17-inch Laser Backlight LCD with 8K, 120-Hz Driving and BT.2020 Color Gamut

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ABSTRACT

We succeeded in prototyping a 17-inch 8K liquid crystal display satisfying the BT.2020 specification. The pixel density of the display is 510 ppi, while its color gamut covers 98% of that of BT.2020. The liquid crystal response time is 5 ms, which is sufficient for 120-Hz driving.

1 INTRODUCTION

In Japan, Nippon Hoso Kyokai (NHK) started to broadcast “Super Hi-Vison” with ultra high-definition video in December 2018. The specifications of “Super Hi-Vison” were defined by the International Telecommunication Union Radiocommunication Sector (ITU-R) Recommendation BT.2020 [1]. The specifications required for a display in BT.2020 are 8K, a high color gamut [2], and 120-Hz driving.

To satisfy the BT.2020 specification, we developed an 8K TFT-LCD with 120-Hz frame-rate driving [3]. However, the color gamut and response time were insufficient.

The BT.2020 color gamut is defined from the three primary colors of monochrome. Therefore, changing the light source of the backlight from conventional light-emitting diodes (LEDs) to lasers is required. It has been reported that LCDs with the laser backlight satisfy the BT.2020 color gamut [4-6]. The laser backlight is a backlight using a laser diode (LD) as a light source.

It is necessary to complete the response within 8.3 ms in 120-Hz driving. We developed a faster in-plane switching LCD (IPS-LCD) named short-range lurch control (SLC) IPS-LCD [7]. To satisfy the 120-Hz driving, we applied the SLC-IPS-LCD to 8K LCDs.

In this report, we describe the structure of the side edge type laser backlight, color filter developed to satisfy the BT.2020 color gamut, driving method of the LD for reducing speckle, and SLC-IPS-LCD sufficient for 120-Hz driving.

2 LASER BACKLIGHT

2.1 Structure of Laser Backlight

Figure 1 shows the structure of the developed laser backlight and optical path from the LD to the LCD. This laser backlight is of a side-edge type, while the LD is arranged at the end of the light guide plate. Red, green, and blue LDs are arranged in this order. A reflection sheet is arranged at the lower side of the light guide plate, and an optical sheet is arranged at its upper side.

The light emitted from each LD spreads and enters the end of the light guide plate. White light is created by mixing colors. The light from the LD is repeatedly reflected on both surfaces and prisms on the lower surface of the light guide plate, and the light is guided. The ray angle against the surface increases when reflected by the prism. When the ray angle is greater than the total reflection angle, it is obliquely emitted from the light guide plate. The optical sheet on the upper surface of the light guide plate is used to convert oblique light emitted from the light guide plate to the direction normal to the LCD.

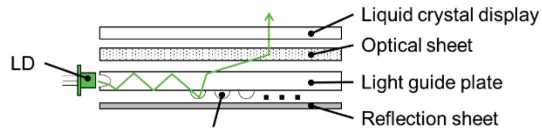

Fig.1 Structure of the laser backlight

2.2 Light Guide Plate for Laser Backlight

Figure 1 shows the structure of the light guide plate in the developed laser backlight. The light guide plate has a concave shape on the light incident surface. The prisms are not fabricated in the vicinity of the light incident surface. On the other hand, the conventional light guide plate in an LED backlight has no concave shape on the light incident surface and has prisms in the vicinity of the light incident surface.

Figure 2 shows the optical paths in the developed light guide plate. The ray with angle θ_1 is emitted from the light guide plate at the place away from the LD compared to the ray with angle θ_2 which is greater than angle θ_1. Generally, the light distribution of an LD has a tendency, whereby the emission intensity is weaker at large angles and stronger at smaller angles, as demonstrated in Fig.3. Therefore, the luminance distribution of the light emitted from the light guide plate result in the place away from the LD being brighter than the place near the light source. To obtain uniform brightness, the intensity difference between θ_1 and θ_2 should be reduced.

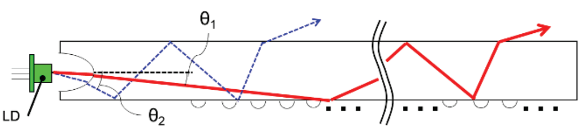

Fig.2 Side view of the developed light guide plate

To reduce the intensity difference, we applied the concave shape to the light incident surface. Figure 3 shows the light distribution of an LD with the concave shape. The concave shape makes the emission intensity of θ_1 and θ_2 to be the same. This enables the suppression of the luminance distribution.

