

Comparing Color Gamut of LCD and OLED Displays at Different Viewing Angles Using Gamut Rings

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Abstract

Evaluating display color gamut under various viewing conditions is crucial for understanding color performance. This study measured the color gamuts of a prototype LCD with blue-green LEDs, a conventional LCD, and an OLED display. By analyzing the color gamut intersections using gamut rings, differences in lightness, chroma, and hue angle were visualized, revealing that hue shifts in the LCDs were minimal compared to those in the OLED display.

Author Keywords

gamut rings; gamut ring intersection; blue-green LEDs; wide color gamut; viewing angle

1. Introduction

Currently, a considerable number of displays are used in a variety of applications under a wide range of viewing conditions. While a wide color gamut and high color reproducibility are ensured at the normal viewing angle, observers perceive different colors at oblique viewing angles. For instance, automotive displays are typically viewed at oblique angles by passengers. As displayed content becomes increasingly diverse—ranging from driver information to entertainment—there is a growing need to evaluate the color performance of these displays across varying viewing angles.

The traditional approach to describing the “color capability” of a display relies on representing the gamut as the area of a triangle formed by connecting the chromaticity coordinates of the RGB display primaries on a chromaticity diagram. However, when the white point and/or RGB primaries shift, it becomes challenging to interpret the resulting changes in hue, lightness, and saturation in the 2D chromaticity diagram.

The gamut rings unwrap the volumetric information of the color gamut and map it into rings in a 2D diagram, providing the information needed to describe the ranges of hue, chroma, and lightness. This method has been adopted by international standard-setting organizations [1–3]. Gamut ring intersections facilitate the comparison of color gamuts measured under different conditions and visualizes the differences.

In this study, Nichia developed a prototype LCD equipped with novel LED packages containing blue and green LEDs (BG LEDs). Each BG LED package integrated a single blue LED, a single green LED, and red phosphor into a single unit. The color gamuts of the LCD with BG LEDs, an LCD with conventional white LEDs, and a glass-sealed OLED display designed for PCs were measured and compared.

2. Development of Prototype LCD with BG LEDs

LCDs rely on color filters for color separation; however, the separation characteristics of these filters are not sharp. To achieve a wide color gamut, it is essential to narrow the bandwidth of the emission spectra for each RGB component of the backlight. Conventional LED backlights for LCDs generate RGB colors by

using a blue LED to excite red and green phosphors. However, a broader bandwidth of the green phosphor’s emission spectrum poses a limitation to achieve a wider color gamut.

To address this issue, we developed a novel BG LED package by replacing the green phosphor with a green LED. Figure 1 illustrates a structural comparison of the BG LED package with a white LED package using conventional phosphors. Figure 2 compares the emission spectra of the BG LEDs and the conventional LEDs. The BG LED package exhibited a narrower bandwidth in its emission spectrum compared to the conventional LEDs. This narrower spectrum contributed to improved color separation, particularly enhancing the distinction between red and green.

3. Measurements

Two LCDs and one OLED display were evaluated in this study. The LCDs included a 15.6-inch prototype LCD with the BG LED backlight (peak luminance: 1600 nits) and a 16.0-inch LCD with the conventional white LED backlight (peak luminance: 500 nits). Both displays used the IPS-LCD method, which had superior viewing angle characteristics compared to VA-LCD. The OLED display was a 16.0-inch glass-sealed unit designed for PCs with a peak luminance of 400 nits and less luminance degradation at oblique viewing angles than the LCDs.

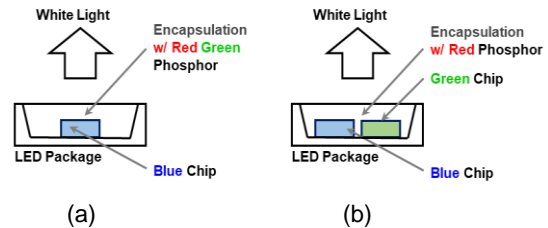


Figure 1. Structure of white LED packages: (a) Conventional LED and (b) new BG LEDs.

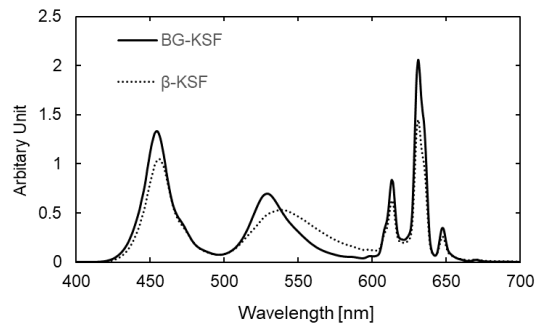


Figure 2. Spectrum of conventional LEDs and new BG LEDs.

