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Technical seminar on

"RECENT ADVANCES ON QUANTUM DOT ENHANCED LIQUID CRYSTAL DISPLAY"

Presented By

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INTRODUCTION

- A quantum dot display is a display device that uses quantum dots (QD), semiconductor nanocrystals which can produce pure monochromatic red, green, and blue light.
- Photo-emissive quantum dot particles are used in a QD layer which converts the backlight to emit pure basic colors which improve display brightness and color gamut by reducing light losses and color crosstalk in RGB color filters.
- This technology is used in LED-backlight LCDs, though it is applicable to other display technologies which use color filters, such as white or blue OLED or MicroLED. LED-backlit LCDs are the main application of quantum dots.

- quantum dot(QD) enhanced backlight is emerging and it has found widespread applications because of following outstanding features:

1) Its central emission wavelength can be tuned by controlling the size of the nano particles.

2) Its FWHM is around 20-30 nm, which is mainly determined by the size uniformity.

3) Its photoluminescence efficiency is high.

4) Its device configuration is simple. Briefly speaking, the QD backlight uses a blue LED to excite green/red colloidal nano particles, generating a white light with three well-separated RGB peaks.

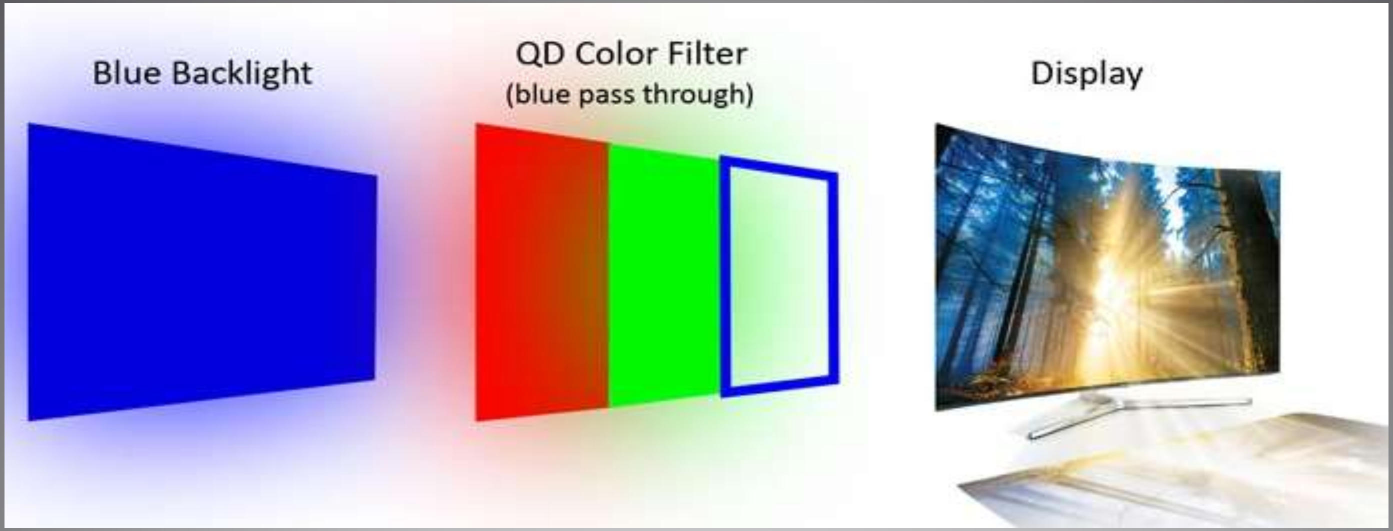


Fig1:Next Generation QD Color Replacement

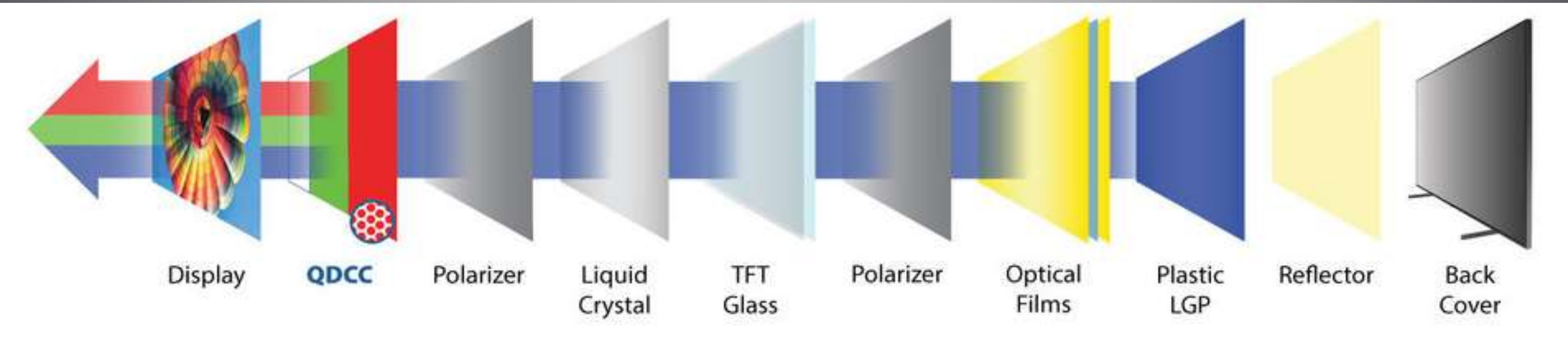


Fig2: Quantum Dot Technology Roadmap

LITERATURE REVIEW

SL. NO	Paper Details	Contribution	Drawbacks
1.	Haiwei Chen & Shin-Tson Wu (2019**) Advanced liquid crystal displays with supreme image qualities, Liquid Crystals Today**, 4-11, 15 july 2019	• The recent progress on LCD from three key display metrix was proposed. • Investigation was done on how the response time affects the motion blur.	• Caculating MPRT of an active matrix display was difficult. • The color gamut improvement is not much affective.
2.	Yun-Hyuk Ko, Mohammed Jalalah, Seung-Jae Lee & Jea-Gun Park **Advanced Semiconductor Materials and Devices** Center, Department of Electronics and Computer Engineering, Hanyang University, 2018	• QDEF working in tandem with a blue LED backlight unit was proposed. • To minimize the crosstalks between the polarized emitting B,G,R light	• The color gamut performance of PRQD functional LCD using only blue LED BLU is performed. • Light emitting power loss from QDEF is high.

