Design of Mini-LED Backlight Using Reflective Mirror Dots with High Luminance Uniformity for Mobile LCDs

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ABSTRACT

A new mini-LED local dimming backlight with reflective dots is proposed for high uniformity, high contrast, and low power consumption in small LCDs. The proposed backlight, comprising a small number of mini-LEDs, was verified as having high luminance uniformity due to the optimized backlight thickness and light distribution of mini-LEDs.

1 INTRODUCTION

In recent years, liquid crystal displays (LCDs) have been used in a wide range of applications, resulting in a demand for improved contrast and lower power consumption. A conventional method to satisfy these demands is local dimming method [1]. Local dimming method is a feature of direct-lit backlights that controls the brightness of LED with respect to that of the image, thus improving the contrast and lowering the power consumption.

Local dimming method has been applied to large LCDs, such as TVs, but not to small LCDs such as smartphones, due to the dimensions of conventional LEDs. In recent years, smaller LEDs (about 80–500 μm in size) called mini-LEDs [1-4] have been developed with an expectation that they will be applied to mobile LCD backlights.

Recently, mini-LEDs with batwing emission patterns [1] have been commonly used for fabricating mini-LED backlights. The batwing-pattern mini-LEDs have a wide light distribution. However, several to tens-of-thousands of mini-LEDs are needed to fabricate backlights; the associated high manufacturing cost is of concern [1].

One potential solution is to spread the light from each mini-LED such that the light distribution is wider than that of batwing-emission mini-LEDs.

In this paper, a new backlight structure with reflective dots is presented and the optical properties were evaluated by computational simulations.

2 PRINCIPLE AND STRUCTURE OF THE PROPOSED MINI-LED BACKLIGHT

The structure of the proposed backlight with reflective dots is shown in Figure 1. The reflective dots are arranged on the top surface of the light guide plate; the bottom surface of the light guide plate is reflective mirror. Light from the mini-LED is reflected within the light guide plate and emitted through the gaps between reflective dots; this creates a high luminance uniformity, wider light distribution of each mini-LED.

A diffuser and a QD sheet are placed above the light guide plate to change the color of the light from blue LEDs.

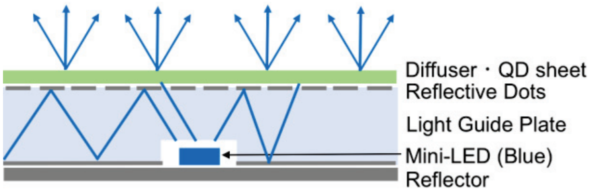

Figure 1. Proposed mini-LED local dimming backlight structure with reflective dots (one segment)

3 DESIGN OF BACKLIGHT

For the proposed backlight structure, the light distribution of mini-LEDs, thickness of the light guide plate, and dimensions and placement of the dots are significant because these parameters affect the optical properties of the backlight. Therefore, the light use efficiency of the backlight was studied using theoretical calculations to optimize the light distribution of the mini-LEDs and the thickness of the light guide plate. Moreover, the reflective dots were optimized while fixing the reflectance at 97% with respect to Ag for all of the reflective surfaces. It was intended to obtain luminance uniformity over 80% based on other papers [3][4] reporting on mini-LED backlights.

3.1 CONDITIONS FOR SIMULATION

In this study, the size of a smartphone display was assumed to be 6 inches diagonal, with the backlight divided into 512 segments for local dimming method; each segment of the backlight was a square 4.26 mm on a side. each segment has one mini-LED so that the total number of mini-LEDs required for the backlight is 512. The light use efficiency and luminance uniformity of nine segments of the backlight were evaluated. LightTools (Cybernet) was used for ray tracing simulation; the simulation parameters are shown in Table 1.