The color gamuts of the displays were measured in a dark

environment at viewing angles of 0°, 15°, 30°, and 45°. A colorimeter (CA-VP410T, Konica Minolta, Japan) was mounted on an arm that rotated around the display's measurement point, as shown in Figure 3. The colorimeter was selected from the viewpoint of the focal depth required for measurements at oblique angles. To verify the accuracy of the measurements, additional data were collected using another colorimeter (Prometheus, Admesy, Netherlands) and a spectroradiometer (CS-2000, Konica Minolta, Japan). The measured volume variation was within 3%.

4. Results and Discussion

Figure 4 shows the chromaticity gamuts of the LCD with conventional LEDs, LCD with BG LEDs, and OLED display measured at viewing angles of 0° and 45°. The RGB points of the OLED display were more shifted between 0° and 45° than those of the LCDs. Table 1 summarizes the chromaticity gamut area size ratios and coverage ratios of these displays at the viewing angles of 0° and 45°. The LCD with BG LEDs covered the Adobe RGB and DCI-P3 gamuts even at 45°. The chromaticity gamut area size ratios of the LCDs increased slightly, while that of the OLED display decreased for each reference gamut.

To understand the reasons for the results, it is necessary to interpret the changes collectively in hue, chroma, and lightness. From another perspective, the white points of chromaticity gamuts in Figure 4 are also different between 0° and 45°. However, when the display is viewed at an oblique angle, as in automotive applications,

the passenger adapts to the observed white point. In this study, gamut rings were found to be optimal for visualizing and evaluating the color gamut under these conditions.

Figure 5 shows the gamut rings measured at viewing angles of 0°, 15°, 30°, and 45°. Comparing the gamut rings between 0° and 45°, no significant changes were observed for the LCD with conventional LEDs. For the LCD with BG LEDs at 45°, the volume size ratio was 107% of that at 0°, which was attributed to a shift in the white point. For the OLED display at 45°, the volume size ratio was 98%, and the hue of RGB primary colors appeared to rotate.



Figure 3. Colorimeter and rotation arm for color gamut measurement at various viewing angles.

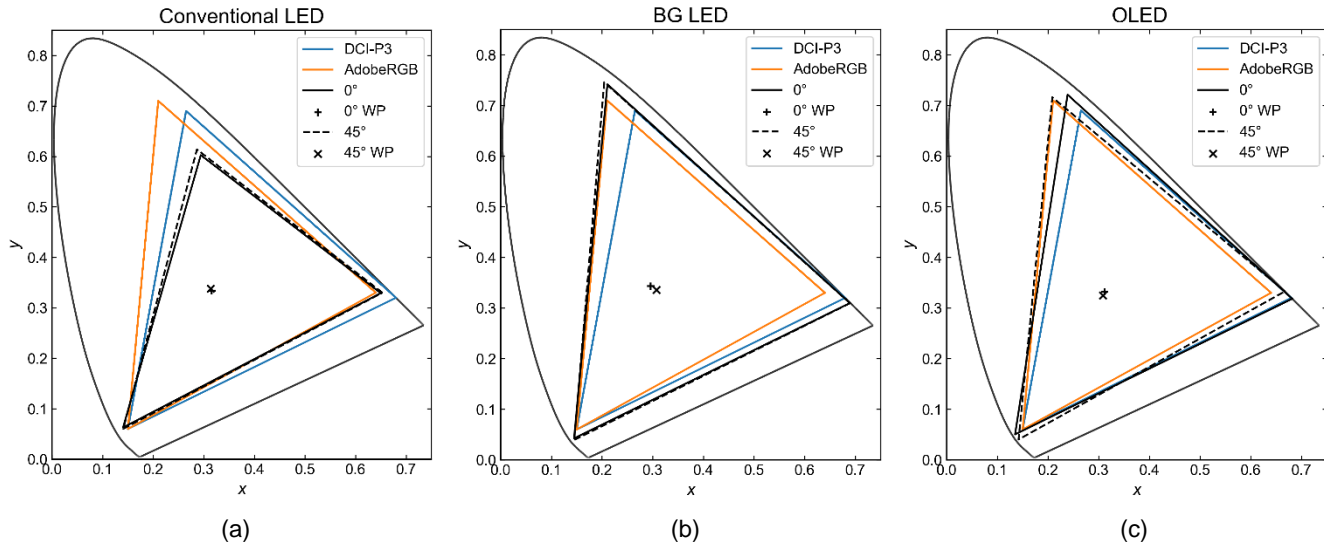


Figure 4. Chromaticity gamuts of (a) LCD w/ conventional LEDs, (b) LCD w/ BG LEDs, and (c) OLED display measured at 0° and 45° viewing angles.