SL. NO	Paper Details	Contribution	Drawbacks
3.	Guanwei Liang, Junchi Chen, Shudong Yu, Siyang Feng, Caiman Yan, Binhai Yu and Zongtao Li **Enhancing optical performance of quantum dotconverted LEDs via electrospun fiber rods** 19th International Conference on Electronic Packaging Technology, 2018	• They have introduced a novel design scattering structure fiber rod via electro spinning. • The transmittance and haze of only fiber rod diffuse films were measured.	• Lumin enhancement efficiency in QDs are limited. • The nanofiber fabricated by electro spinning is not suitable in packaging directly.
4.	Masayuki Sugawara **“Parameter values for ultra-high definition television systems for production and international programme exchange,”** 2017.	• The application that use image formats beyond HDTV was dicussed. • The STFT as a time and frequency localized version of the FT is proposed.	• The overall system cost is high. • ITU-R provides ineffective usage of resource.

SL. NO	Paper Details	Contribution	Drawbacks
5.	Zhenyue Luo, Yuan Chen, and Shin-Tson Wu "**wide color gamut lcd with a quantum dot backlight**" , The College of Optics and Photonics, University of Central Florida, 25 oct 2013, 4 november 2017.	• They have used multi objective optimization method to refine the QD emission spectra. • A fundamental trade off between color gamut and system efficiency is explained	• Systematic performance analysis of a QD display is still lacking. • Though QD LED performance is high rather leads to a higher cost.
6.	T.Okumura, A. Tagaya,Y.Koike,M. Horiguchi, and H. Suzuki, **"Highly efficient backlight for liquid crystal display having no optical films,"** 2017.	• They have proposed a highly efficient backlight that require no optical film. • They have employed a Monte Carlo method based on Mie scattering theory.	• The backlight consumes more lcd modules. • Advanced HOST backlight not easily adopted to applications requiring LCDs.

OVERVIEW OF QUANTUM DOT LIQUID CRYSTAL DISPLAY

MATERIAL SYNTHESIS AND CHARACTERIZATIONS

This is attributed to the unique core-shell structure of QDs, as Fig.3 shows. Shells as well as the surrounding organic ligands work as the protection layer and provide necessary processability. Both efficiency and lifetime would be enhanced compared to the core-only systems.

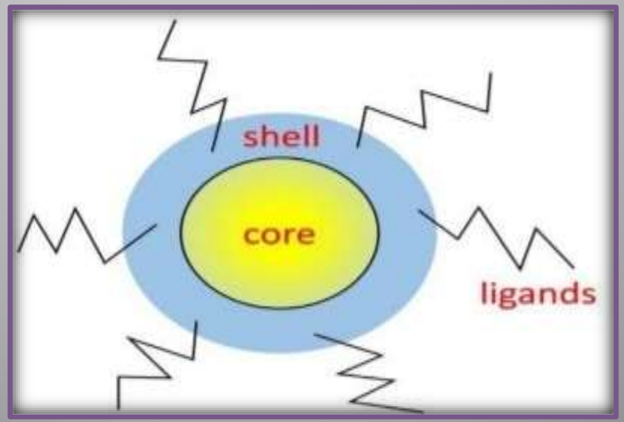


Fig 3. Schematic diagram of QD's core-shell structure.

❑ Various QD materials have been synthesized and studied; they can be roughly divided into two groups they are heavy metal-based QDs and heavy-metal-free QDs.

1. Heavy Metal-Based QDs

❖Emission spectrum can be adjusted to cover the entire visible region by tailoring the particle size, as illustrated in Fig.4(a).

❖Fig.4(b) depicts the typical emission spectra for green and red CdSe QDs as well as a high power in GaN blue LED.

❖Such a high quality QD material seems to be a perfect choice for display applications.

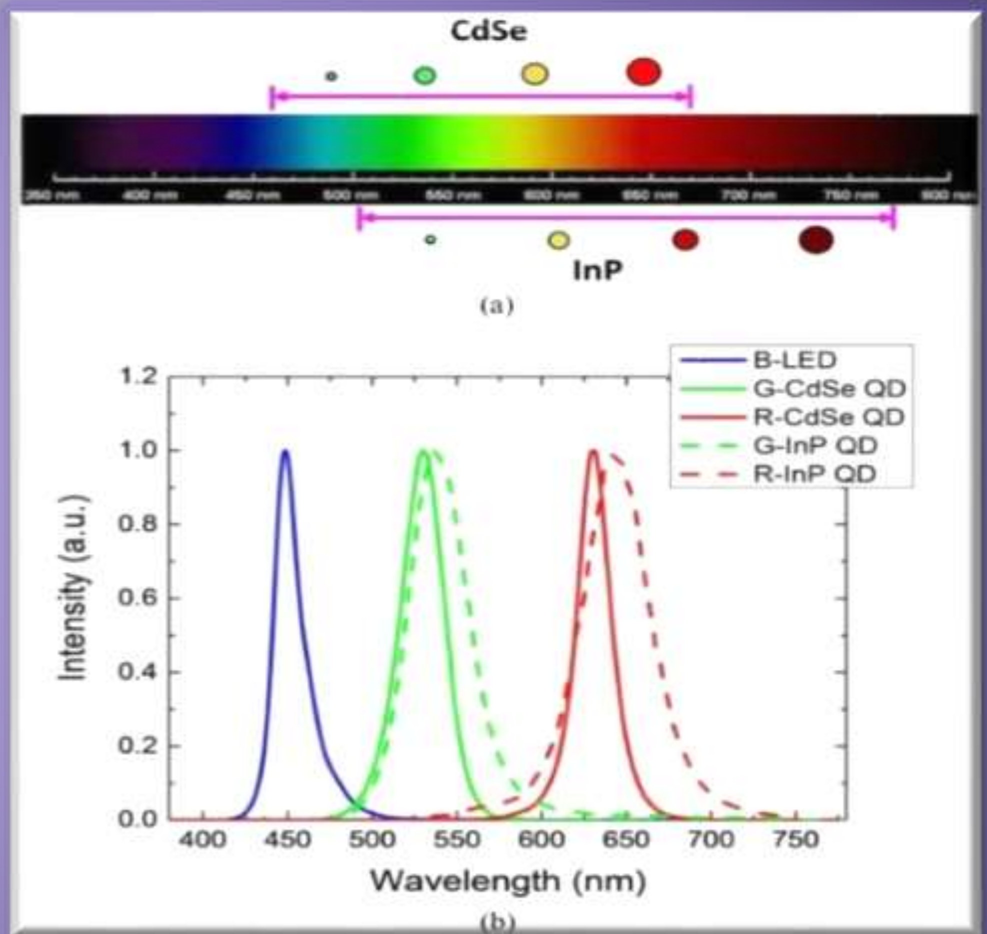


Fig. 4 (a) Potential emission spectral range of CdSe and InP QDs;

(b) Typical emission spectra for green and red quantum dots using CdSe (solid line) and InP (dashed line).

2. Heavy Metal-Free QDs

- Among several candidates for Cd-free QDs, InP has been identified as the most viable alternative for the visible light. Its bandgap for bulk material is 1.35 eV, which is smaller than that of CdSe. Thus, to reach the same emission wavelength, the core size of InP dots has to be smaller than that of CdSe [Fig.4 (a)].

