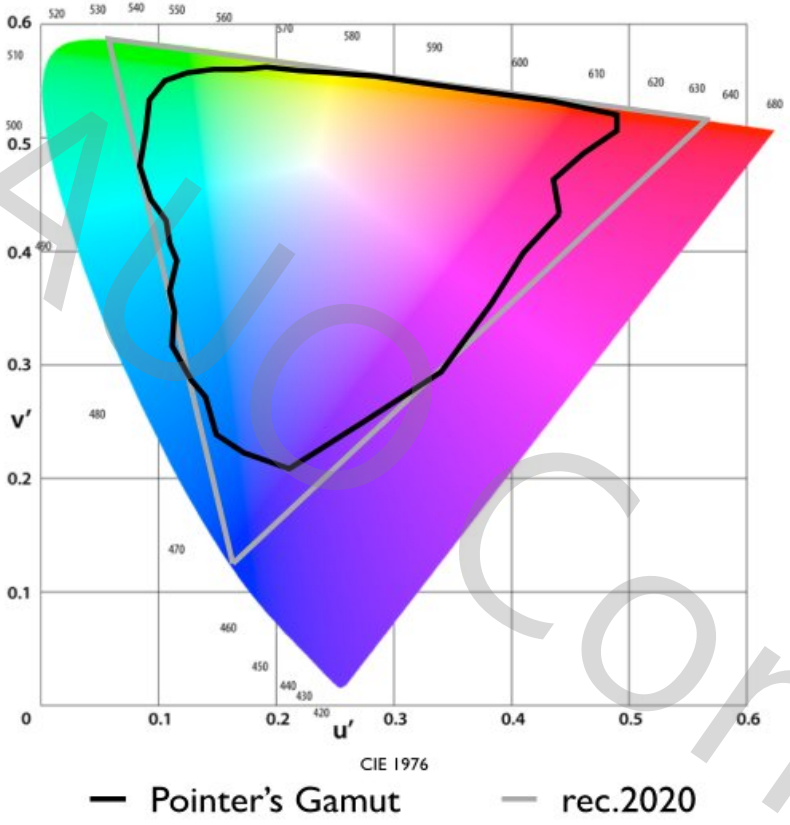
2. **The DCI-P3 color space covers 41.7% % of color space for the human eye and only covers 85.5%of Pointer's gamut**

3. **2016, UHD Alliance announced UHD device need to at least 90% DCI-P3 color space for home cinema entertainment.**

Apple - iPad Pro 9.7 (2016)

Figure from : https://dot-color.com/

What is Rec2020/BT.2020 ?



Rec.2020 - ITU-R Recommendation for UHD TV

→ **Wide-gamut TV colorimetry should handle all the colors covered by existing TV systems and other related non-broadcasting systems.**

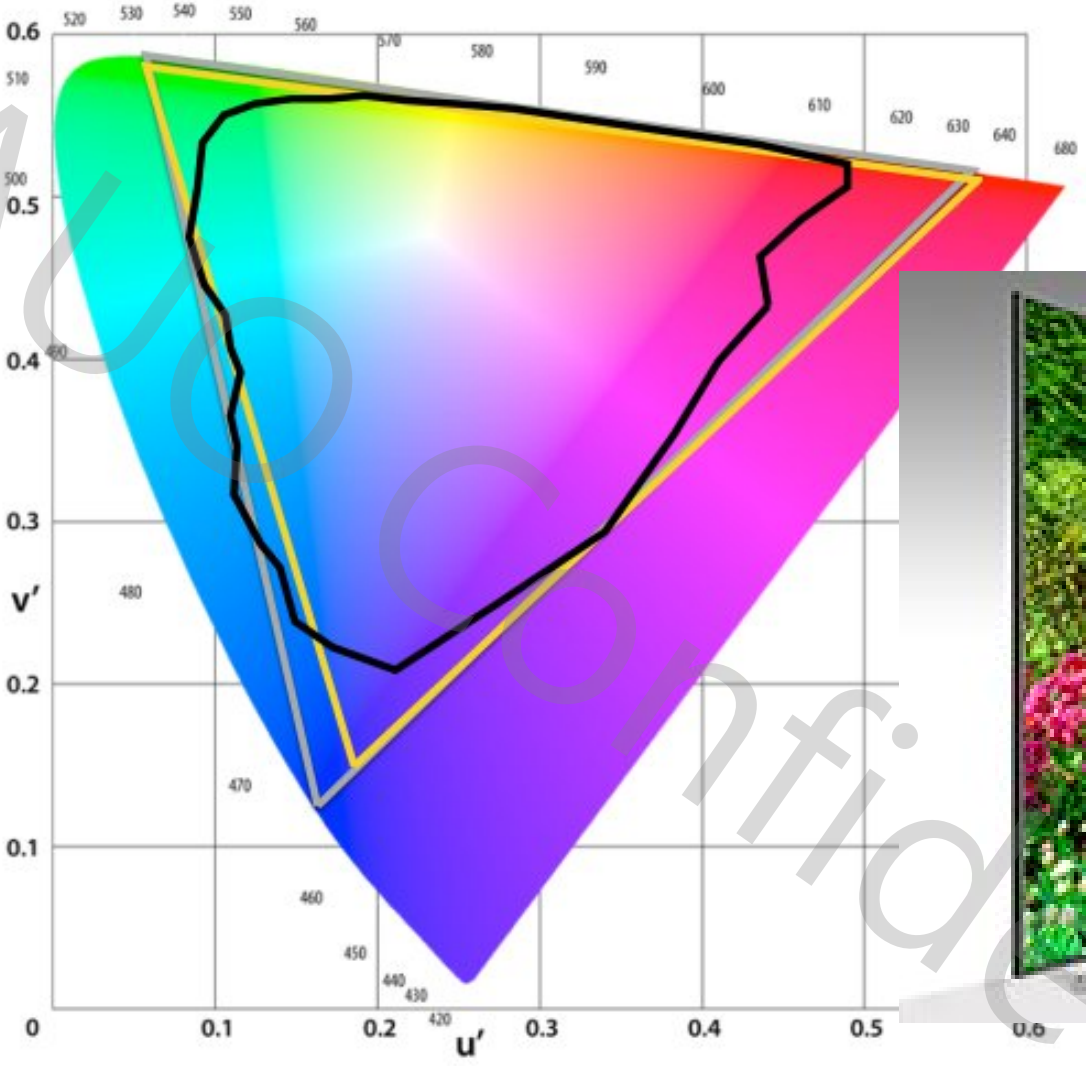
→ **The color-coding efficiency of wide-gamut TV should be comparable to that in the currently used broadcasting systems.**

→ **Every color used in wide-gamut content should be displayable on a reference monitor so that broadcasters can monitor and control the image quality.**

1. **Covers 76% of color space seen by human eye**
2. **Covers ~100% of Pointer's gamut, NTSC, sRGB, Adobe RGB, and DCI-P3**

Figure from : https://dot-color.com/

Is rec.2020 UHD broadcast spec really capable?



AUO ALCD TV Display

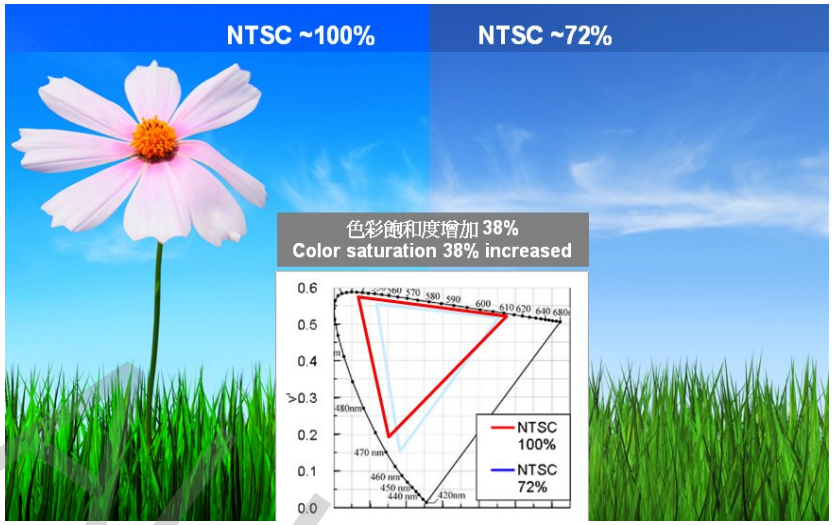
AUO ALCD TV displays adopt 3M Quantum Dot Enhancement Film, achieving over NTSC100% color saturation.

Figure from : https://dot-color.com/

What is Wide Color Gamut Display?

