Development of wavelength-selective transmission and reflection film for 2D-backlight with blue mini-LEDs

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ABSTRACT

Two dimensional backlights with blue mini-LEDs and a color conversion film are currently regarded as the leading technology in LCD market to achieve high color gamut and High Dynamic Range (HDR). To improve the backlight efficiency, blue light transmission mirror film which transmits blue light and reflects green and red light based on Multi-layer Optical Film technology was launched and the development of modified one is required to meet the market trend.

1 Introduction

1.1 2D-backlight trend

Recently, 2D (Two dimensional) - backlights with mini-LEDs (Light Emitting Diodes) is remarkable technology in LCD (Liquid Crystal Display) market and this technology is being applied to a variety of applications, VR, Automotive display, Notebook PC, Monitor and TV. The biggest advantage of 2D-backlight is that it enables HDR (High Dynamic Range) with local diming of thousands of zones by approximately tens of thousands of mini-LEDs. This provides a high contrast ratio comparable to an OLED (Organic Light Emitting Diode) display even in LCD and high-quality image with a sense of depth can be obtained in LCD using 2D-backlight with mini-LEDs [1] [2] [3]. Moreover, it is also worth noting that wider color gamut can be achieved by combining blue mini-LEDs and a color conversion sheet with luminescent materials representative by QDs (Quantum Dots) and inorganic phosphors [4] [5]. Two points mentioned above, HDR and wider color gamut are regarded indispensable features in current and future high-performance display and 2D-backlight is vital technology in order for LCD to achieve the above two features.

On the other hand, an inordinate number of mini-LEDs are mounted on 2D-backlight to deliver superior performance and the power consumption in 2D-backlights is larger in comparison with conventional edge-lit type backlights and the improvement of efficiency in 2D-backight is one of technical challenges.

1.2 Solution for improvement of efficiency in 2D-backlight

To improve the efficiency of 2D-backlight with blue mini-LEDs, blue light transmission mirror film had been developed and launched and it is currently being used by LCD backlight manufacturers. This film has a structure of MOF (Multi-layer Optical Film) and it is characterized by wavelength-selective transmission and reflection performance based on the unique MOF technology. Fig.1 is the transmittance spectrum of blue light transmission mirror film in a visible light range and Fig.2 is schematic diagram of the actual assumed stack of optical films in 2D-backlight with blue mini-LEDs. As Fig.1 shows, blue light transmission mirror film has distinctive optical properties such that light in the short wavelength blue region is transmitted but light in the long wavelength green and red region is reflected.

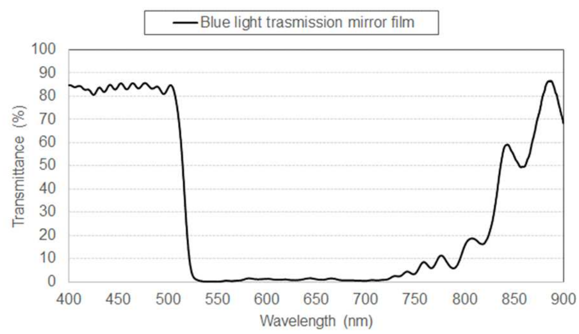


Fig.1 Transmittance spectrum of blue light transmission mirror film

In the actual 2D-backlight with blue mini-LEDs, it is assumed that the loss of light by scattering and reflection loss will occur. Blue light from mini-LEDs is incident on the color conversion film and the color conversion sheet converts the blue light to green and red light by luminescent materials representative by QDs and inorganic phosphors in the sheet and finally generates white light by good balance of blue, green and red. In the case of using blue light transmission mirror film, green and red-light emissions from the conversion sheet are effectively reflected by blue light transmission mirror film with the unique optical property described above and when used together with other optical films, light recycling is promoted and light from the light source is effectively utilized, thus increasing the overall efficiency of the backlight.