- Smaller bandgap and smaller particle size lead to much stronger confinement effect. Thus, the emission spectrum of InP QDs is more susceptible to particle size variation.

- As a result, its FWHM is somewhat broader (>400nm), as shown in Fig.4(b), corresponding to 70−80%.

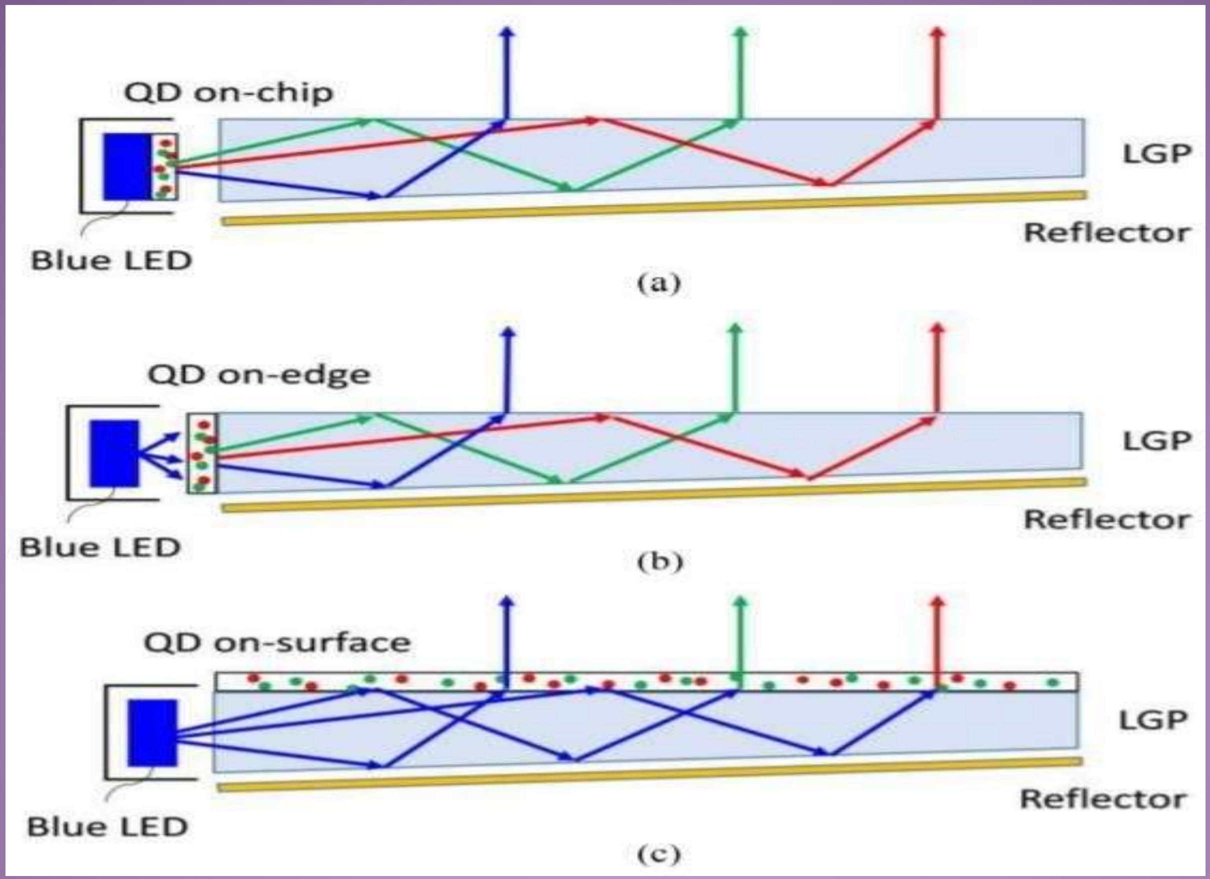


Fig.5 Schematic diagram for three different device geometries implementing QD mixtures (a)Q Displaced within an LED package. (b) Q Displaced between LED and light guide plate, or known as quantum rail. (c)Q Displaced on the top surface of light guide plate, or known as quantum dot enhancement film (QDEF). (LGP: light guide plate).

DEVICE CONFIGURATIONS

A. On-Chip Geometry

- This design consumes the least amount of QD material, and is cost effective.
- It is fully compatible to current backlight unit, leading to much simpler optical design. And what we need is to simply replace the phosphors with QD mixtures as the energy down-conversion layer, within an LED package, as shown in Fig. 6.

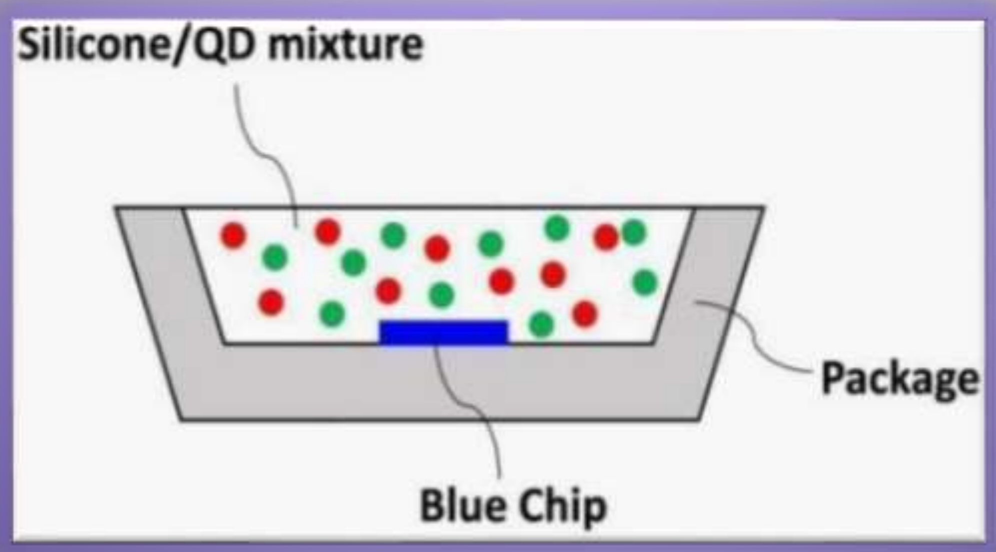


Fig. 6 Schematic diagram of QD on-chip geometry.

B. On-Edge Geometry

The on-chip design is not yet mature for practical display applications, the on-edge geometry becomes a suitable alternative, especially for large size TVs. In fact, Sony released its 55” QD TV using such configuration in 2013. Compared to on-chip design, QD rail’s lifetime is much improved because it is located further away from the blue LED. Also, the consumption of QD material is still acceptable.