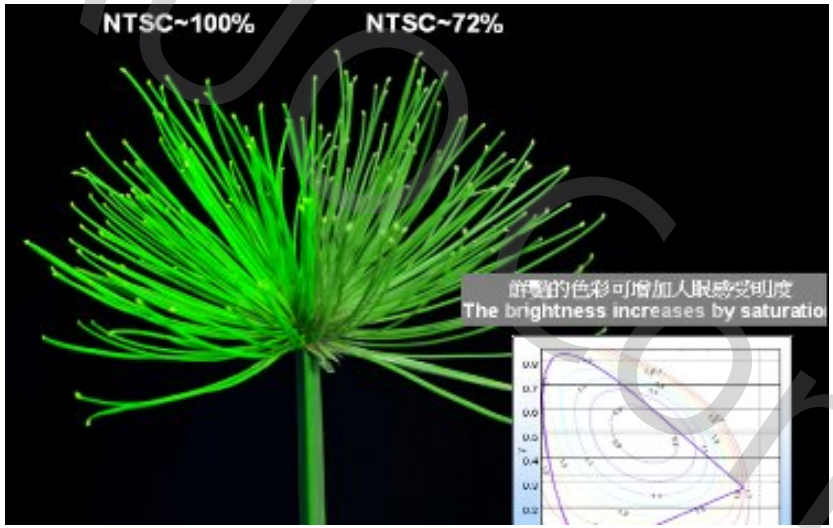
Why should we need WCG Display?

How to approach WCG LCD ?

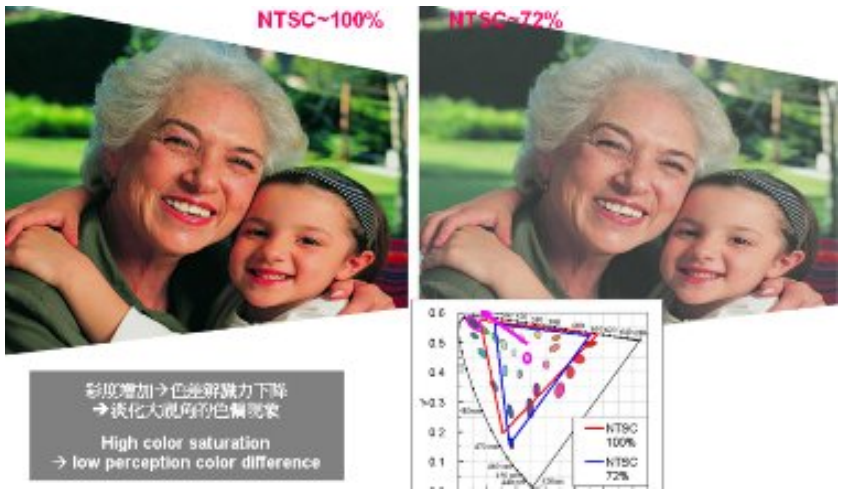


Enrich for best Picture Quality

Wide Color Gamut for Vivid Color (high saturation)



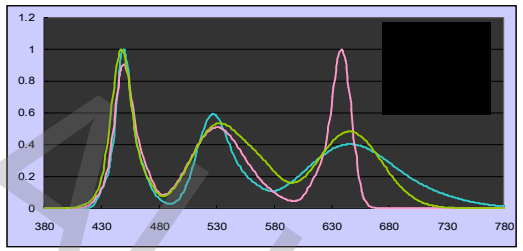
High saturation, high contrast perception



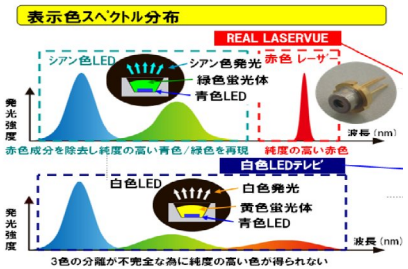
High saturation, better color shift

LCD Development Trend for Much More OLED-Like

New BL Solution



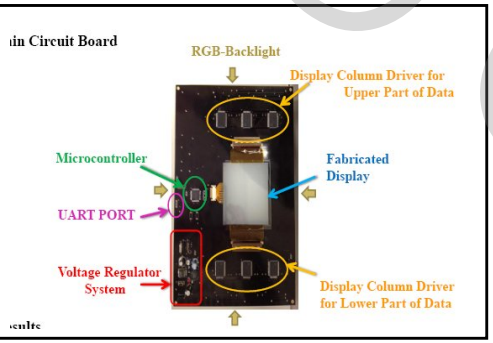
Narrow Green peak



Narrow Red peak

LED/Laser hybrid BL

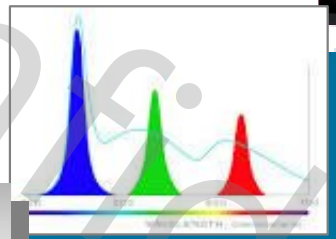
LED Diming or Sequential



2013
4K TV

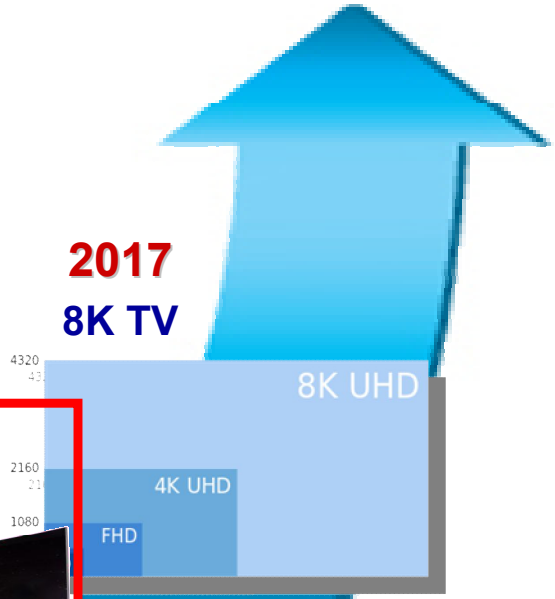
2014
Curved 4K TV

2015
Quantum Dot TV

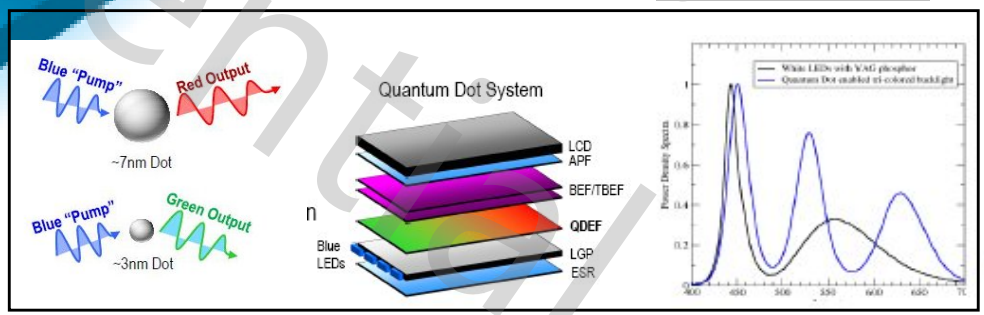


2016
OLED-Like TV

2017
8K TV

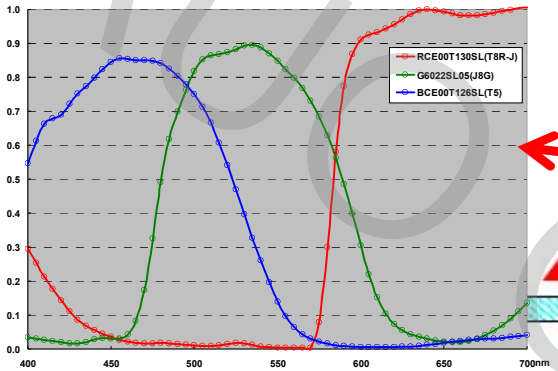


QD Solution

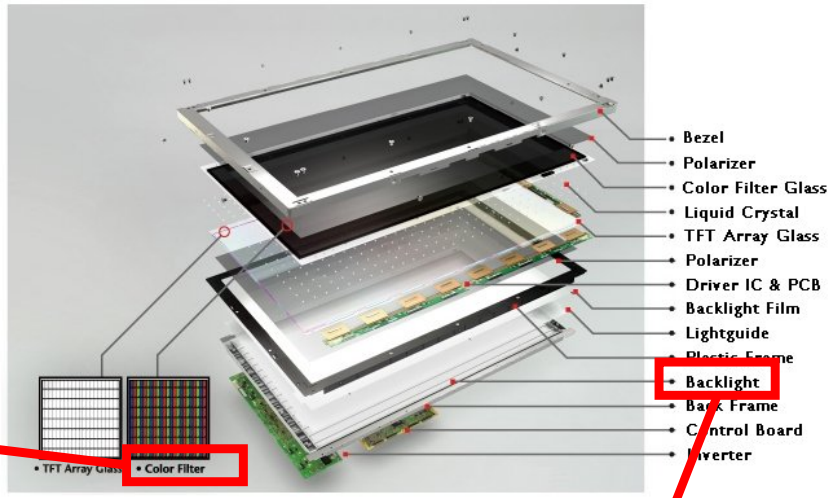


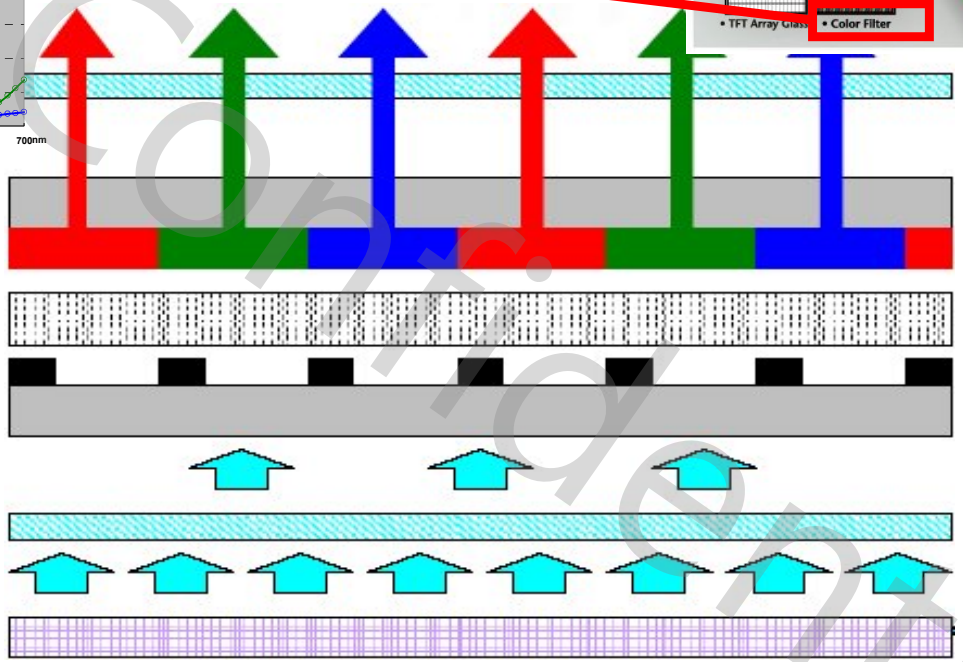
TFT-LCD Panel Structure

Light source and color filter are two key factors which affect the color of panel most.



