Wide color gamut industry issues and market status

Son, Seungkyu Richard
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Wide color gamut display, essential for high-end displays

• With the appearance of products with wide color gamut displays, such as organic light-emitting diode (OLED) TVs and quantum dot (QD) TVs, the wide color gamut display market is growing at a steady pace.

• At the Consumer Electronics Show (CES) 2016, Samsung Electronics Co. actively promoted a new premium TV brand called SUHD TV, focusing on its QD display, and gained favorable responses from both attendees and exhibitors. On the other hand, LG Electronics Co., which is competing with Samsung Electronics in the TV market, also drew attention by introducing its OLED TV that boasts superior wide color gamut. In the meantime, rapidly growing Chinese TV set makers presented a series of TVs employing QD or OLED solutions.

• It seems that TVs with wide color gamut displays are cementing their position as a high-end TV product.

• Many companies are known to have applied wide color gamut solutions to information technology (IT) devices like monitors as well as TVs and planning to mass produce and launch such products, so the wide color gamut display market is expected to grow further.
What is color gamut?

Definition and standards of color gamut

<table>
<thead>
<tr>
<th>TVs</th>
<th>Color gamut (NTSC %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRT</td>
<td>78% ~ 82%</td>
</tr>
<tr>
<td>PDP</td>
<td>90% ~ 95%</td>
</tr>
<tr>
<td>OLED</td>
<td>100% ~ 110%</td>
</tr>
<tr>
<td>LCD (CCFL)</td>
<td>54% ~ 73%</td>
</tr>
<tr>
<td>LCD (WCG CCFL)</td>
<td>85% ~ 95%</td>
</tr>
<tr>
<td>LCD (White LED)</td>
<td>68% ~ 78%</td>
</tr>
<tr>
<td>LCD (C/F + LED)</td>
<td>90%</td>
</tr>
<tr>
<td>LCD (RGB LED)</td>
<td>95% ~ 100%</td>
</tr>
<tr>
<td>LCD (Quantum dot)</td>
<td>100%↑</td>
</tr>
</tbody>
</table>

Source: IHS

*CIE (Commission Internationale de l'Eclairage)*
Standards for Color gamut

> **sRGB**: It is a color space for monitors and printers made by Microsoft Corp. and Hewlett-Packard Development Company, L.P. in 1996, which has the same color area as Rec.709. Most PC monitors and TVs sold in the market can express 100% of the sRGB color space. This color space was used in commercial color matching systems until the mid-2000s and was designed to fit to home and office viewing conditions.

> **REC. 709**: It is the standard broadcasting signal for high-definition (HD) TV recommended by the International Telecommunication Union (ITU) in 1990. It is also called BT-709, and its color space is the same as sRGB. HDTV broadcasting must operate 100% of the Rec.709 color space.

> **NTSC (NTSC 1953)**: National Television System Committee (NTSC) is the broadcasting standard for analog TVs in more than 50 countries in North and Central America, Latin America, Northeast Asia, and Southeast Asia. Generally, if the word color gamut is used alone, it refers to the color space based on the NTSC standard. Monitors and liquid-crystal display (LCD) TVs released in the 2000s are generally within 72% of the NTSC standard because they were made based on the Rec. 709 (sRGB) standard.

> **Adobe RGB**: Adobe Systems Software Ireland Ltd. suggested its own color space in 1998, complementing the loss in green and cyan colors that can’t be expressed in the sRGB. Compared to the sRGB color space, Adobe RGB was developed for the color space that can be ideally reproduced in printing machines, and it encompasses most colors of cyan, yellow, magenta, and black (CMYK). However, with the chromaticity near green being extremely high, there are color spaces that cannot be reproduced with printing equipment.

> **DCI-P3**: It is a color space suggested by Society of Motion Picture and Television Engineers (SMPTE) in 2007, encompassing a wider color range than sRGB. Currently, all digital movies are created based on the color space of DCI-P3. In 2013, the first monitor adopting the DCI-P3 was released.

> **Rec. 2020**: It is a broadcasting signal for ultra high-definition (UHD) TV (4K, 8K) suggested by the ITU in 2012. It is an extension of the Rec. 709, and it has a much wider color space compared to all other standards currently being used.
Wide color gamut solutions

Wide color gamut solutions

Others
- CGEF (Color Gamut Enhanced Film)
- Polarizer

LED/CF solutions
- Red, Green, Blue chip
- Blue chip + RG phosphor etc.
- Thick color filter