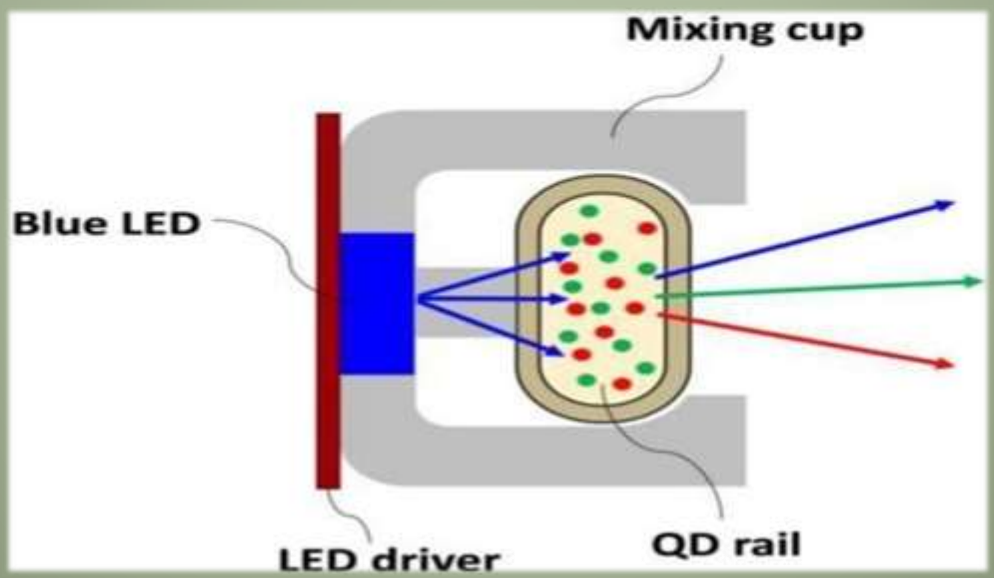


Fig. 7 Schematic diagram of QD on-edge geometry (i.e. QD rail).

On-Surface Geometry:

This is the most commonly used geometry, also known as quantum dot enhancement film (QDEF). It is placed above the LGP [Fig. 5(c)], decoupled from the LED heat source spatially. As a result, the resultant operating temperature should be close to the room temperature. Both reliability and longterm stability are enhanced significantly.

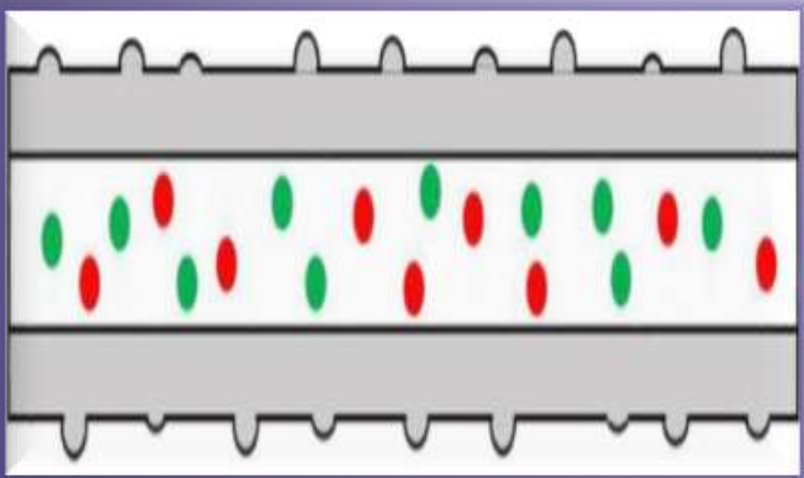


Fig. 8 (a) Schematic diagram of QD on-surface geometry (i.e. QDEF).

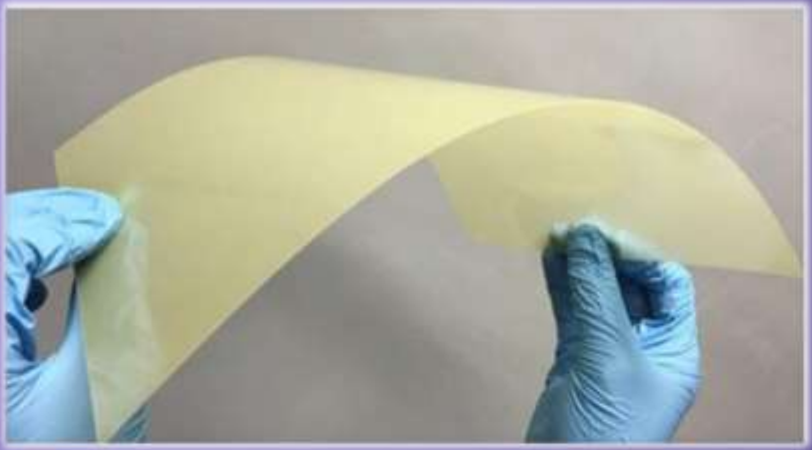


Fig .8 (b) photographic image of QD on-surface geometry (i.e. QDEF).

- Fig.8(a) shows a sketched structure of QDEF, which comprises three layers two plastic barrier films sandwiching a layer of quantum dots suspended in a polymer matrix.
- The barrier film for QDEF is optically clear to let light pass through, flexible for rolling and thin to allow a slim device profile, while prevents degradation from oxygen and moisture in a package.
- QD layer contains trillions of red and green-emitting quantum dots, yielding yellow appearance for QDEF, as shown in Fig. 8(b).
- One drawback of QDEF is the massive material consumption, especially for large screen TVs. As the capacity of QDEF keeps growing, the cost should decrease gradually in the near future.