Color Filter





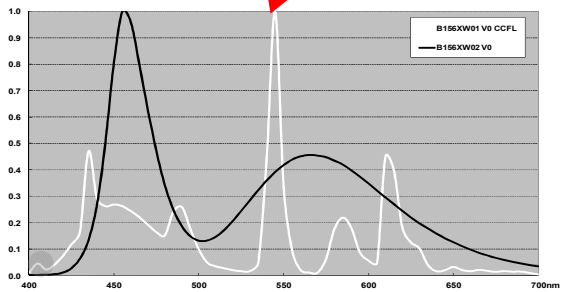
Liquid Crystal

TFT Array

Polarizer

Backlight Unit

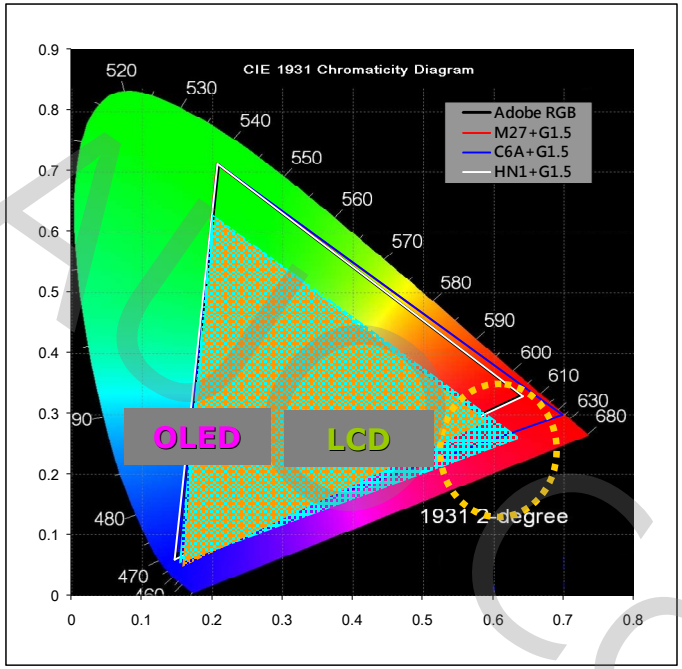
Light Guide Plate



Light Source

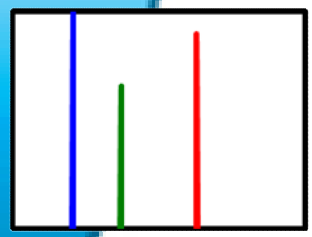
How to improve WCG by Back Light?

OLED → OLED-like LCD

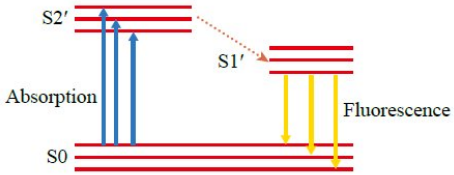


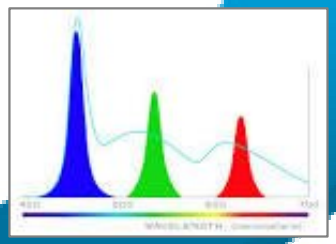
BLU evolution
- Two peak → Three peak
- FWHM: Broad → Narrow

2017~
Laser TV?

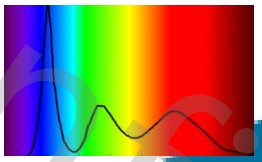


2015
Quantum Dot TV



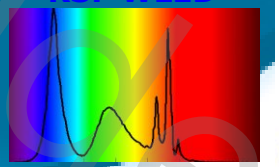


B+RG WLED

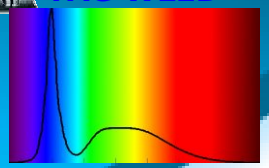


2009
LED TV

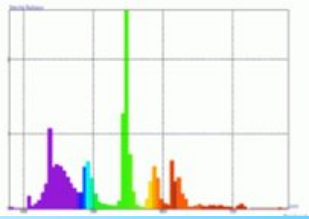
KSF WLED

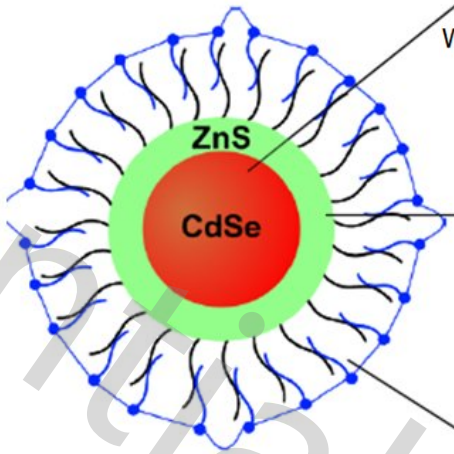


YAG WLED



~2009
CCFL TV



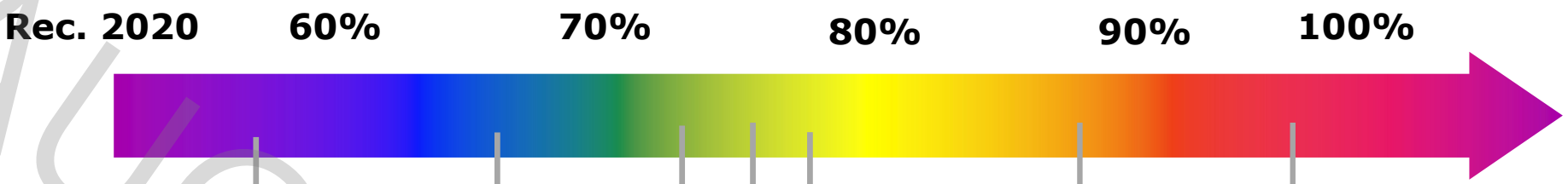


Core (3~8 nm)
Well Semiconductor
Emission wave length
CdSe, CdTe, ZnTe, CdS, InP

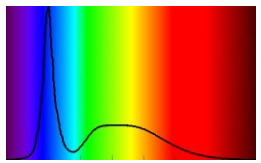
Shell (1~1.5 nm)
Barrier Semiconductor
Surface passivation
ZnSe, ZnS, CdS …

Ligand (0.5~1 nm)
Surface stablier
QD solubility
With COOH, NH_2, P, TOPO

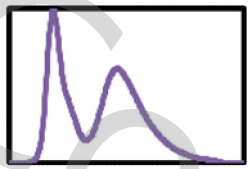
WCG vs Back Light Development Trend



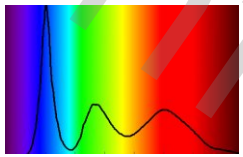
YAG WLED



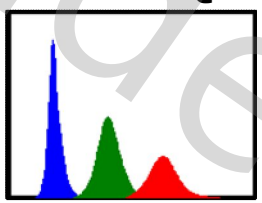
White OLED



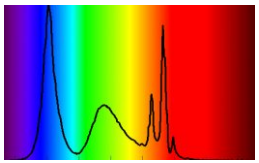
B+RG WLED



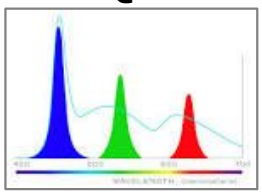
Cd-free QD



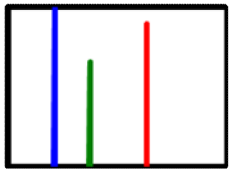
KSF WLED

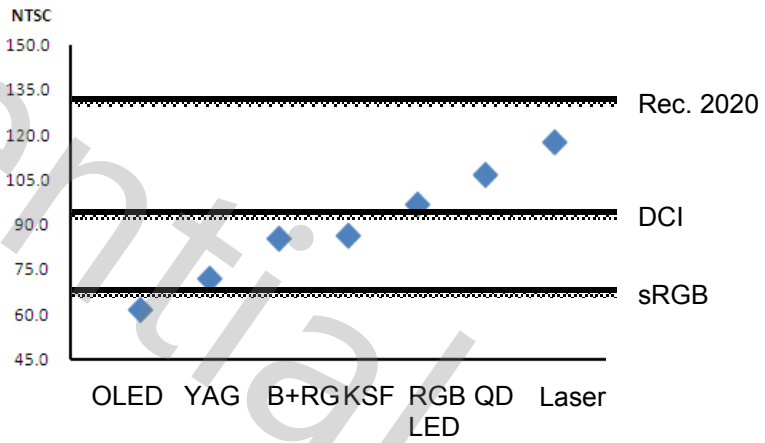


Cd QD



RGB Laser





Multi-peak and narrow FWHM BLU will have better color performance

Methods for WCG WLED BLU

Due to the matural technology of higher efficiency, low cost, …
→ B+Y, B+RG are the mainstream solution of white LED