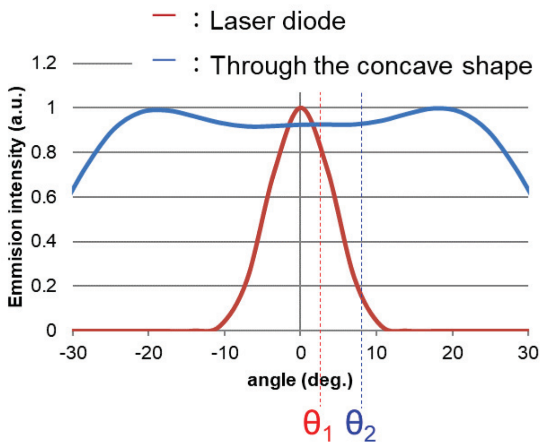

Fig.3 Light distribution

Top views of the developed light guide plate are shown in Fig. 4. Only the green LDs and light from them are drawn. The light emitted from the LDs spreads radially. It is reflected by the prism of the light guide plate, and the light guide plate emits the light. If prisms existed in the vicinity of the light incident surface, there would be no light emitted from the light guide plate between the LDs since the light distribution angle of the laser is narrow. The place between the LDs would be dark, and it would cause un-uniformity of the luminance. In the developed light guide plate, the prisms do not exist in the vicinity of the light incident surface. Thus, light is not emitted from the light guide plate. As a result, it is possible to suppress the un-uniformity of the luminance.

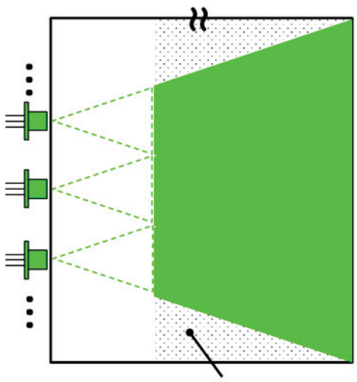

Fig.4 Top view of the developed light guide plate

2.3 Speckle

One of the problems of the backlight that uses an LD as a light source is speckle. Speckle is a glare generated by the coherence of laser light, which negatively affects the display quality. It has been reported that speckle can be suppressed by pulse driving which decline the coherence of LDs [8]. To obtain speckle free in a laser backlight, we considered the driving condition of LDs.

We confirmed that the speckle of the laser backlight LCD depends on the frequency of the driving voltage applied to the LD. The speckle was better when the frequency decreased from several MHz to several tens Hz. However, the flicker occurred when the frequency was less than 100 Hz. Thus, we decided that the frequency is 100 Hz. Figure 5 shows the observation results for the developed laser backlight LCD. In particular, Fig.5(a) shows the observation result at DC driving which is conventional, while Fig.5(b) shows that at 100Hz driving which is developed. We confirmed that the speckle of the laser backlight can be reduced by applying 100 Hz driving.

(a) DC driving (conventional) **(b) 100Hz-driving (developed)**

Fig.5 Speckle of laser backlight

3 COLOR FILTER for WIDE COLOR GAMUT

Figure 6 shows the color gamuts in the CIE 1931 color coordinates of the BT.2020, an LCD using the conventional color filter with a laser backlight, and an LCD using the developed color filter with a laser backlight. The color gamut of the LCD with the conventional color filter and a laser backlight is much narrower than that of the BT.2020.

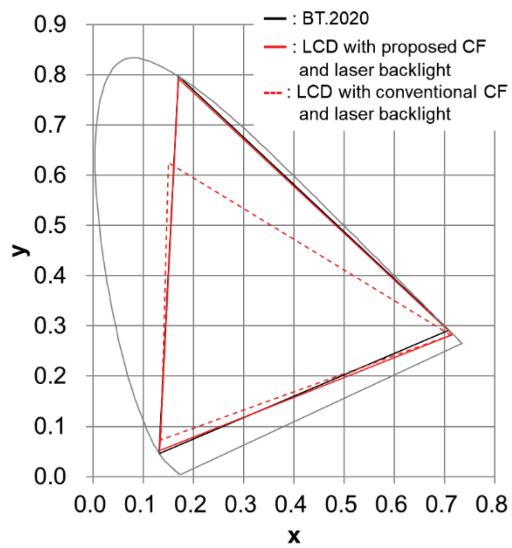

Fig.6 Color gamuts in the CIE 1931 color coordinates

Figure 7 shows the transmission spectra of the color filters and emission spectrum of the developed laser backlight. For the transmission spectrum of the color filters, the broken line represents conventional color filters, whereas the solid line represents the developed color filters.