METHODOLOGY OF QUANTUM DOT LIQUID CRYSTAL DISPLAY

SYSTEM PERFORMANCE

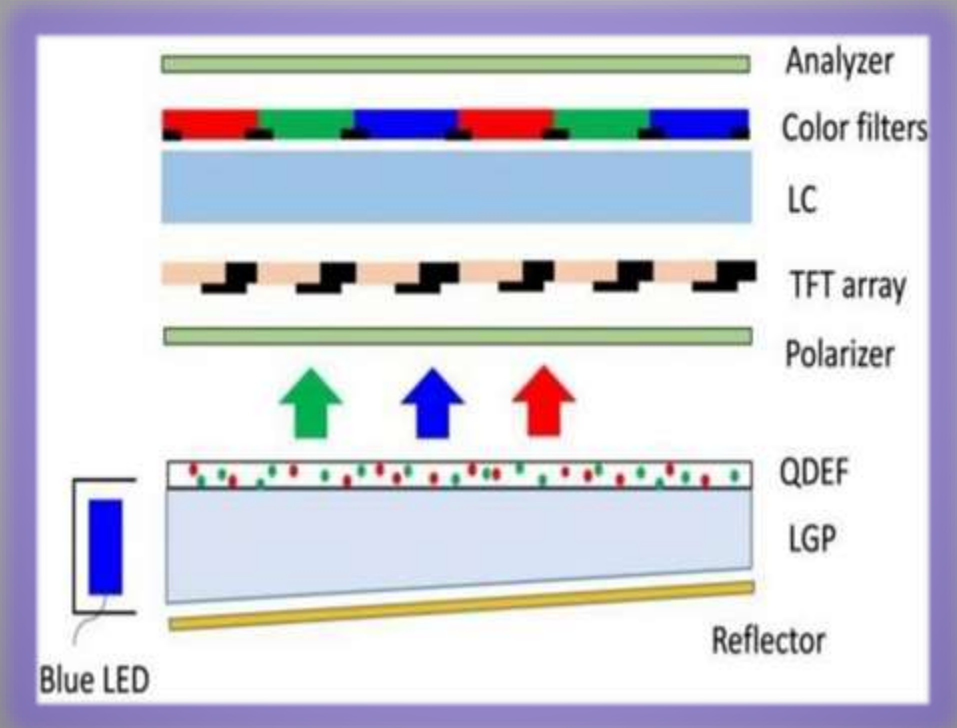


Fig.9 System configuration of a typical LCD panel (LC: liquid crystal; TFT: thin film transistor).

- The system configuration of a typical LCD panel is shown in Fig 9.

- The incident light $S_{in}(\lambda)$ is split into three channels: red(R), green(G) and blue(B) corresponding to RGB color filters.

- Then they pass through the thin film transistor (TFT) backplane, LC layer, and color filter array successively.

- Finally, the RGB channels mix together and transmit out of the LCD panel with spectrum

$$S_{out}(\lambda) = S_{out,R}(\lambda) + S_{out,G}(\lambda) + S_{out,B}(\lambda)$$

Gaussian Fitting Effect

The Gaussian fitting is commonly conducted to extract the peak wavelength and FWHM as shown in Figure 10.

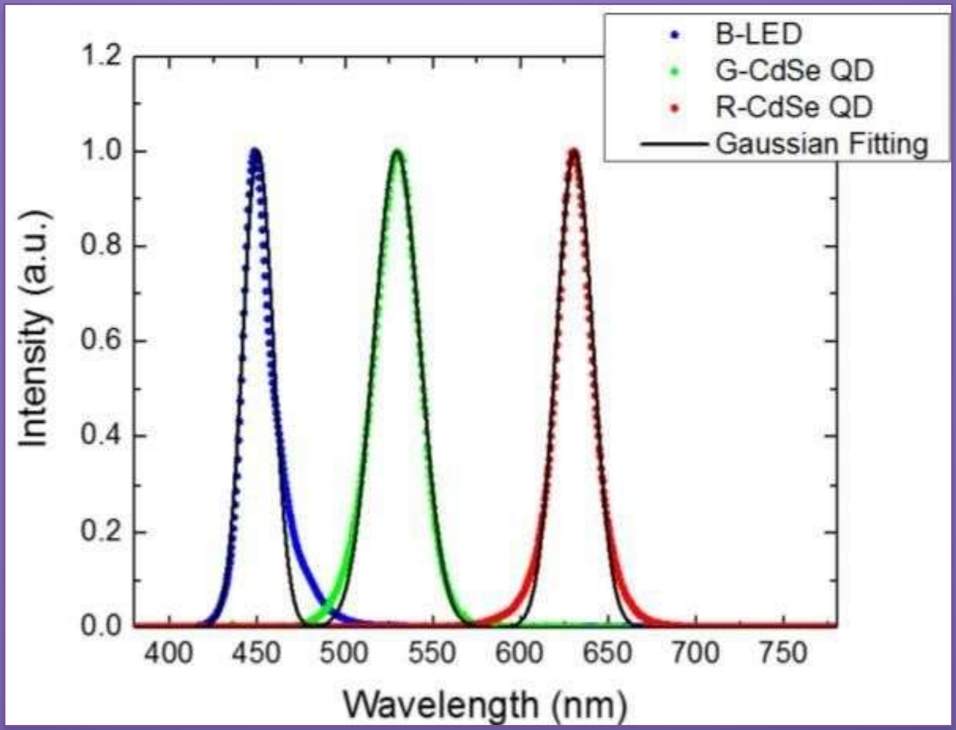
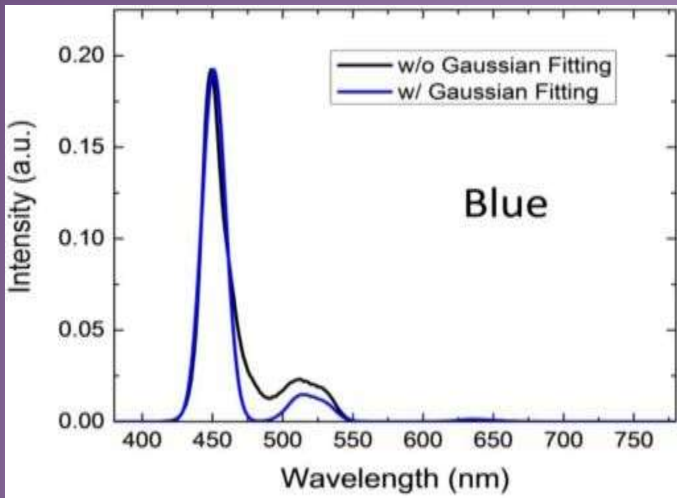
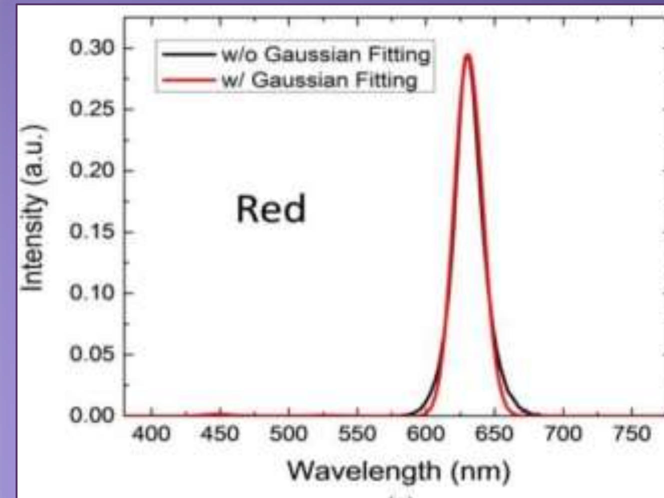


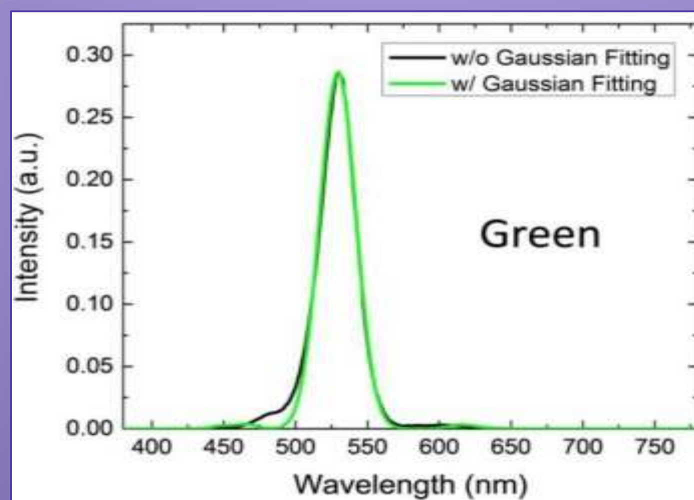
Fig.10 Gaussian fitting of the whitelight spectrum using a blue LED to excite green/red CdSe QDs.