RGB- LEDs
- RGB LEDs的特性不一致
- 驅動電路複雜
- 發光效率低, 價格昂貴
- Excellent NTSC (>100%)

BLED + Y
- 技術成熟
- 高發光效率, 成本低廉
- 專利問題
- Low NTSC (68-74%)

BLED + RG
- 發光效率較 BLED+Y低 10%
- 紅色螢光粉比黃粉成本貴(>10倍)
- High NTSC (>78%)

UVLED + RGB
- 高效率UV晶片尚待開發
- 發光效率低, 尚未成熟
- High NTSC (72%-90%)
- UV信賴性疑慮

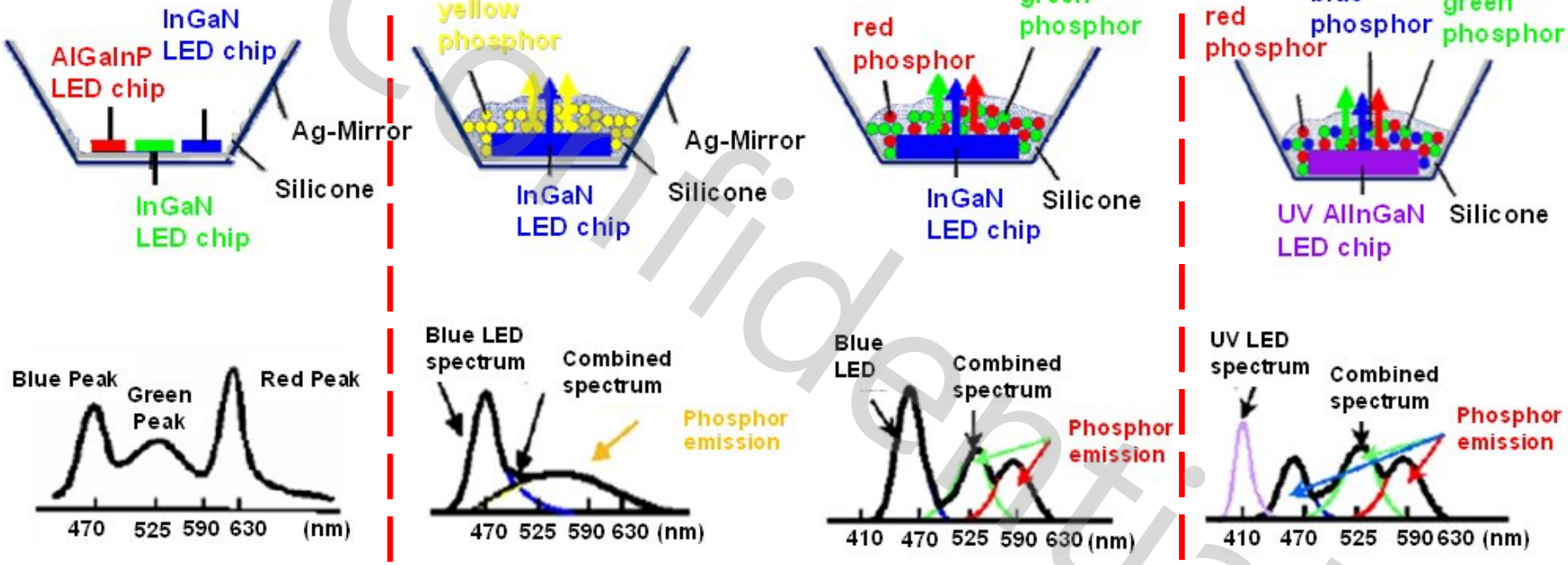
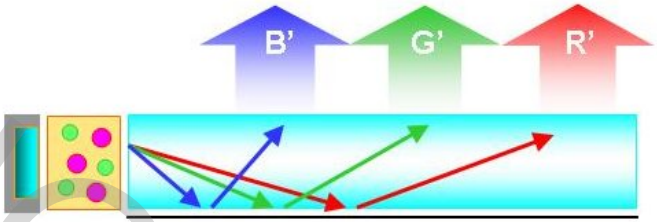
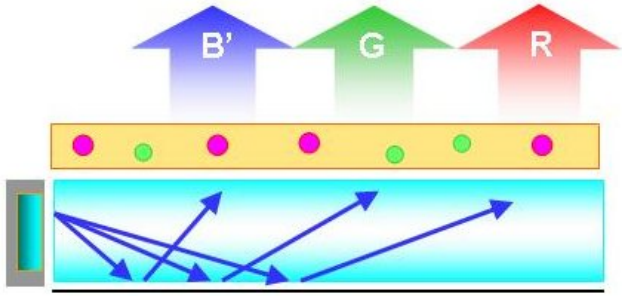


Figure form ITRI

Quantum Dot (QD) for WCG BLU

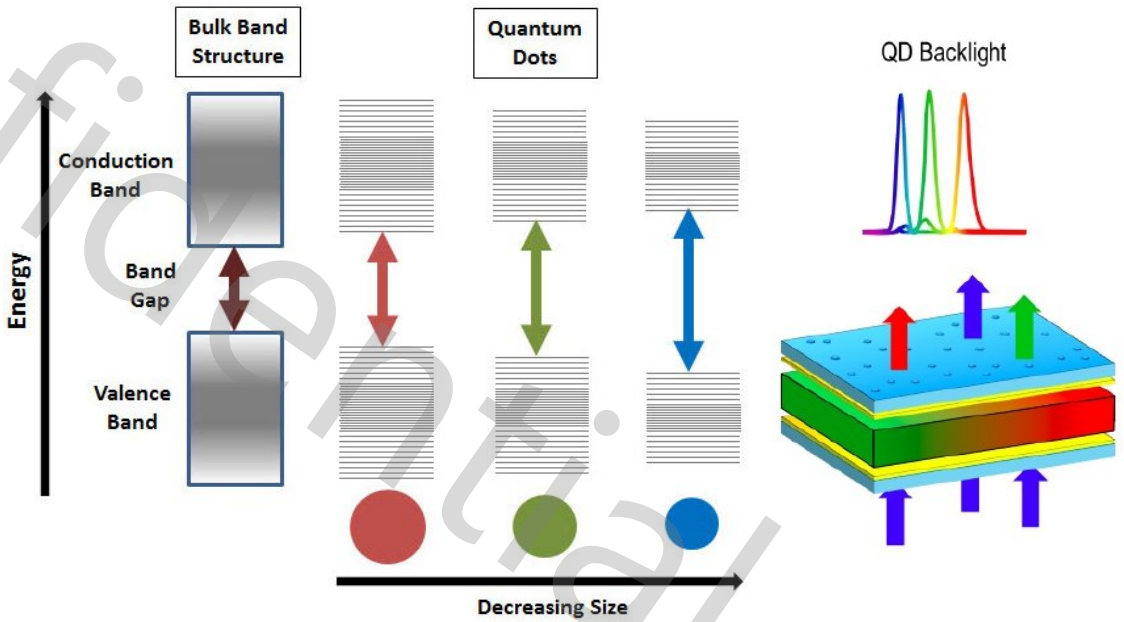
	Quantum Rail	Quantum Dot Enhancement Film
Structure		
Pros	✓ With zero change in thickness ✓ For mobile devices ✓ Little Color shift	✓ With little change in overall thickness ✓ Can be scaled to any size, from tablets to large format TVs ✓ Uniformity

Quantum confinement effect

$$E_n = \frac{n^2 h^2}{8mL^2}$$

$$\Delta E = E_{n+1} - E_n = \frac{(2n+1)h^2}{8mL^2}$$

L↘ → ΔE↗ → λ↘



Fiture from Sigma-Aldirch & Techbriefs

Cd or Cd-free QD v.s. ROHS Standard

ROHS Six Restrain Material

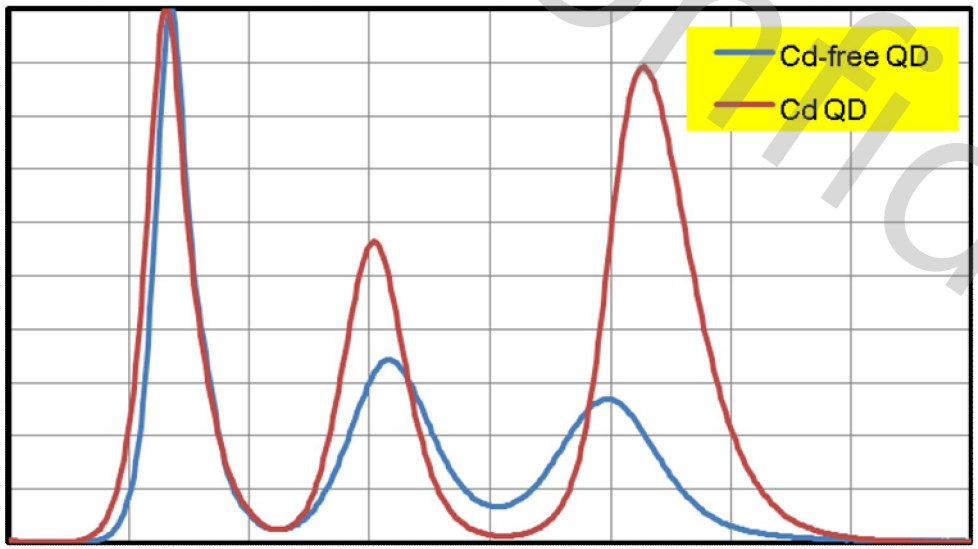
Restrictions on the Use of Certain Hazardous Substances in Electrical and Electronic (products)