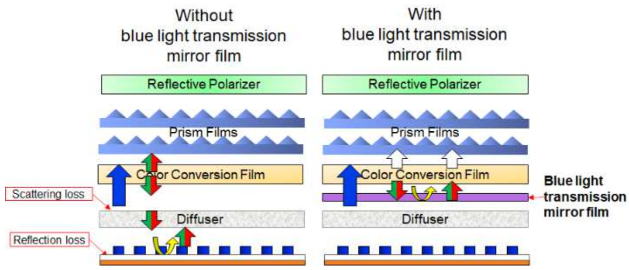


Fig.2 Schematic diagram of 2D-backlight

1.3 Challenge of existing blue light transmission mirror film

In the process of introducing blue light transmission mirror film, it became clear that the phenomenon called “color mura” in this film related to display quality was one of the technical challenges (Fig.3). Our investigation into this phenomenon and our solution derived from this will be described in the next section.

Fig.3 Color mura in a display (on white image)

2 Experiment

2.1 Our investigation

First, the display was divided and both transmittance spectrum on normal area and color mura area of blue light transmission mirror film was measured (Fig.4). LBE50 (Left Band Edge 50), which is the wavelength at which the film transmittance reaches 50% in the short wavelength side, was found to be slightly shifted to the long wavelength side in areas with color mura in comparison with the LBE in normal areas (Fig.5). To verify the difference of average value in both groups is statistically significant, it was analyzed by 2-sample t. The result shows that P-value is 0.039 < 0.05 and it is proven that the difference is statically significant.

Additionally, Fig.6 shows that transmittance spectrum for average data of normal area and color mura area and luminescent spectra from the color conversion film. It was found that the overlap area between LBE and green emission peak in color mura area was larger than that in normal area. From the result of this investigation, our conclusion was that the overlap between LBE in blue light transmission mirror film and green emission peak of a color conversion film would cause color mura in a display.

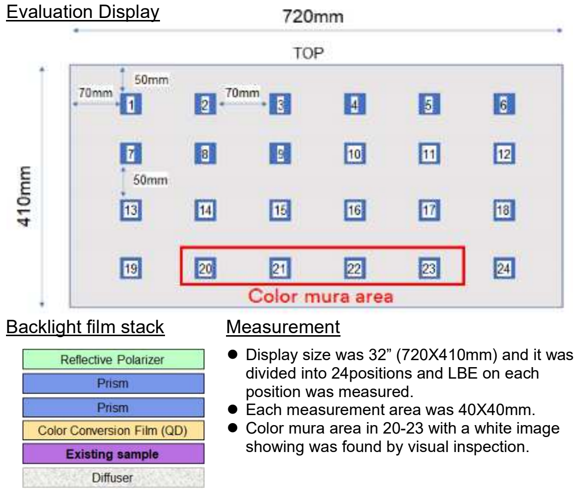


Fig.4 Measurement of LBE in the display plane

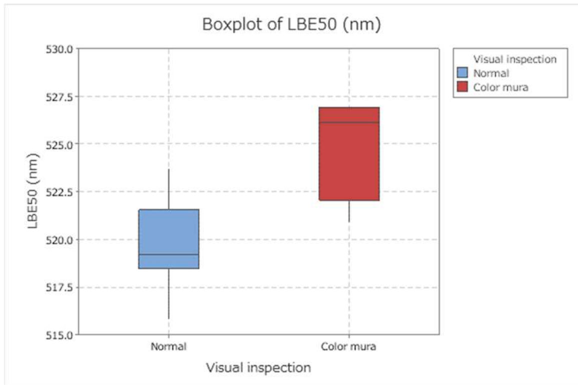


Fig.5 Result of LBE measurement

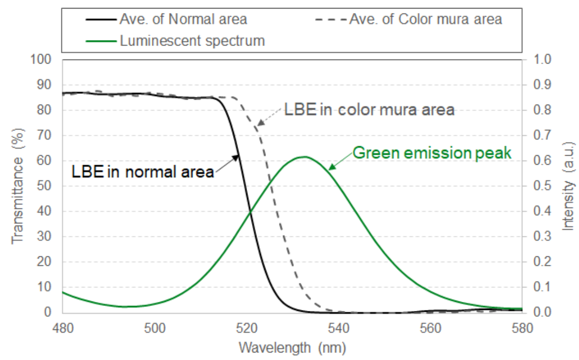


Fig.6 transmittance spectra of blue light transmission mirror film and luminescent spectra of color conversion sheet