(a)



(c)



(b)

Fig 11 (a) (b) (c) Calculated output spectra for blue, green and red primary colors after LC layer and color filters (CF1).

Color Filter Effect

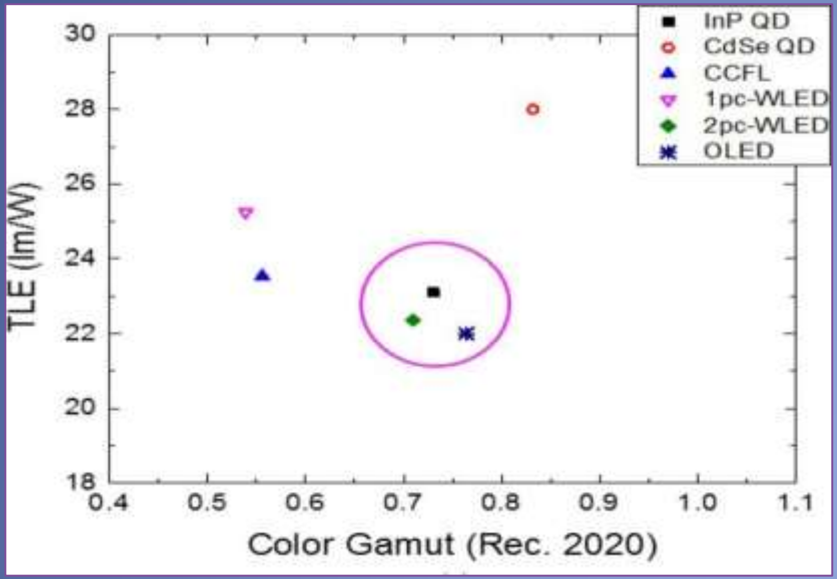


Fig 12(a) TLE versus color gamut using CF-1

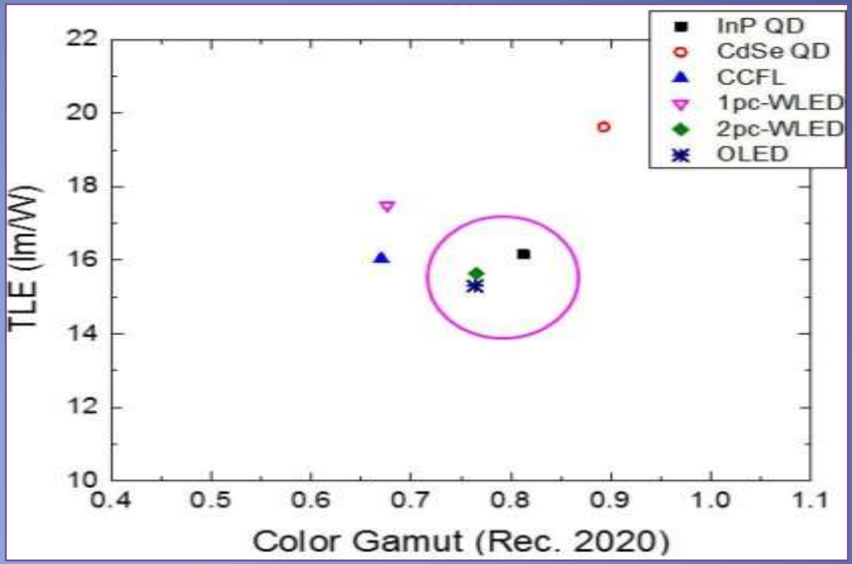


Fig 12(b) TLE versus color gamut using CF-2

Fig.12 shows the calculated color gamut and light efficiency. For comparison purpose, besides CdSe and InP QDs, it also include three other light sources:

1) cold cathode fluorescent lamp (CCFL)

2) yellow phosphor-converted white LED (1pc-WLED)

3) green and red phosphor-converted white LED (2pc-WLED).

Fig.12, the Cd-based QD-enhanced backlight shows the best performance in terms of light efficiency and color gamut. While 2pc-WLED, OLED, and InP QD hold a similar electro-optic performance. This is understandable because they all exhibit similar FWHM emission spectra (40 nm~ 50 nm).

Helmholtz–Kohlrausch Effect

➢The perceived quality metric (PQM), or known as display quality score (DQS),as shown in Fig 13 is proposed to describe the display quality quantitatively.

➢This figure describes how display quality is affected by both luminance and color gamut.