Quantum dot
- On edge (Tube)
- On surface (Film)
- On chip
- Color filter

OLED
- WOLED

QLED
- RGB OLED
High color gamut LED Package

- Mainly focused on obtaining pure colors with advanced phosphors.
  - Use RGB LEDs as the light source (Expensive and reliability issue)
  - Use B LED + YAG phosphor + R phosphor (NTSC can be 80-90%)
  - Use B LED + R phosphor + G phosphor (NTSC can be 90-95%)
- Strongly depends on unique phosphor material selection
  - Hard to adjust emission wavelength; Discontinuous wavelength by phosphor selection

<table>
<thead>
<tr>
<th>LED solutions for wide color gamut</th>
<th>R,G,B chip</th>
<th>Blue chip -G/R phosphor</th>
<th>Blue/green chip -R phosphor</th>
<th>Blue/red chip -G phosphor</th>
<th>Blue chip -R phosphor + green chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>YAG phosphor</td>
<td>100%</td>
<td>90~95%</td>
<td>85~95%</td>
<td>92~100%</td>
<td>90~100%</td>
</tr>
</tbody>
</table>

Source: IHS
LED PKG makers to focus on KSF(K$_2$SiF$_6$:Mn$^{4+}$) phosphor

- FWHM (Full Width at the Half Maximum) : 7 nm or below.
- Uniform characteristics regardless of its size
- Non-rare earth element
- Major suppliers: GE, Mitsubishi chemical, Denka etc.

**Property of KSF**

![Graph showing the property of KSF phosphor](image_url)

Source: IHS
Color filter tuning

- The color filter solution adjusts the thickness of the color filter to prevent some wavelengths from penetrating each color filter, improving color gamut.

![Color filter solutions for wide color gamut](source: IHS)
RGB OLED

• The picture below shows a RGB OLED structure, in which red, green, and blue subpixels, each, individually emit light, and the three subpixels’ organic light-emitting materials, each, are deposited in different thickness to adjust the light-emitting efficiency. In addition, instead of the fluorescent materials used on AMOLED panels for mobile applications, phosphorescent materials with higher light emitting efficiency are expected to be used, but as of now, phosphorescent materials are only applied on red and green colors.

WOLED

• Unlike the RGB OLED solution, this method creates white light source by combining OLED subpixels, and then transmitting the white light through a color filter to change the color. LG Display Co. applies this solution on its active-matrix organic light-emitting diode (AMOLED) TV panels. The white OLED light-emitting solution creates a three-tandem structure with the blue color in the top and bottom layers and yellow-green color in the middle layer.
Quantum dot solutions

- A QD is a semiconductor nanocrystal composed of two or more elements. Generally, two elements among ZnS, CdS, CdSe, and gallium nitride (GaN), form a Wurtzite crystal structure. It is a very small particle with a size of several nanometers. It shows quantum mechanical properties, such as quantum limit effect and quantum size effect. Studies are underway for its application in various industries, such as biology and display devices. Depending on the application industry, QDs with slightly different structures and shapes are used for different functions. QD structure can be divided into core, shell, and ligand depending on functions.

- Core is the most important part that determines QD’s main properties. All the functions, such as absorption or emission of light, and injection and transportation of electrons are controlled by the core. Sometimes a QD is composed only of core without shell and the core can be regarded as the QD itself. The size of core plays a key role in determining light-emitting wavelength according to the size of QDs. It is mainly composed of II-VI group elements, such as CdSe or CdS, and for semiconductors with small band gap, PbSe and PbS are used. Recently, development of QD that uses III-V group elements, such as InP and GaP, is underway to avoid the use of heavy metals like cadmium and lead.

<table>
<thead>
<tr>
<th>QD structure</th>
<th>Types of QD by band gap size and location of core and shell</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="https://example.com/qd_structure.png" alt="QD Structure Diagram" /></td>
<td><img src="https://example.com/types_of_qd.png" alt="Types of QD Diagram" /></td>
</tr>
</tbody>
</table>

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Quantum dot display by type in LCD BLU

1. On-chip

Blue LED

RG Quantum Dots

LGP

Reflector

D-BEF

BEF

2. On-edge

RG Quantum Dots (Tube)

LGP

Reflector

D-BEF

BEF

3. On-surface

RG Quantum Dots (Film)

LGP

Reflector

D-BEF

BEF

Source: IHS

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Quantum dot applied to color filter

- QD color filter is a solution that incorporates QD materials into a color filter to produce wide color gamut displays.
- Display panel makers manufacture and manage color filters in LCD panel manufacturing processes, so they are leading the development and mass production of color filters. Considering this, QD color filter solution could benefit panel makers.

Properties of color filter adopting QD materials

Source: IHS
QLED technology

- QLED or QD-LED refers to QDLED, a technology that excites electroluminescence in QDs by injecting electrons and holes, similar to the OLED technology.

- The biggest difference between QLED and OLED is found in their optical properties. The emission spectrum of QLED shows a very narrow line width.