In the conventional color filters, the green color filter transmits the blue light from the laser backlight. This means that the blue light leakage occurs from the green color filter. The blue color filter transmits the green light. This means that the green light leakage occurs from the blue color filter. The light leakage narrows the color gamut of the LCD with the conventional color filter and laser backlight compared to the BT.2020.

According to these results, development of a laser backlight alone is insufficient to satisfy the BT.2020 color gamut, i.e., an appropriate color filter must be developed. The transmission spectral width of the developed color filter is narrower than that of the conventional color filter. As a result, we reduced the light leakage of the conventional color filter. As shown in Fig.6, the color gamut of the LCD with the developed color filter is expanded, and nearly the same as the color gamut of the BT.2020.

To satisfy the BT.2020 color gamut, we developed a laser backlight and a color filter that successfully covered 98% of the BT.2020 color gamut.

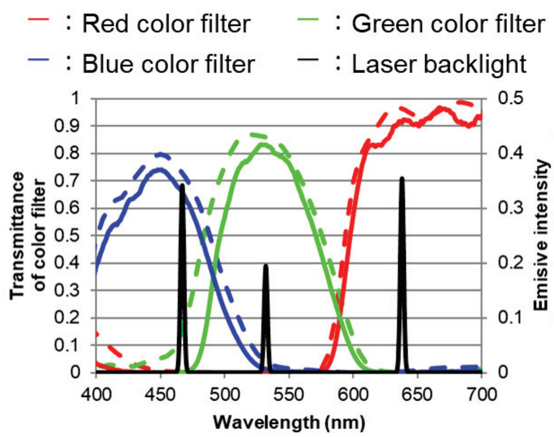

Fig.7 Transmission spectra of color filters and emission spectrum of laser backlight

4 SLC-IPS-LCD for 120-Hz DRIVING

Table 1 lists the response times of the IPS-LCD and SLC-IPS-LCD.

It is necessary to complete the response within 8.3 ms to realize a blur-free display with 120-Hz driving required for BT.2020. However, the response time is more than 8.3 ms in the IPS-LCD, even in the black-to-white response that is the fastest. Therefore, motion blur occurs.

We developed 8K-SLC-IPS-LCDs. SLC-IPS-LCDs are high-speed IPS-LCDs using a special electrode structure. The response time of the SLC-IPS-LCD depends not only on the cell thickness but also the electrode pitch [9]. Therefore, a faster response can be realized by reducing the electrode pitch in the SLC-IPS-LCD.

The response time of the SLC-IPS-LCD is less than 8.3 ms, even in the gray-to-gray response. Therefore, we employed the SLC-IPS-LCD rather than the conventional IPS-LCD to satisfy 120-Hz driving required by BT.2020.

Table 1 Response time of IPS-LCD and SLC-IPS-LCD

	IPS-LCD	SLC-IPS-LCD
Black to white	10ms	3ms
White to black	12ms	2ms
Gray to gray (worst)	25ms	5ms

5 SPECIFICATIONS of DEVELOPED LASER BACKLIGHT LCD SATISFYING THE BT.2020 SPECIFICATION

Figure 8 shows the developed laser backlight LCD. The displayed image was provided by the Institute of Image Information and Television Engineers (ITE) [10]. Table 2 lists the specifications of the developed LCD. The size of the display is 17.3 inches, and the resolution is 510 ppi at 8K. The frame frequency is 120-Hz. To drive the display at 120-Hz, we used the SLC-IPS-LCD. We succeeded in realizing a blur-free display using the SLC-IPS. Furthermore, we achieved a coverage ratio of BT.2020 color gamut of 98%, using the proposed laser backlight and color filter. This means that the developed laser backlight LCD satisfies the main BT.2020 specifications (i.e., 8K, high color gamut, 120-Hz driving).

Fig.8 Developed laser backlight LCD

Table 2 Specifications of the developed laser backlight LCD

Item	Specification
Display diagonal size	17.3-inch
Number of Pixels	7980 x RGB x 4320
Aspect ratio	16:9
Resolution	510 ppi
Picture frame rate	120-Hz
Color gamut	BT.2020 (coverage ratio : 98%)

6 CONCLUSION

To satisfy the BT.2020 specification, we developed a laser backlight, a color filter, and an 8K SLC-IPS-LCD.

We demonstrated that the BT.2020 color gamut can be satisfied by combining the proposed laser backlight and color filters. In addition, we achieved a response time of 5 ms, by employing the SLC-IPS-LCD, which is sufficient for a120-Hz driving.

Acknowledgement

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