2.2 Our approach to solve this challenge

From the result of our investigation, we thought that it would be an effective way to locate the LBE away from green emission peak and we decided to shift LBE in blue light transmission mirror film to the shorter wavelength side by adjusting process condition. And Fig.7 showed the transmittance spectrum of existing and modified one. The LBE in the modified one is shifted to the shorter blue wavelength side in comparison with existing one. The LBE50 value is calculated to 515nm in existing one and 507nm in modified one.

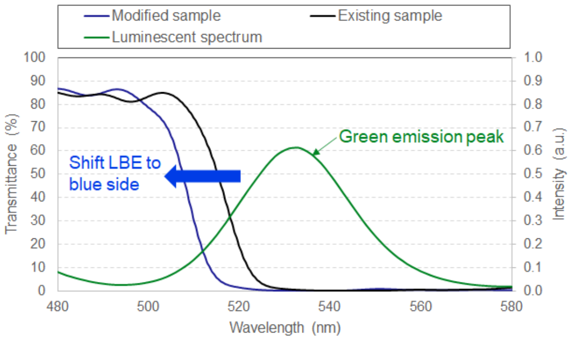


Fig.7 Transmission spectra of existing and modified one

3 Results

3.1 Color mura evaluation

To evaluate color mura in existing and modified one, the test bed shown in Fig.8 was prepared and green light was used as light source for this evaluation. The emission spectra under each condition are also shown in Fig.8 and the color mura through each sample is evaluated by not only visual inspection but also color distribution at 25 points in a plane.

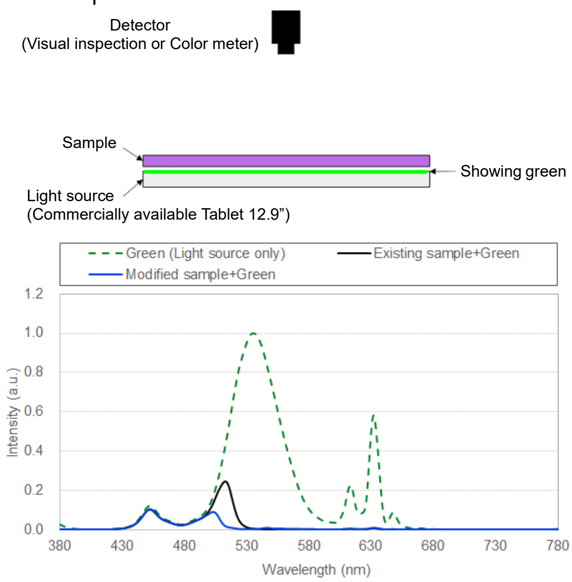


Fig.8 Composition of test bed for color mura evaluation and emission spectra under each condition

Fig.9 shows the result of visual inspection and actual appearance was captured by a digital camera. As Fig.9 shows, the modified sample looks more blue than the existing sample. This corresponds to emission spectra in Fig.8 and there is less green light transmission in modified sample than existing sample. And it seems that color mura in the modified sample was mitigated in comparison with existing by visual inspection.