- The FWHM of QDs is very narrow at 20–30 nm, about half that of the organic materials. Therefore, QLED can show deeper and more vivid colors than OLED without additionally using a complex optical structure.

![Comparison of EL spectrum of QLED and OLED](image-url)
## Comparison of major properties of QLED and OLED

<table>
<thead>
<tr>
<th>Feature</th>
<th>QLED</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Low – Mid</td>
<td>High</td>
</tr>
<tr>
<td>Emission bandwidth (color saturation)</td>
<td>Narrow (FWHM &lt;30 nm)</td>
<td>Broad (FWHM ~ 40–80 nm)</td>
</tr>
<tr>
<td>Color tunability</td>
<td>Excellent (By QD size &amp; composition)</td>
<td>Low (Different emitter molecule)</td>
</tr>
<tr>
<td>Manufacturing process</td>
<td>Solution-based</td>
<td>Vacuum deposition / Solution-based</td>
</tr>
<tr>
<td>Large area display</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Transparent &amp; flexible display</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Cost of emitter</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Color range</td>
<td>420–1500 nm (Visible to Near IR)</td>
<td>450–650 nm (Visible)</td>
</tr>
</tbody>
</table>

Source: IHS
Wide color gamut display market forecast

In-depth analysis for Quantum Dot display market
Wide color gamut display market forecast

- OLED and Quantum dot are key solution to grow in the wide color gamut display market.

- In particular, the QD solution that is applied in large-sized wide color gamut displays boast color gamut comparable to that of OLED solution-based displays, while offering a relatively lower production cost.

- With its competitive edge, the QD has primarily targeted the high-end large display market, and the QD is expected to settle down as a key solution in the market.
Business structure of wide color gamut display industry

TV Set

- QD film
- QD Tube

Lighting source
- Phosphor (KSF)
- QD Chip

Display panel

- Color filter
  - Thick color filter
  - Quantum dot color filter
- OLED
- Polarizer
Samsung, Key marketing point is quantum dot display in 2016

• In 2015 CES, Samsung electronics focused on marketing its new brand-SUHD TV

• But, in 2016 CES Samsung electronics decided to attract the audience with its quantum dot display technology and was pursuing aggressive marketing activities for quantum dot.
TV brand, to lead quantum dot display industry

- TVs are a key application that drives demand for QD solutions
- Most of the QD TVs released recently are high-end and large-sized, over 50 (fifty) inches,
- Making the QD display technology more prominent in the wide color gamut display market

Quantum dot display market forecast

<table>
<thead>
<tr>
<th>Millions of units</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>15</td>
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<tr>
<td>20</td>
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<tr>
<td>25</td>
</tr>
<tr>
<td>30</td>
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<tr>
<td>35</td>
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</tbody>
</table>

Source: IHS

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Panel and BLU Cost analysis of QD TV

**Panel / BLU cost ratio for 55” TV**

<table>
<thead>
<tr>
<th>Color gamut (NTSC%)</th>
<th>Panel / BLU cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>100%</td>
</tr>
<tr>
<td>80%</td>
<td>150%</td>
</tr>
<tr>
<td>90%</td>
<td>200%</td>
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<tr>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>110%</td>
<td></td>
</tr>
</tbody>
</table>

- Normal
- QD film
- QD tube
- Blue chip + R,G phosphor + thick C/F
- Blue chip + R,G phosphor
Barrier film is importance of quantum dot film reliability and manufacturing cost

Quantum dot film manufacturing process

- PET
  - Wet
  - Dry
  - Wet coating (top)
  - Dry
  - Wet coating (under)
- Primer
- QD material
- Barrier film (2 sheet)
- Quantum dot material
Supply chain analysis for Quantum dot TV market

QD Major suppliers in TV industry

- **<IP/Material>**
  - SAIT/Hansol Chemical
  - Nanoco/Dow chemical

- **<Barrier film>**
  - i-components
  - Toray/DNP

- **<QD film>**
  - MN tech
  - Global

- **TV brand**
  - Samsung electronics
  - China TV brand

- **QD vision(tube)**
  - 3M

Source: IHS
**QD components market forecast**

- QD display demand is projected to grow steadily with QD technology being adopted by other applications, such as monitors following TV products.
QD will have a big opportunity in the wide color gamut market in the future

- QD color filter will likely be introduced in 2018, and it will compete with other QD solutions.
- If QD color filter does not offer better performance and cost competitiveness compared with QD film and QD Chip, it will not successfully enter the wide color gamut display market.

<table>
<thead>
<tr>
<th>QD technology in display forecast</th>
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<tbody>
<tr>
<td>2015</td>
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<tr>
<td>2016</td>
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<tr>
<td>2017</td>
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<td>2018</td>
</tr>
<tr>
<td>2019</td>
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<tr>
<td>2020~</td>
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