Table 1. Chromaticity gamut area size ratios and coverage ratios of LCD w/ conventional LEDs, LCD w/ BG LEDs, and OLED display measured at 0° and 45° relative to Adobe RGB and DCI-P3.

Measured Angle		LCD w/ conventional LEDs		LCD w/ BG LEDs		OLED display	
		0°	45°	0°	45°	0°	45°
Adobe RGB	Area Size Ratio [%]	77	81	120	122	112	111
	Area Coverage Ratio [%]	77	80	100	100	96	100
DCI-P3	Area Size Ratio [%]	77	80	119	121	112	110
	Area Coverage Ratio [%]	77	80	100	100	100	96

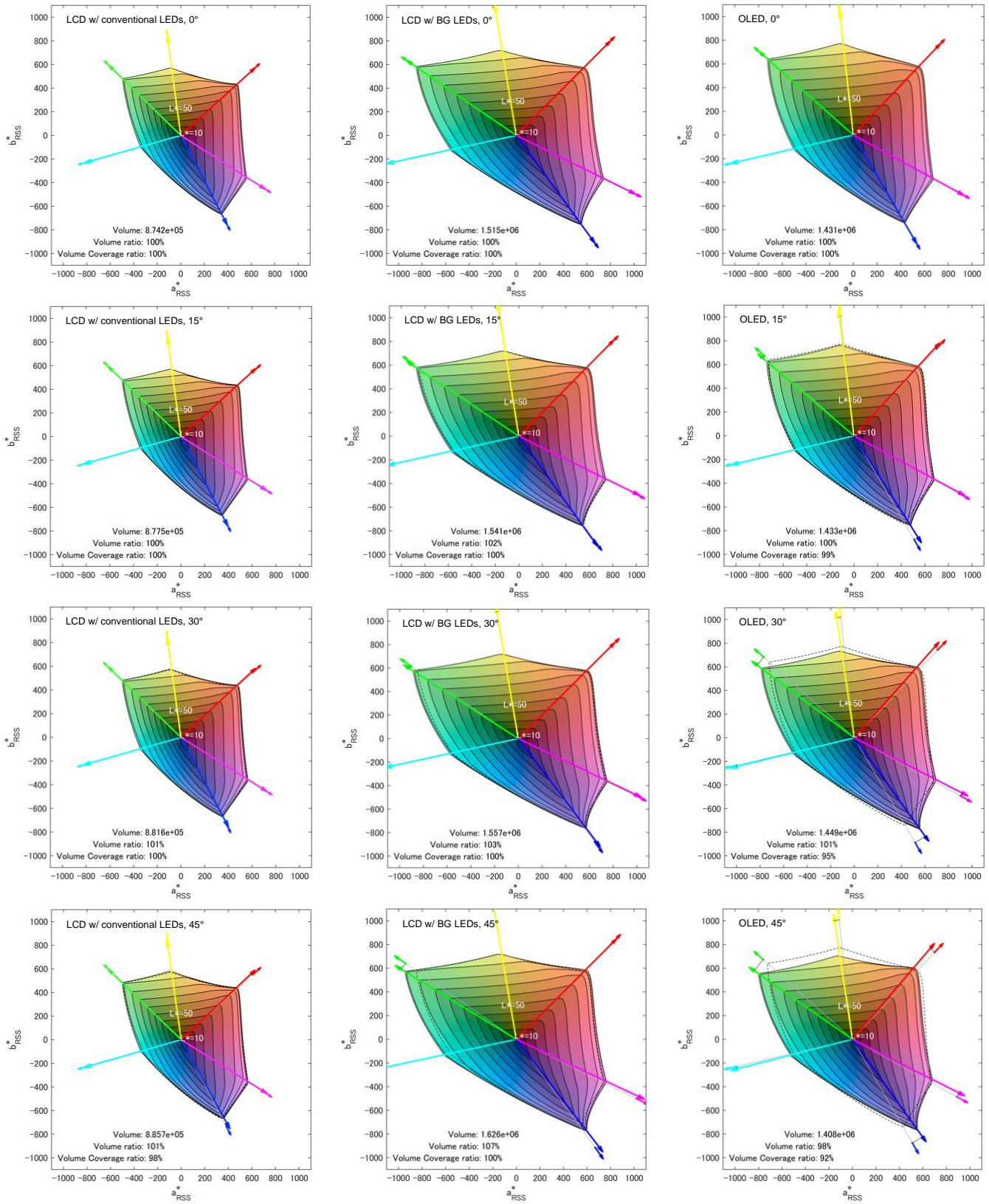


Figure 5. Gamut rings measured at the viewing angles of 0° (top), 15°, 30°, and 45° (bottom) of LCD w/ conventional LEDs (left), LCD w/ BG LEDs (center), and OLED display (right). The dashed line in each plot shows the outline of the gamut rings measured at 0°.