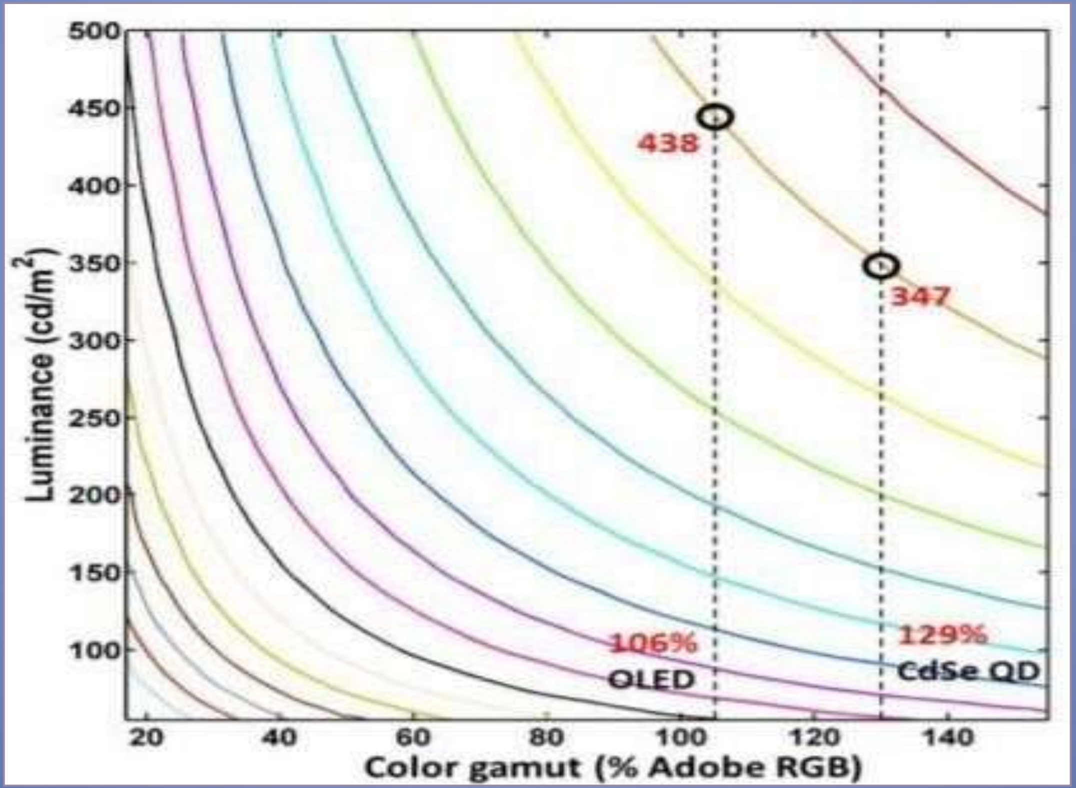


Fig.13 Isoquality curves of the perceived quality metric

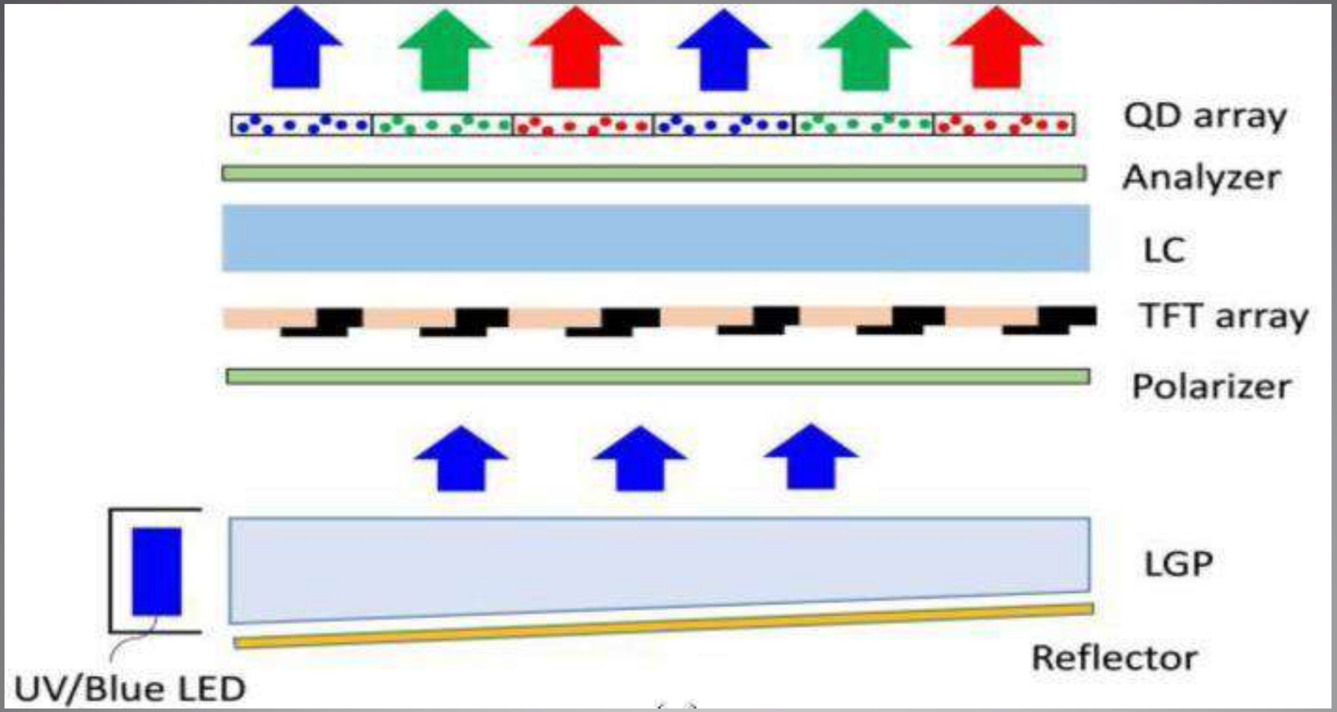
- In this isoquality figure, the line at the upper right corner represents better perceived quality, and points on the same line is considered as equal quality.

- Here, we focus on the CdSe QD and OLED’s performances; the 2pc- WLED and InP QD exhibit similar color gamut as OLED. In comparison, CdSe QD shows much larger color gamut than OLED. When it comes to the perceived image quality, QD-LCD would be 1.26X more efficient than OLED. Similar phenomenon has been reported when comparing OLED with 1pc-WLED based LCD or in LED projectors .

RESULTS

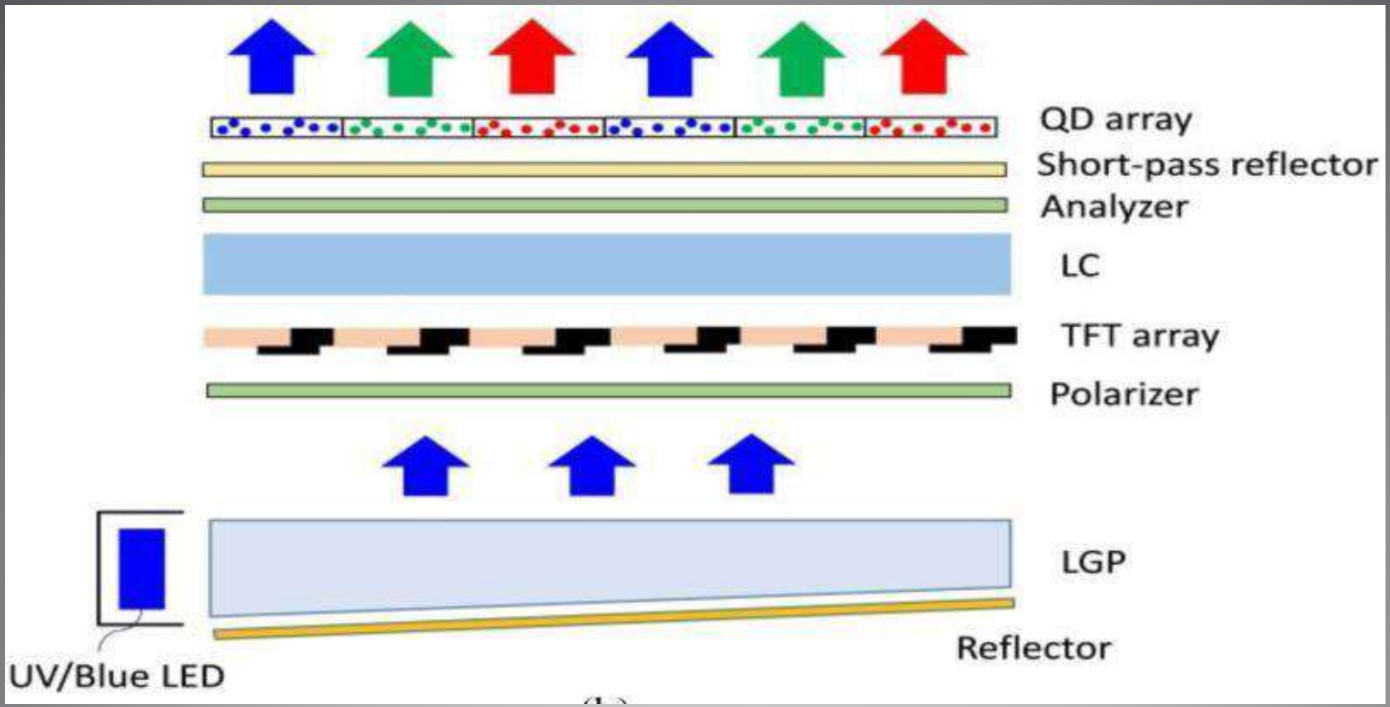
Fig. 14 Illustration of perceived image quality for OLED and QD-LCD.