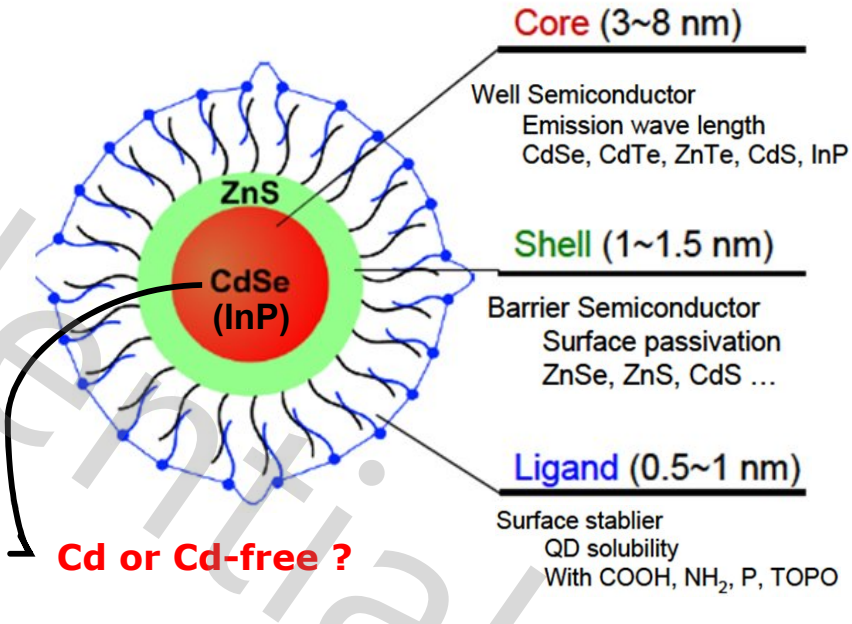
Six restrain material	Pb、Cd、Cr6+、Hg、PBBs and PBDEs

European Commission announce the restrain material standard including Cd, the wt% of Cd< 0.1% can be applied on 7 Mach, 2016 .

Can Cd QD be applied for LCD after 2017?

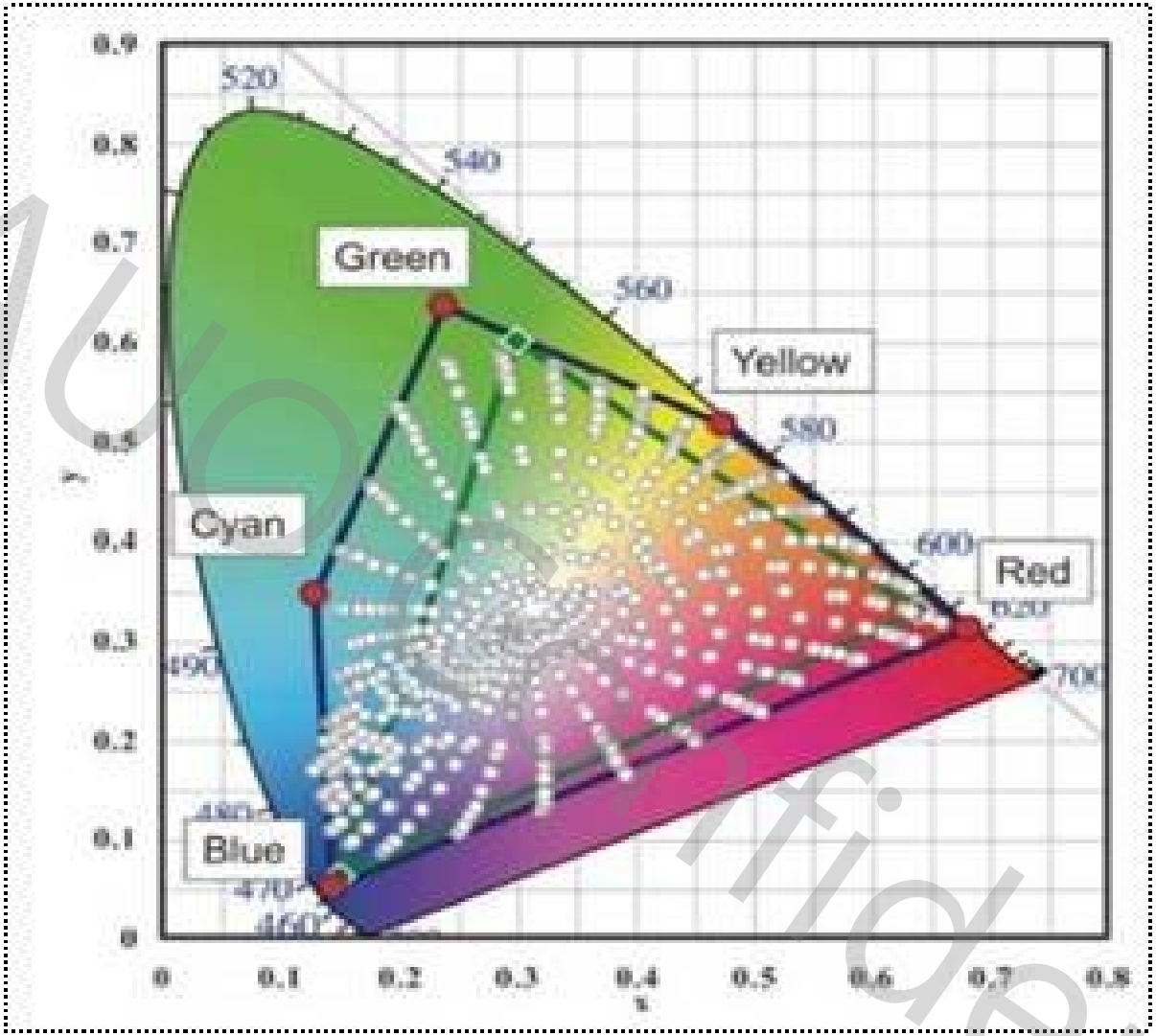
➔ Cd-free have poor QY and broad FWHM than Cd QD

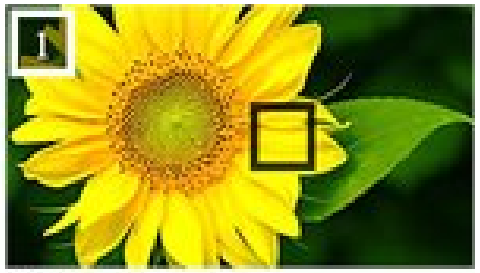




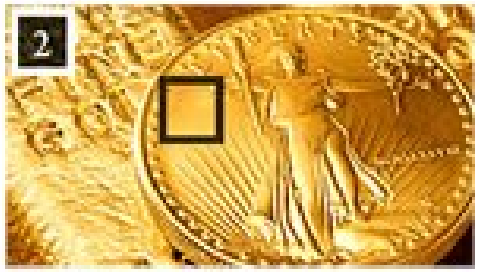
Reference: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0217&from=EN

