Comparing displays for high-end desktop monitors - LCD, OLED, and mini LED

The LCD with mini LED backlight has more advantages over OLED in desktop monitor application.
Key findings

- Both the LCD with mini LED backlight and OLED have their own challenges but the mini LED has better chances of being adopted for the high-end desktop monitor display.
- OLED is a self-emissive device, therefore its contrast ratio, which is the ratio of the darkest black to the brightest white, is the best. With a mini LED backlight, the contrast ratio of the LCD can be improved.
- OLED is expensive, difficult to make, and has very limited panel suppliers.
- As a result of OLED’s organic color materials constraint, it is difficult to achieve Delta E <2. This means that end users may easily perceive the color inconsistency in the OLED, as well as find the discordance in the color tone even though OLED has a better color gamut.

Apple is an early adopter of the mini LED backlight monitor

Apple Pro Display XDR is a 32-inch 6K×3K monitor

As analyzed in the Omdia Display Dynamics article entitled *Apple steps toward LED display with Pro Display XDR*, Apple has announced its manufacturing plan for a new monitor equipped with Pro Display XDR technology, coming this fall. The Pro Display XDR applies 2D backlighting with an array of 576 light-emitting diodes (LEDs) for a 32-inch 6K display.

Apple appears to be focused on mini LED backlighting technology as an intermediate stage toward the era of micro LED displays. A mini LED backlighting display can achieve both the extreme high-dynamic range (HDR) and wide color gamut of a micro LED display. Yet, the resource input required to manufacture a mini LED can be much lower than for a micro LED.

The high-end desktop monitor is a growing market, especially for gaming applications, as well as the content creation PC monitor. Since there are many special applications, the high-end desktop monitor display must meet several requirements—high brightness, high contrast ratio, high color gamut, HDR, slim form factor, high resolution, and lower power consumption. The traditional LCD monitor display cannot meet all these requirements. Therefore, several new technologies have been developed; the ones currently receiving the most attention are the LCD with mini LED backlight and OLED.

The most remarkable feature of the Pro Display XDR is its backlighting. Apple revealed that it has applied 2D backlighting with an array of 576 blue LEDs, unlike typical LCD monitors, which are edge-lit by a strip of white LEDs. The Pro Display XDR is similar to the mini LED backlighting display,
which is a hybrid LCD and micro LED display (refer to the figure below). In recent years, there have been several rumors about Apple’s activities related to the micro LED display. The mini LED backlighting of the Pro Display XDR seems to be the first commercial trial toward a micro LED display.

Why, then, did Apple select the mini LED backlighting instead of using a micro LED display? While manufacturing cost is likely the main reason, the LED supply chain is also a factor. Chips for micro LED displays are typically smaller than 0.1 mm. Since they are rarely used in other applications, equipment for micro LED chip manufacturing is exclusive to LED displays. The market forecast for micro LEDs is still uncertain, so some major LED makers are still hesitating to invest in equipment for micro LEDs. Meanwhile, chips for 0.1–0.3 mm mini LEDs are compatible not only for mini LED backlighting but also for many other applications like mobile LEDs, and they are currently manufactured by many LED makers. Thus, LED makers can manufacture mini LEDs with a minimum investment, while investment for micro LEDs appears to be riskier, and eventually more expensive, than for mini LEDs.

LG Display promoted OLED monitor display

As analyzed in the Omdia Market Insight entitled Display at CES 2020, both LG Display and LG Electronics (LGE) are aggressively promoting the super large-sized OLED, especially the over 50-inch display for super gamers. The following are LGE’s demonstration at CES 2020 as well Alienware’s 55-inch OLED monitor:

- LGE 48-inch OLED gaming monitor: UHD resolution, 120Hz driving frequency, and NVIDIA G-sync compatible gaming TV with HDMI 2.1 connection.
- LGE 65-inch OLED gaming monitor: UHD resolution, 120Hz driving frequency, and NVIDIA G-sync compatible gaming TV with HDMI 2.1 connection.
- Alienware 55-inch OLED gaming monitor: UHD resolution, 120Hz driving frequency, NVIDIA G-sync compatible gaming TV with HDMI 2.1 connection, and special 98.5% DCI-P3 color gamut.
Figure 1: LGE 48-inch OLED gaming display at CES 2020

Source: Photo taken by Linda Lin/Omdia at CES, Las Vegas, Nevada, January 2020

Figure 2: LGE 65-inch OLED gaming display at CES 2020

Source: Photo taken by Linda Lin/Omdia at CES, Las Vegas, Nevada, January 2020
OLED has several advantages over LCD, such as an excellent contrast ratio (which is even better than the LCD with mini LED backlight), excellent thickness, and low power consumption, especially in dark mode. With these features, some display makers are confident that it is suitable for the high-end monitor, particularly for gaming use, such as LG Display, which has conquered the production challenges of the large-area OLED display.
Comparing the LCD, mini LED, and OLED

Table 1: Emerging display feature comparison for desktop monitors

<table>
<thead>
<tr>
<th>Feature</th>
<th>LCD</th>
<th>LCD with passive-matrix mini LED BLU</th>
<th>LCD with active-matrix mini LED BLU</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness</td>
<td>Standard</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor (decade vs. lifespan)</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>Maximum to 2000:1 (edge type)</td>
<td>Good</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Standard</td>
<td>Very high (&gt;5× of conventional BLU)</td>
<td>High</td>
<td>Good (except white background)</td>
</tr>
<tr>
<td>Thickness</td>
<td>Standard</td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent (no backlight)</td>
</tr>
<tr>
<td>Cost</td>
<td>Standard</td>
<td>Very high (more than OLED)</td>
<td>N/A (investment and idle capacity)</td>
<td>&lt;3× of conventional LCD</td>
</tr>
<tr>
<td>Barriers to entry</td>
<td>Standard</td>
<td>Standard</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>Proposed usage</td>
<td>Standard</td>
<td>Gaming</td>
<td>Gaming</td>
<td>Professional display</td>
</tr>
<tr>
<td>Adaptive sync availability</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Difficult</td>
</tr>
<tr>
<td>Pixel density</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Top emitting &gt; bottom emitting</td>
</tr>
<tr>
<td>Delta E &lt;2</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Difficult (material constraint)</td>
</tr>
</tbody>
</table>

Source: Omdia

According to the above figure, there are several comparison points to note.