Fig.15 Illustartes picture quality for QLED and OLED TVs



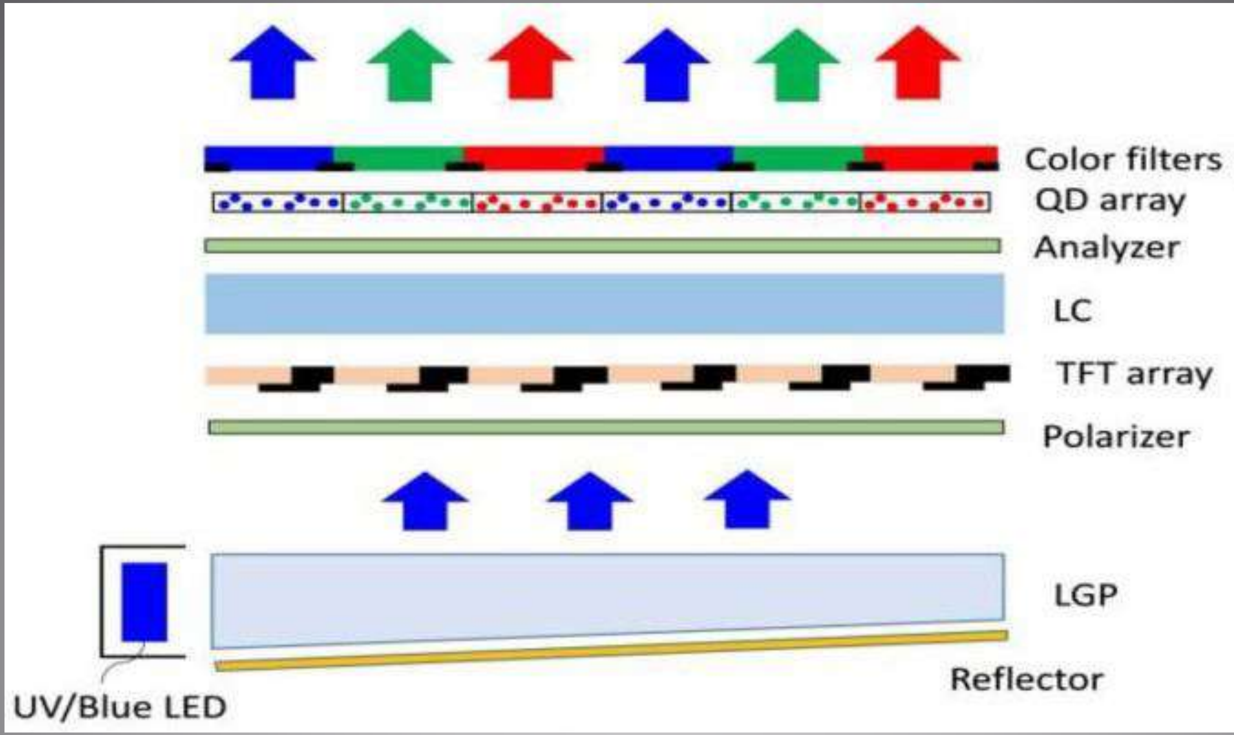
(a) Basic structure QD array

❑Fig. 16(a) depicts the proposed structure, where a patterned QD array is placed above the LC layer. Since there is no spatial CFs, the light efficiency should be tripled. Another implicit advantage is faster response time. This is because only blue light traverses through the LC layer, we can use a thinner cell gap to achieve the required phase retardation.



(b) A short-pass reflector is placed below QD array to recycle backward emission

- A band-pass reflector provides a possible solution [Fig. 16(b)] as it transmits blue light, while reflecting green and red. This way, all the QD emissions can be fully utilized. Such design is particularly attractive for virtual reality (VR) displays. There is no ambient light to excite the QD array.



(c) Conventional color filter is placed above QD array to prevent unwanted ambient light excitation

❑If the display is exposed to an ambient light, then another serious concern would arise. Besides blue backlight, green and red QDs could be excited by the short-wavelength ambient light as well. As a result, the ambient contrast ratio would degrade substantially. To prevent this from, we can place a conventional color filter array above the QD layer to block the unwanted ambient light, as shown in Fig. 16(c).

ADVANTAGES & DISADVANTAGES

ADVANTAGES:

➢Quantum dot technology can also save 20 percent of power than conventional LCDs. This is especially true for QD displays based on electroluminescent quantum dots.

➢It has High peak brightness.

➢Color saturation and the widest color gamut possible.

➢Improved color accuracy.

DISADVANTAGES:

➢A QD display based on LCD will have slower response time than OLED displays in general.

FUTURE SCOPE

- QD LCDs plays an important role in future. Since QD enhanced backlight offers more saturated colors, and higher optical efficiency than conventional WLED, it can been widely used in high-end TVs, monitors, and pads.
- In conventional LCD panels, over 2/3 of the incident backlight is absorbed by the color filters (CFs). Thus, to improve optical efficiency, one approach is to remove or replace CFs.

CONCLUSION

- Cd-based QDs show the best performance, including narrow FWHM, high quantum efficiency and long-term stability from material viewpoint.
- Compared to other backlight sources, QD technology exhibits superior performance, like higher efficiency and wider color gamut. When considering the H-K effect, QD-enhanced LCD is 1.26X more efficient than OLED due to the more saturated primary colors. QD array is used to replace conventional color filters. Some specific structure designs are needed in order to utilize the backward emission and prevent ambient light excitation.

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