Multi Primary Color (MPC) Display

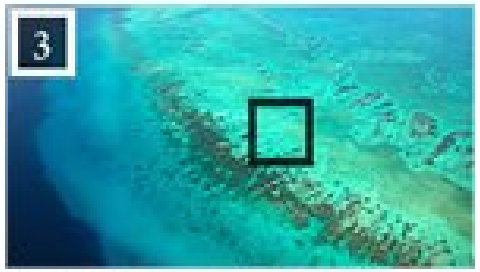




Bright yellows



Sparkling golds



Light blues

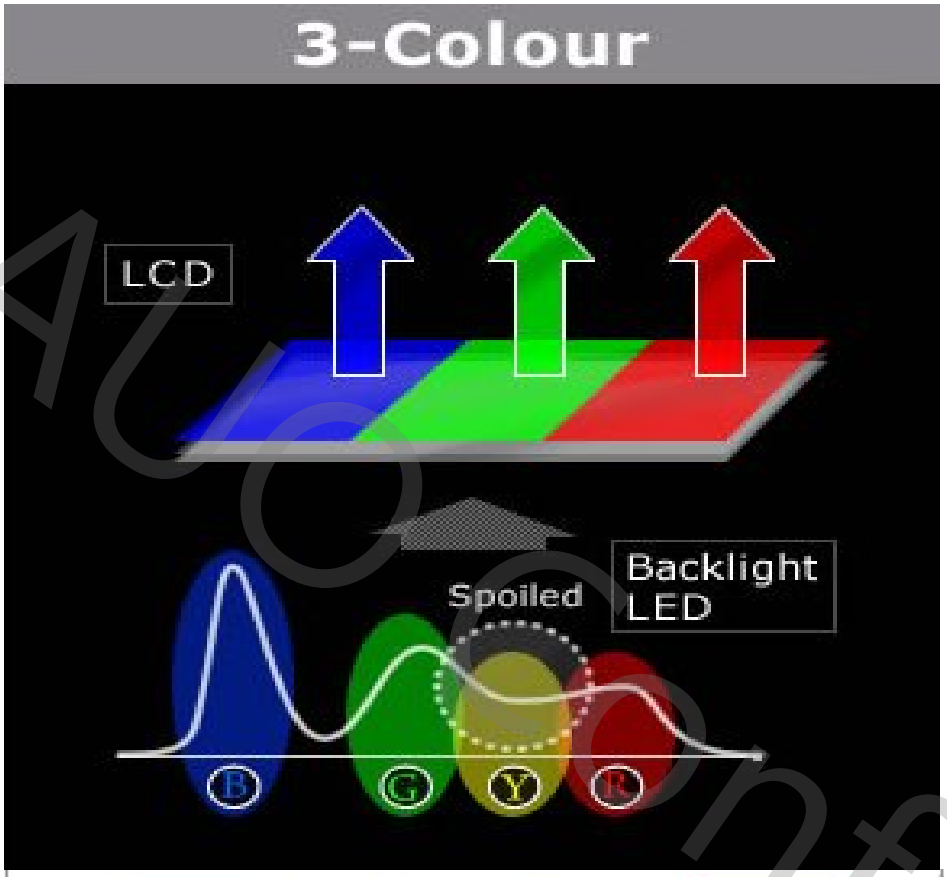
2011 FineTech Sharp

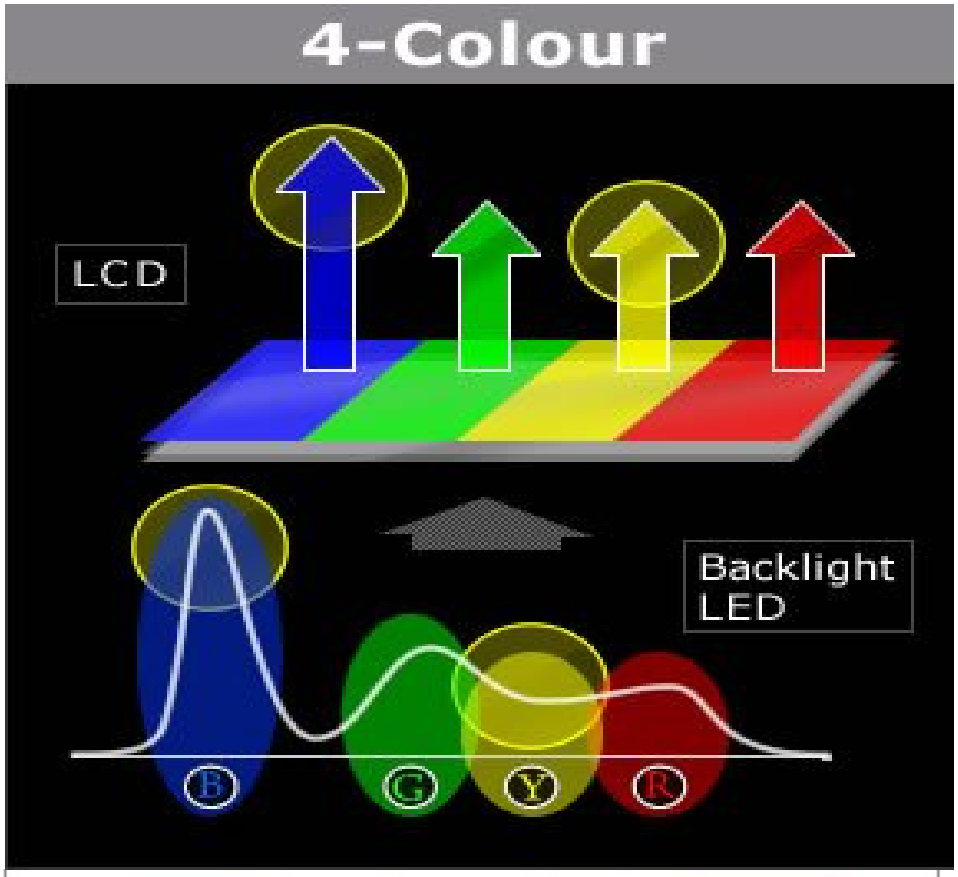
A. Not all of the colors perceived by the human eyes can be obtained by mixing three primary colors (RGB).

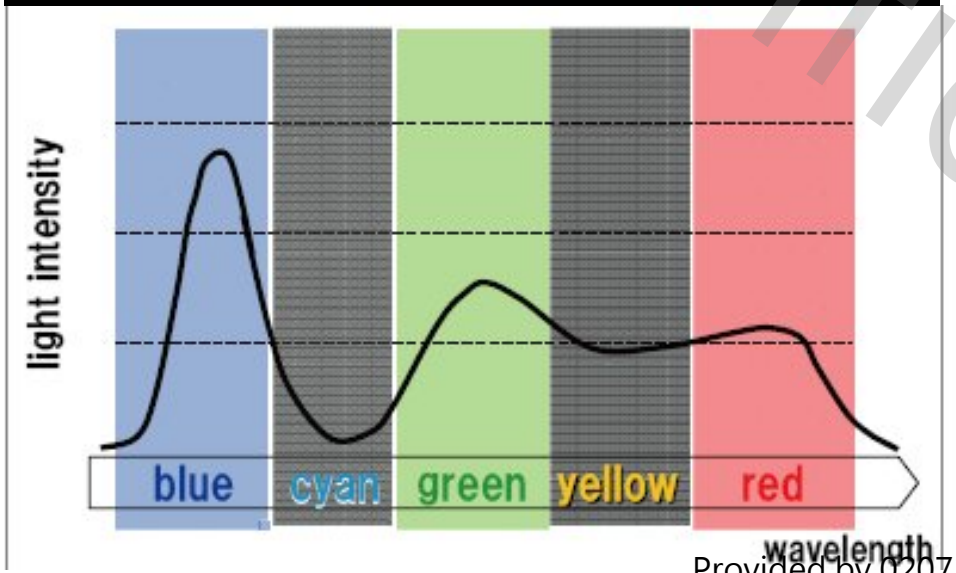
B. A multi-primary color displays are essential if vivid color reproduction is to be achieved.

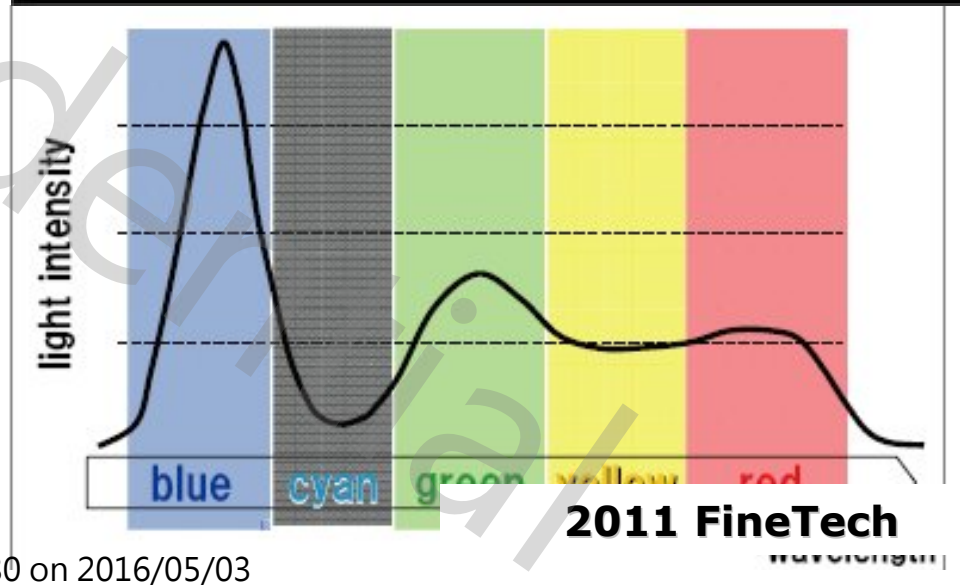
C. The gamut of the MPC display covers much more yellow and cyan colors than sRGB does, which results in high coverage of real surface colors.