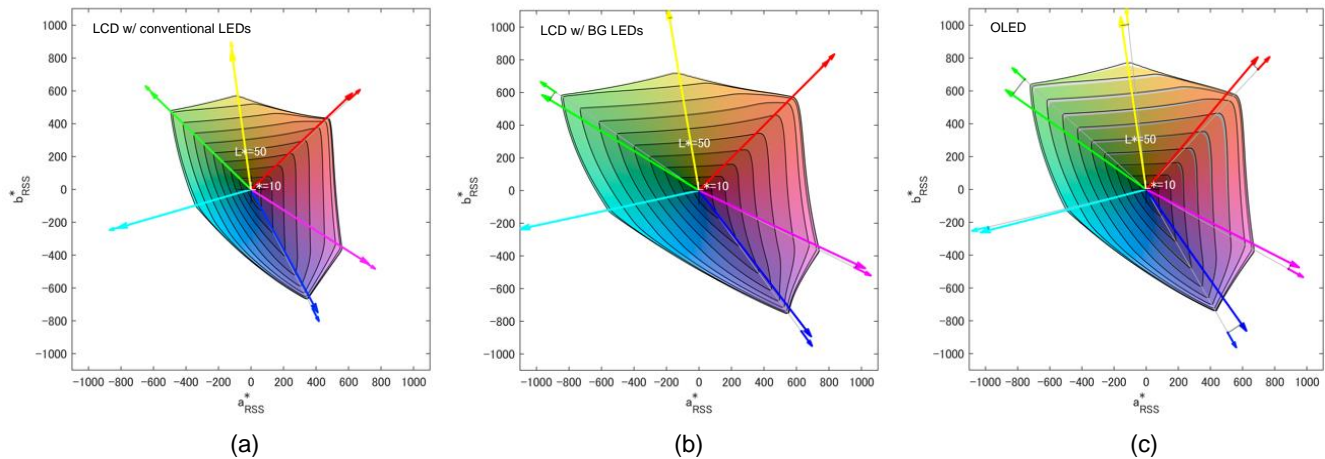


Figure 6. Gamut ring intersections comparing 45° with 0° for (a) LCD w/ conventional LEDs, (b) LCD w/ BG LEDs, and (c) OLED display.

Figure 6 shows a gamut rings intersections comparing 45° with 0° for the LCD with conventional LEDs, the LCD with BG LEDs, and the OLED display. Regarding the LCDs, no gray gap was observed. For the LCD with BG LEDs, the green color shifted slightly. For the OLED display, the hue angle was clearly rotated.

The reasons for the LCD and OLED measurement results are discussed below.

In LCDs, as the viewing angle increases, the effective light path length through the color filter also increases. The longer light path of the green color filter more efficiently suppresses the tailing emission from red phosphors. In addition to the effect of shifting the white point, this could explain why the LCDs maintain and sometimes even extend their hue, chroma, and lightness even at 45°.

In OLED displays, an organic light-emitting layer is placed between the reflective anode and transparent cathode electrodes. This structure essentially forms an optical microcavity, as the thickness of the OLED film is usually on the order of the emitting light's wavelength. In smartphones, this microcavity effect is actively used to increase the brightness in the normal direction. However, in other applications, such as PCs and automotive applications, the microcavity effect is suppressed because it causes an inherent bluish shift at oblique angle. Despite this, the microcavity structure is essential for OLEDs, and some parasitic microcavity effects should remain, contributing to hue rotation in the OLED displays for PCs.

5. Conclusion

The color gamuts of the prototype LCD with BG LEDs, the LCD with conventional LEDs, and the OLED display were measured at various viewing angles. The results were visualized using gamut rings and their intersections, revealing that changes in hue, chroma, and lightness in the LCDs were minimal. In contrast, the OLED display for PCs exhibited evident hue rotation. This phenomenon was attributed to the inherent blue shift at oblique viewing angles, caused by the parasitic microcavity effect of the thin-film structure.

6. Acknowledgments

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7. References

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