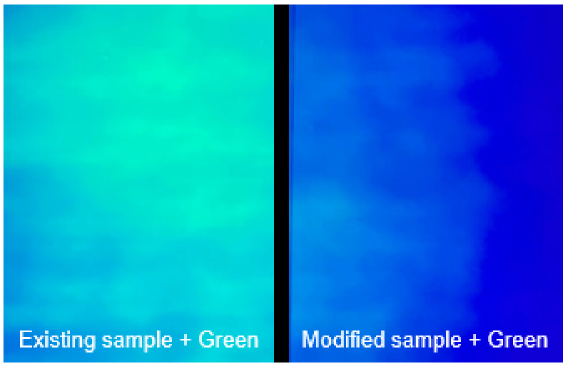


Fig.9 Actual appearance comparisons

In order to evaluate color mura by both samples in a quantitative way, color distribution data on the surface measured by a color meter was used and this data was divided into 25 sections on the screen and used to analyze the color mura of both samples. The y value in CIE color space was the metric used for this analysis because the detected light is spread from blue to green. And the area used for this analysis was 238mm X161mm. The result of this analysis is shown in Fig.10 and Table2. Comparing the difference between maximum value and minimum value and the standard deviation in both samples, those values in modified sample is small and it can be seen that the variability of y in the plane has been improved. This result suggests that the color mura in the modified sample is improved compared to the existing sample. Furthermore, we verified whether there was a statistical difference in the distribution of y-values in the plane of the two samples. Fig.11 shows the result of test for equal variance. P-value in Levene's test is less than 0.05 and it means the difference of two samples is statically significant. This statical analysis reinforces that color mura in modified sample is improved compared to the existing sample.

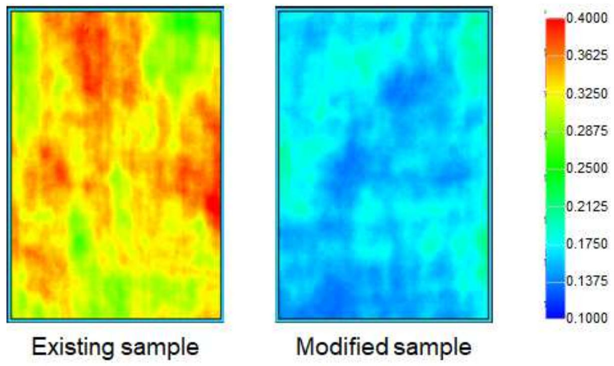


Fig.10 Measurement result of y distribution in the plane

Sample	Max.	Min.	Max.- Min.	STD.
Existing	0.364	0.292	0.072	0.021
Modified	0.191	0.139	0.052	0.012

Table2 Comparison of y in the plan

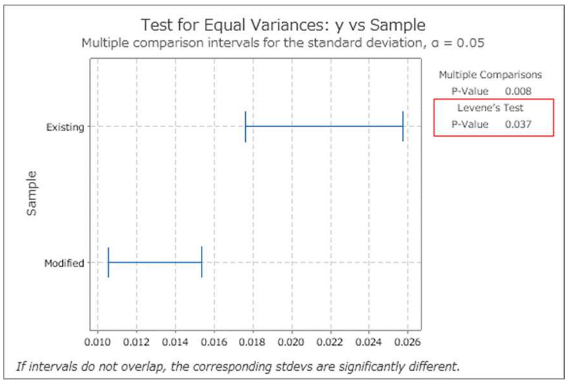


Fig11. Result of test for equal variance

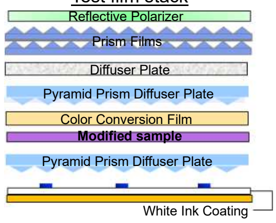
3.2 In-module optical performance evaluation

To assess the improvement of efficiency in 2D-backlight by the modified sample, optical performance in-module was evaluated with a commercialized device. Fig.12 shows the result of in-module optical performance evaluation and the luminance with modified sample is more than 30% higher than without sample. This result shows that this modified sample can contribute to improving the efficiency of 2D-backlight.

Test module

- Test bed: LCD module with 2D-backlight system in commercially available Note PC
- Size: 17.3"
- Resolution: UHD
- HDR spec: HDR 1000
- Blue LED array + Color conversion film (QD)

Test film stack



Condition	Lv (%)	dx	dy
w/o modified sample	100	-	-
w/ modified sample	132	0.0463	0.0469

Fig.12 Result of in-module optical performance evaluation

4 Summary

The above-mentioned solution of wavelength-selective transmission and reflection performance by MOF technology can contribute to improve the efficiency of 2D-backlight with blue mini-LEDs and a color conversion film and both existing and modified products will support LCD backlight manufacturer's design.

This solution can support further expansion and progress on 2D-backlight technology in the LCD market. We expect that the LCD market will grow further by leading technology of 2D-backlight and overall display market will continue growing.

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