Multi Primary Color (MPC) Display







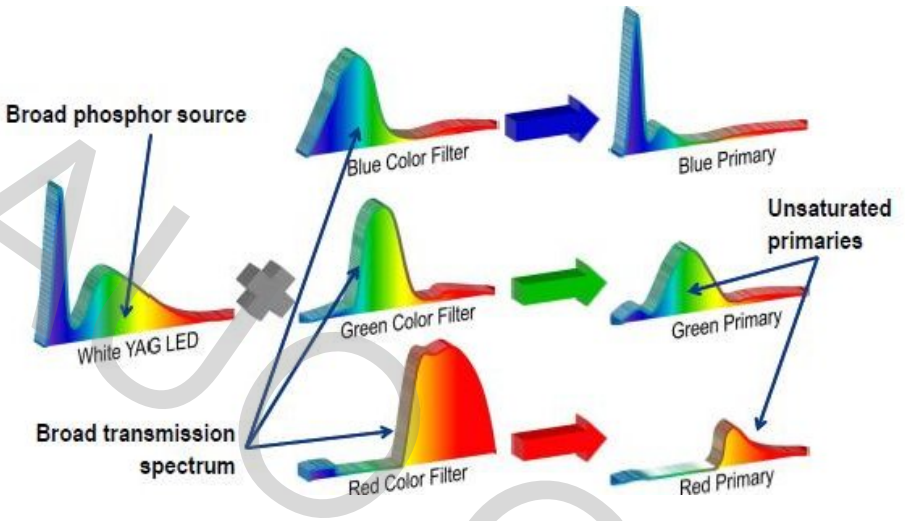


Trend in 3 Primary Color Resist

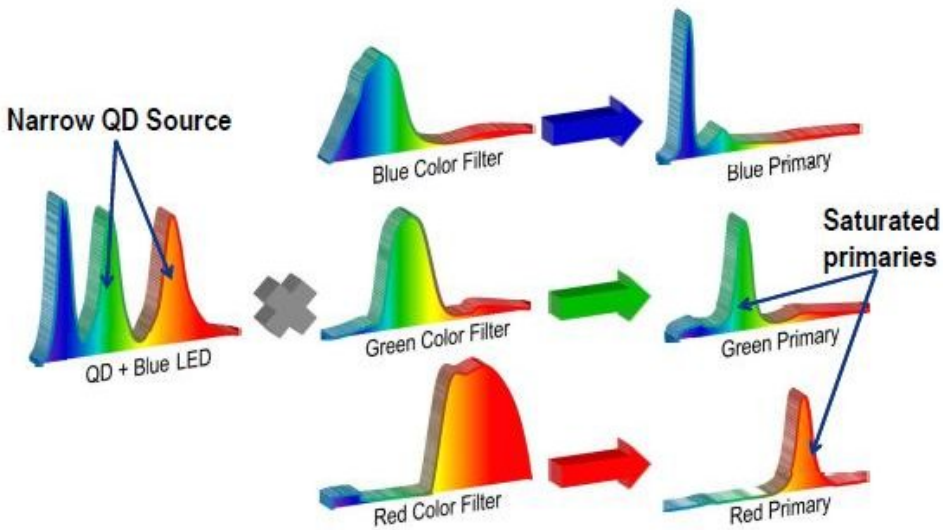
Trend	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Back Light	CCFL		YAG WLED		B+RG WLED		KSF WLED		QD WLED		New-BL?
Color Trend	High Contrast										
			High Brightness								
								Wide Color Gamut			
RED	Pigment R254/R177/Y150				Pigment R254/R177		Hybrid (New R-pig/Dye)			New R pig. ? All Dye ?	
GREEN	Pigment G36→G58			Pigment Y150→Y138			◆Improved Pigment/Dispersant ◆Research of Novel Colorants (New-Pig, Y-Dye, G-Dye)				
BLUE	Pigment B15:6/V23				Pigment B15:6/V-Dye			Hybrid or All Dye? (B Pig/V-Dye/B-Dye)			

Green & Red : Key Materials for WCG

How to improve WCF by 3 Primary Color ?

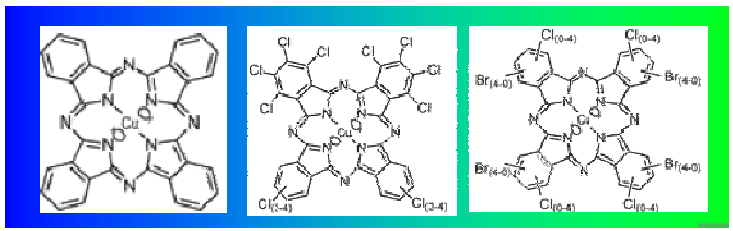


Color filter technology leaks neighboring colors from broad source leading to poor saturation in red and green.

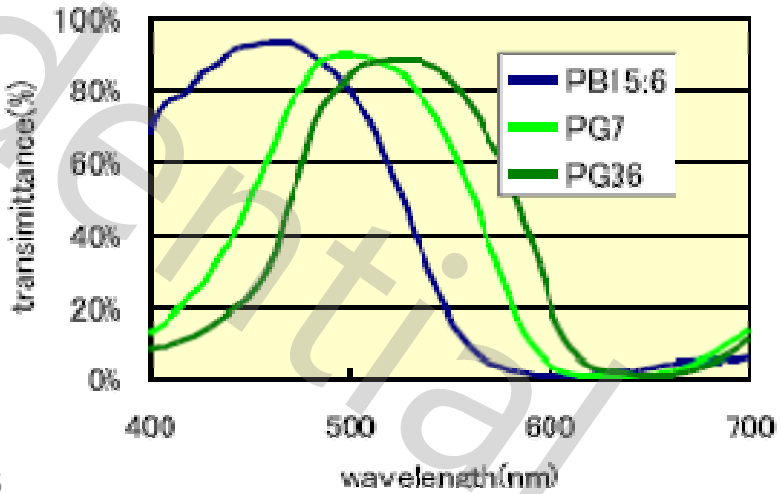


The Narrow QD Spectrum allows for saturated primaries despite broad color filters

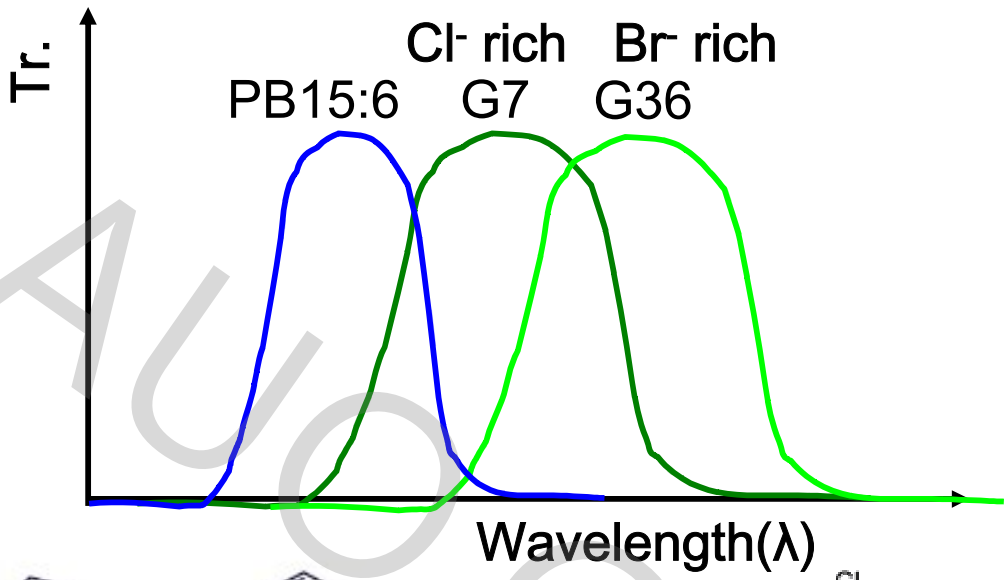
PG7 performance up and new material synthesize

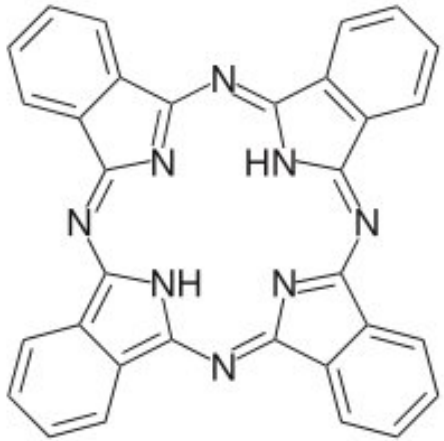


PB 15:6 | **PG 7** | **PG 36/58**

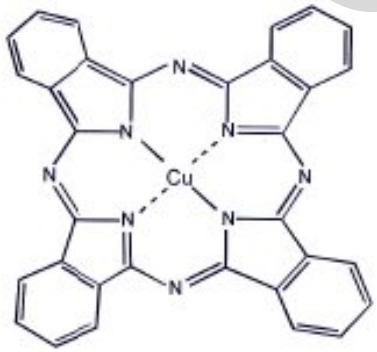


How color resist produce the color?