- The LCD with mini LED backlight, whether an active-matrix or passive-matrix one, has the best brightness; meanwhile, OLED has the brightness decay and lifespan issue and therefore OLED’s brightness is comparatively poorer.

- OLED is a self-emissive device, and thus has the best contrast ratio, which is the ratio of the darkest black to the brightest white. With a mini LED backlight, the contrast ratio of the LCD can be improved.

- The mini LED backlight unit (BLU) has the worst power consumption because of the number of mini LEDs used; passive-matrix mini LED backlight is worse than the active-matrix mini LED backlight. OLED is a self-emissive device, and therefore its power consumption is low, in theory. But for a white background, every pixel and subpixel will be lit, which results in higher power consumption. Nevertheless, its power consumption is still lower than that of the LCD with mini LED BLU.

- OLED has the best thickness, while the mini LED backlight can be quite thick as a result of the arrangement on the mini LEDs. The passive matrix with a printed circuit board (PCB) will be much thicker.

- As analyzed in the Omdia Market Insight entitled Display cost analysis - LCD, OLED, Mini LED, Micro LED and Quantum Dot, it is estimated that the cost of LCD with mini LED backlight will be higher than that of OLED if the same size and resolution panel are applied. This is due to the high cost of the mini LED, and the special heat dissipation module and assembly cost of the mini LED backlight. But in the
meantime, OLED has its own challenges. OLED’s supply capacity is limited, and it is not easy to raise the yield rate of large-area OLED panel production. In other words, the barrier to entry of the OLED, especially for large-area display, is very high. For the mini LED BLU, it is dealing with a more established supply chain, which includes display makers, BLU makers, LED epitaxy makers, and LED package makers.

- OLED can be used for the professional display; as mentioned in the Omdia Display Dynamics article entitled *JOLED’s product planning and development outlook in 2019*, JOLED has launched the 21.6-inch UHD panel with 144Hz frame rate for professional applications and gaming. Meanwhile, the LCD with mini LED backlight is suitable for gaming.

- OLED has some difficulties with regards to adaptive sync availability, high resolution, and pixel density.

- One important index is Delta E, which indicates color difference. The difference or distance between two colors is a metric of interest in color science. It allows quantified examination of a notion that formerly could only be described with adjectives. Quantification of these properties is of great importance to those whose work is color critical. Common definitions make use of the Euclidean distance in a device-independent color space. As most definitions of color difference are distances within a color space, the standard means of determining distances is the Euclidean distance. If one presently has a red, green, and blue (RGB) tuple and wishes to find the color difference, computationally one of the easiest is to call the RGB linear dimensions defining the color space. In other words, Delta E is a single number that represents the “distance” between two colors. The idea is that a Delta E of 1.0 is the smallest color difference the human eye can see. Hence, any Delta E less than 1.0 is imperceptible and it stands to reason that any Delta E greater than 1.0 is noticeable. In theory, it is impossible to achieve a Delta E of 1.0. Thus, a suitable Delta E should be less than 2 so that the picture on the display does not have a very noticeable color difference. LCD has a better Delta E, whereas for OLED, as a result of the organic color materials constraint, it has difficulty in achieving Delta E <2. This means that end users may easily perceive the color inconsistency in the OLED, as well as find the discordance in the color tone even though OLED has a better color gamut.

Mini LED has better chances of being adopted for high-end monitor displays

The LCD with mini LED backlight is considered a great challenger against the OLED for HDR but there are several obstacles:

- The cost of LCD with mini LED backlight is higher than OLED.
- Power consumption is a problem, although the thickness issue is being resolved.
- The active-matrix mini LED is power-saving thanks to the reduction of the LED driver IC. However, monitor display makers currently have no plans to develop it as they think the market scale is too small; instead, they believe the passive-matrix mini LED is good enough for monitors.
- Apple is working on improving mini LED BLU power efficiency (LED emitting efficiency + enhanced power management from the driver IC), as mentioned in the Omdia Display Dynamics article entitled *Apple steps toward LED display with Pro Display XDR*.

OLED is expensive, difficult to make, and has very limited panel suppliers. But now, OLED panel prices are competing with those of premium LCD. As an example, for the UHD high resolution notebook PC, the rigid OLED panel cost is still higher than that of the LCD, but the cost gap has been reducing. OLED is dealing with the following challenges:

- Delta E <2: Color consistency and color tone are a problem currently. As most large-area display OLEDs do not use the RGB OLED and instead use the white OLED, the color filter is able to adjust some of the Delta E.

- The variable frame rate support of OLED is not as good as LCD because organic material decay is caused by a high frame rate, as analyzed in the Omdia Display Dynamics article entitled *High frame rate improves content performance on smartphone display with limitation*.

- For OLED, the power consumption of a white background is higher than it is for LCD.

- As a result of the current driving mechanism, there are images sticking to the OLED screen.
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