Table 1. Parameters for the simulation

Item	Specification
Size of 1 segment	4.26 mm
Number of segments	9 (3x3)
Thickness of the light guide plate	0.8 mm
Thickness of the diffuser	0.2 mm
Thickness of the reflector	0.1 mm
Size of LEDs	100 x 100 μm
LED type	Blue LED
Reflectance of dot pattern and reflector	97 %
Optical property of the diffuser	Lambertian

3.2 EVALUATION OF LIGHT USE EFFICIENCY ACCODING TO MINI-LED LIGHT DISTRIBUTION

Figure 2 shows the light use efficiency calculated while changing the light distribution of a mini-LED; the central segment of the nine segments was turned on. The light use efficiency is the ratio of the luminous flux emitted from the central segment to the luminous flux emitted from the mini-LED of the central segment. Figure 2 shows that a narrower light distribution of the mini-LED reduced the light use efficiency because, when the light distribution of the mini-LED was narrower, the number of reflections within the light guide plate increased while the optical loss due to reflectance of the reflective surfaces also increased. On the other hand, the light use efficiency also decreased when the light distribution of the mini-LED was wider. This was because the light leakage to the adjacent segments increased, leading to reduced light use efficiency. The light leakage to the adjacent segments is the ratio of the luminous flux emitted from the segments other than the central segment to the luminous flux emitted from the mini-LED of the central segment. Figure 2 shows that the maximum light use efficiency was 51% and the light leakage to the adjacent segments was 27% with a maximum light emission angle of the mini-LED of 50°; the optical loss due to reflectance of the reflective surfaces was 22%. From the results, the maximum light emission angle of the mini-LED was set to 50°.

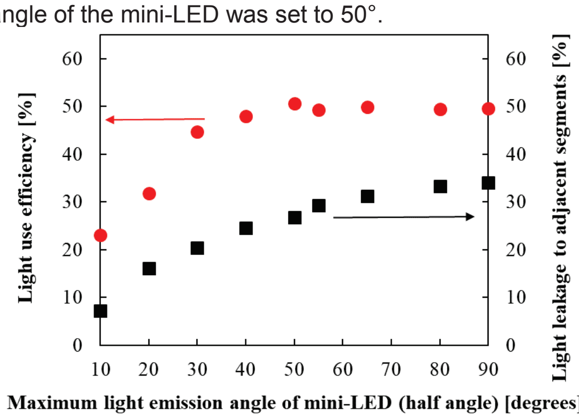

Figure 2. The relationships of the maximum light emission angle of a mini-LED with light use efficiency and light leakage to adjacent segments

3.3 EVALUATION OF LIGHT USE EFFICIENCY ACCODING TO VARIATION IN BACKLIGHT THICKNESS

The influence on light use efficiency of variation in light guide plate thickness was investigated. Figure 3 shows that thicker light guide plates were associated with improved light use efficiency; when the light guide plate was thicker, the number of reflections within the light guide plate decreased, reducing optical loss due to the reflectance of the reflective surfaces.

Based on these results, there is a trade-off between the thickness of the light guide plate and light use efficiency. In this study, the thickness of the light guide plate was set to 0.8 mm.

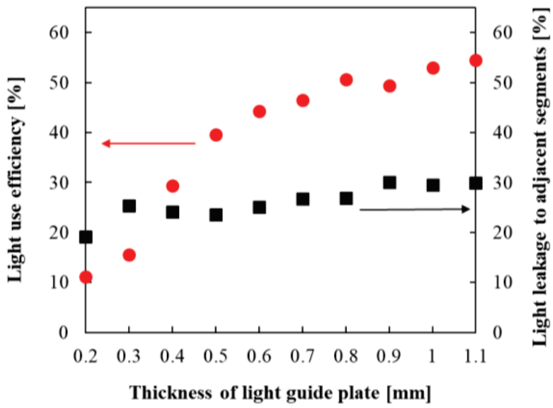

Figure 3. The relationships of light guide plate thickness with light use efficiency and light leakage to adjacent segments

4 LUMINANCE DISTRIBUTION OF BACKLIGHT

Figures 4(a) and (b) show the luminance distributions of the nine backlight segments designed based on the results of the previous sections. To calculate the luminance of the backlight, a light observing plane was placed 0.002 mm away from the diffuser. The light emitted within a half-angle of a luminance meter was evaluated by scanning the light observing plane sequentially with the luminance meter. It was assumed that smartphones are generally angled at 30° during use by the general public; the half angle of the luminance meter was thus set to 30°.

Figure 5 shows the luminance distribution of the nine backlight segments; the variation in luminance among segments was minimal, i.e., the luminance uniformity was 86%. Thus, the proposed backlight structure can produce high luminance uniformity with a wider light distribution of each mini-LED.