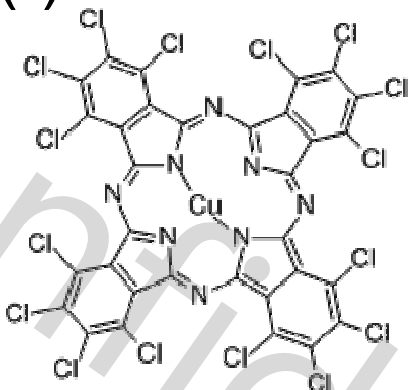


Phthalocyanine



PB15:6, PB15:3

Halide added



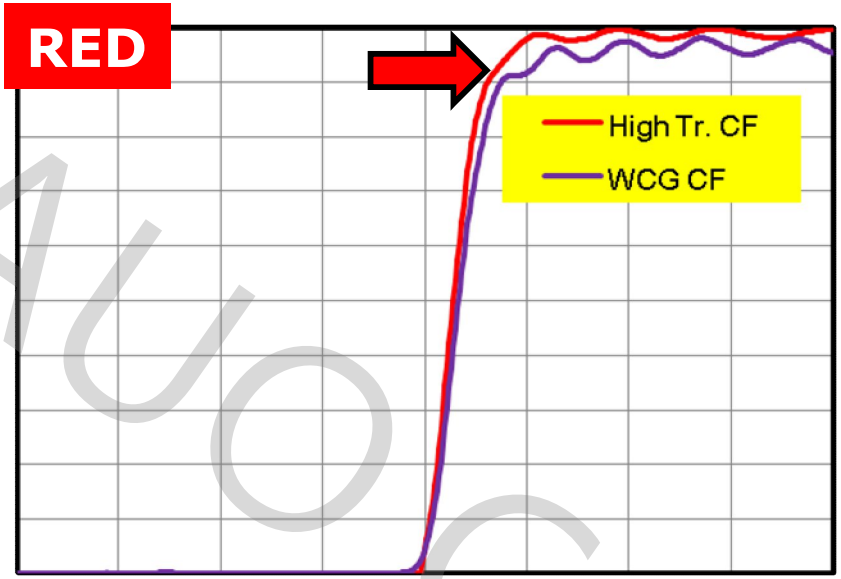
G7

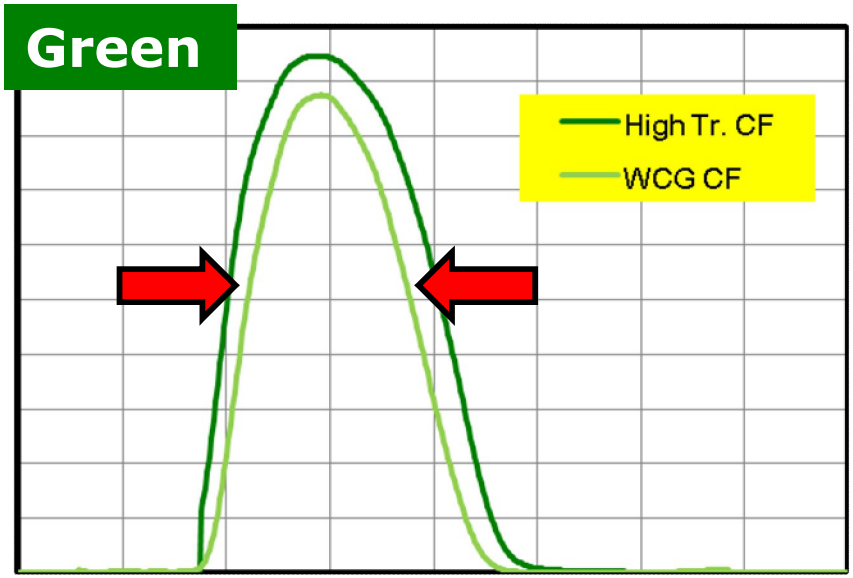
Cl-/Br- ratio adjust

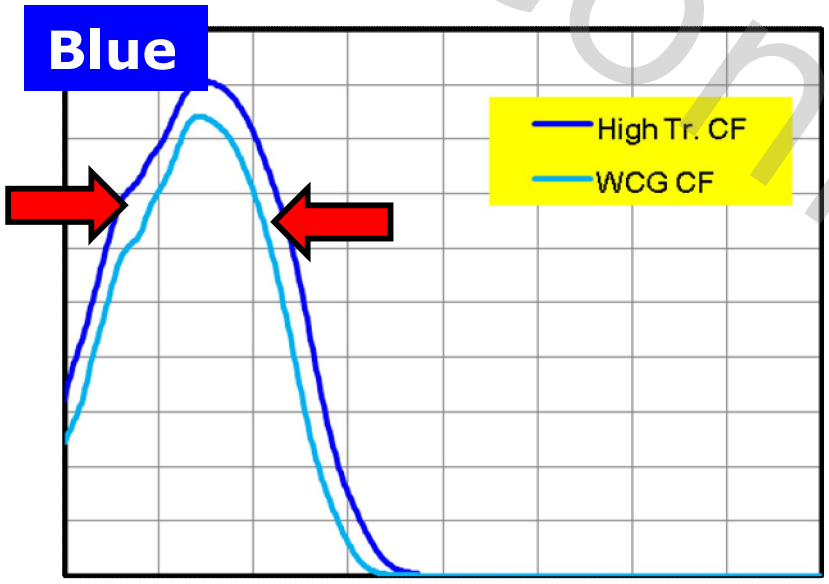
PG36

- **Phthalocyanine is often used to pigment, the central metal and functional group cause different optical property.**
- **Halide(Cl^-, Br^-, I^-) is electron withdraw group**
  - ➔ **The color filter spectrum shift to long-wavelength**
- **Spectrum shift caused of Cl^- and Br^- ratio**
  - ➔ **Cl^- rich cause hypsochromic**
  - ➔ **Br^- rich cause bathochromic**

How to improve WCF by Color Filter

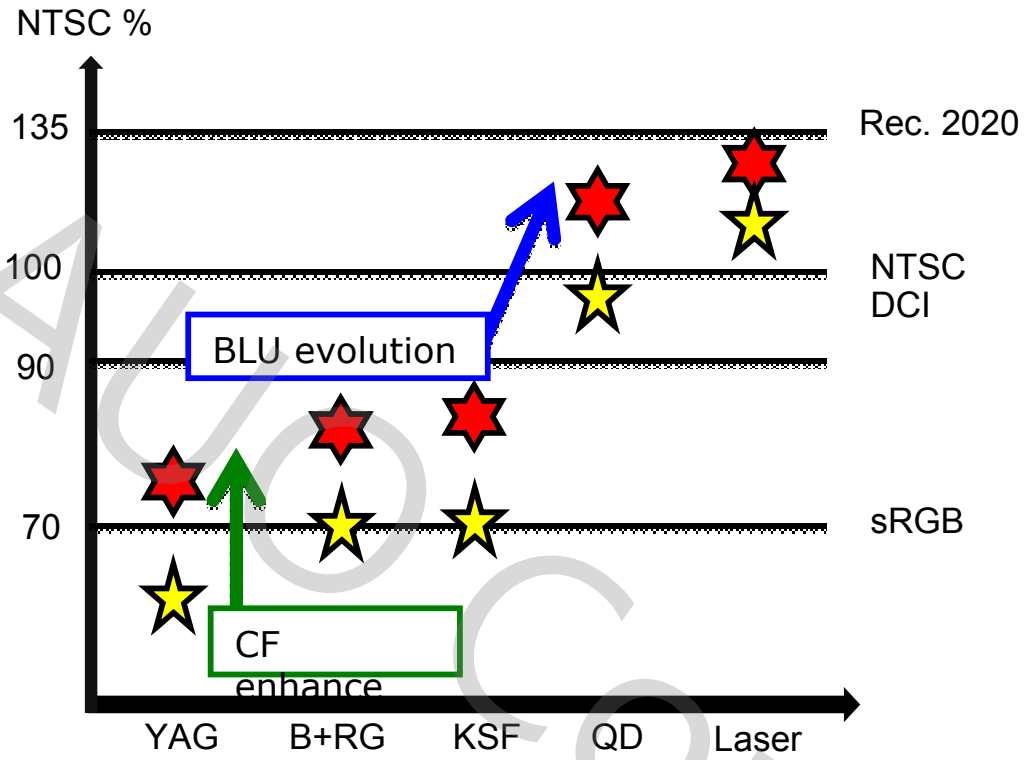






WCG CF will cut the bandwidth
→ Narrow band CF is the key of wide color gamut display

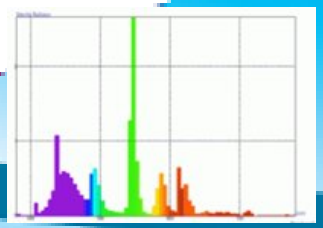
CF + BLU Optimization for WCG



WCG CF

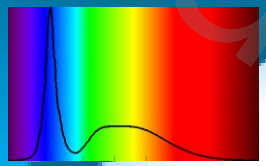
High Tr. CF

~2009
CCFL TV

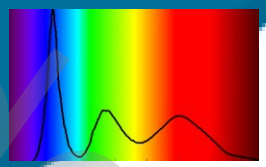


2009
LED TV

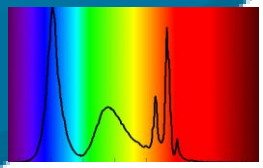
YAG WLED



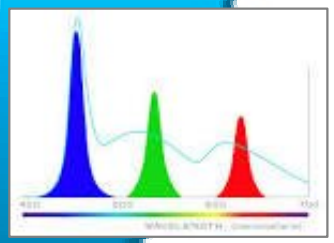
B+RG WLED



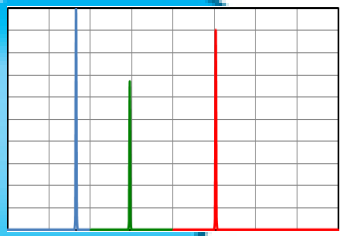
KSF WLED



2015
Quantum Dot TV



2017~
Laser TV?



CF & BLU are two key factors
- **Narrow band BLU.**
- **WCG CF.**

➔ **WCG Gamut Get!**