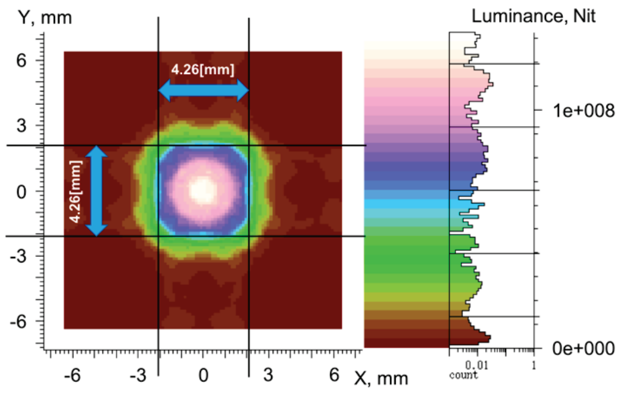

Figure 4(a). Luminance distribution of the central backlight segment

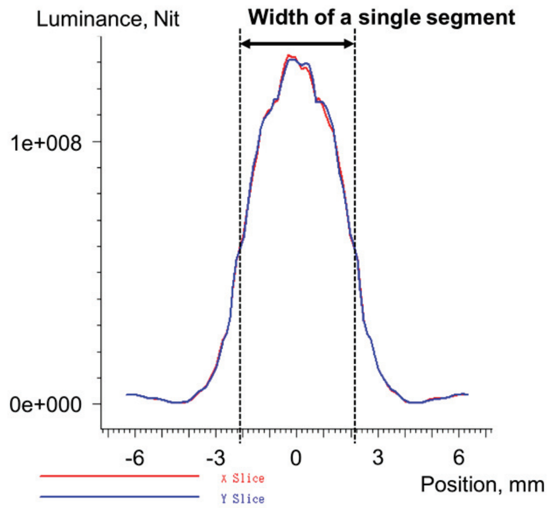

Figure 4(b). Cross-sectional luminance distribution of the central backlight segment

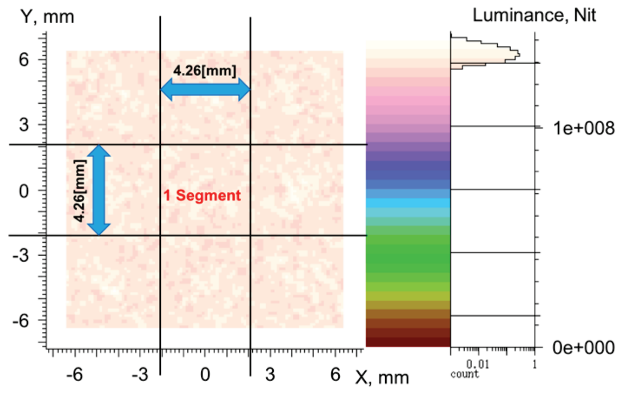

Figure 5. Luminance distribution of the nine backlight segments

5 CONCLUSIONS

Using simulation modeling, this study demonstrated that the proposed backlight structure provides high luminance uniformity and a wider light distribution of each of a small number of mini-LEDs. It was found that light use efficiency is maximized when the emission angle of the mini-LEDs is 50°; moreover, the uniformity of the proposed backlight can exceed 80%.

In future work, a prototype of the proposed backlight will be fabricated for an experimental demonstration.

6 REFERENCES

[1] Binyi Zheng, et al., “An Advanced High-Dynamic-Range LCD for Smartphones”, SID Symposium Digest of Technical Papers, pp566-568 (2019)

[2] Takeshi Masuda, et al., “Mini-LED Backlight for HDR Compatible Mobile Displays”, SID Symposium Digest of Technical Papers, pp390-393 (2019)

[3] Bing Zhang, et al., “Research on the effect of simplified structure of mini-LED backlight module on luminous efficiency”, SID Symposium Digest of Technical Papers, pp1599-1601 (2019)

[4] Zhuo Deng, et al., “High Dynamic Range Incell LCD with Excellent Performance”, SID Symposium Digest of Technical Papers, pp996-998 (2018)