

High luminance hybrid light guide plate for backlight module application

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Abstract: We introduce a hybrid backlight module, which consists of a hybrid light guide plate (HLGP) and a brightness enhancement film (BEF). The HLGP comprises functions of a conventional light guide plate, a reflector, and a BEF. The HLGP allows one-dimensional rays to be collimated. We add a BEF above the HLGP, and let the crossed-dimension rays to be collimated. Comparing with the conventional edge-lit backlight module, the optical efficiency improves to 1.3-times and the on-axis luminance improves to 3.7-times by using the hybrid backlight module.

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1. Introduction

In recent years, owing to awareness of environmental protection, liquid crystal displays (LCDs) have gradually replaced traditional cathode ray tube (CRT) monitors. Compared with CRT monitors, LCDs have the advantages of low power consumption, long life, and small size, so LCDs are widely used in miscellaneous products, such as computer monitors, cell phones, and televisions. Since the LCD is a non-spontaneous emission display device, an external light source is necessary for the display operation. For power saving, this external light sources of a LCD are light emitted diodes (LEDs) [1,2]. The rays emitted from the LEDs propagate through a backlight module, a rear polarizer, a liquid crystal module, a color filter (CF), a front polarizer, and into human eyes sequentially. Due to energy loss resulted from absorption or interface reflection while the emitted rays penetrate the optical elements mentioned above, total energy enter the human eyes is less than 5%. Especially, the energy loss caused by the backlight module is 55% of the total energy loss [3,4], thus reducing the energy loss of backlight module becomes an important issue for development of LCD.

There are various methods that reduce energy loss and increase on-axis luminance of a backlight module. For energy-coupling improvement between a light source and a light guide plate (LGP), a hybrid LED backlight [5] is fabricated by the LGP with the embedded LEDs inside to reduce the energy loss. For improvement of BEFs, a new cone sheet [6] is designed to replace conventional crossed BEFs. For development of compound optical film, a new light extraction film [7] and a lenslet brightness enhancement film (LBEF) backlight module [8] are designed for functions of both diffuser and conventional crossed BEFs. There is also research that combines a LGP, diffusers and BEFs for shortening assembly time [9]. However, those methods don't provide significant improvement of energy loss. Generally, the improvement of energy loss is less than 75%. Those methods also increase the backlight module's cost with new manufacture process.

In this study, we proposed a hybrid backlight module with a hybrid light guide plate (HLGP) and a BEF. The HLGP with functions of a conventional LGP, a reflector, and a BEF allowed rays to be collimated in one dimension. We added a BEF above the HLGP to let the rays be collimated in the crossed dimension. The half-luminance angle is 5 degree in horizontal direction and 17 degree and vertical direction. This hybrid backlight module was highly collimating. Compared to the conventional backlight module, the optical efficiency was increased to 1.3-times and the on-axis luminance was increased to 3.7-times under the same power consumption. Moreover, the up and the bottom surface of the HLGP have microstructures which could be fabricated by ultra-precision machining [10], thus the production cost could also be reduced.

2. The principle of hybrid light guide plate

The hybrid light guide plate (HLGP) is shown in Fig. 1(a). In order to match total internal reflection (TIR) condition in the main layer, we designed materials' indices of the HLGP to conform condition $n_1 > n_2$ [11]. When rays stroke microstructures on the main layer, deflection of the rays is shown in Fig. 1(b). The relationships are described as following:

$$\alpha = \theta_m - \theta_t, \quad (1)$$

$$\alpha = \beta + \theta_t, \quad (2)$$

$$\beta = \theta_m - 2\theta_t. \quad (3)$$

When the incidence angle $\beta \leq \sin^{-1}(n_2 / n_1)$, the rays were no more trapped in the main layer. The rays propagated through the sub-layer and were reflected by the reflective layer. According to the Snell's law, the propagation directions of the rays could be demonstrated as follows. The ray path is shown in Fig. 1(c), and the rays kept the following equations.

$$n_1 \times \sin(\beta) = n_2 \times \sin(\gamma), \quad (4)$$

$$n_2 \times \sin(\gamma) = n_1 \times \sin(\varepsilon), \quad (5)$$

$$\beta = \varepsilon. \quad (6)$$

We got an angle θ_r for the microstructures on the reflective layer such that the rays were collimated. The microstructures on the reflective layer were coated with silver. By the reflection of the microstructures on the reflective layer, the rays were collimated. The derivations of the ray path are described by Eq. (7) and (8):

$$\varepsilon = 2\omega, \quad (7)$$

$$\omega + \theta_r = 90^\circ. \quad (8)$$

According to the condition the rays refracted into sub-layer, and combining the Eq. (6), (7) and (8), we got Eq. (9):

$$\theta_r = 90^\circ - (1/2) \times \sin^{-1}(n_2 / n_1). \quad (9)$$

From the Eq. (9), we designed a corresponding angle θ_r to let the output rays be collimated for determined materials of the HLGP.

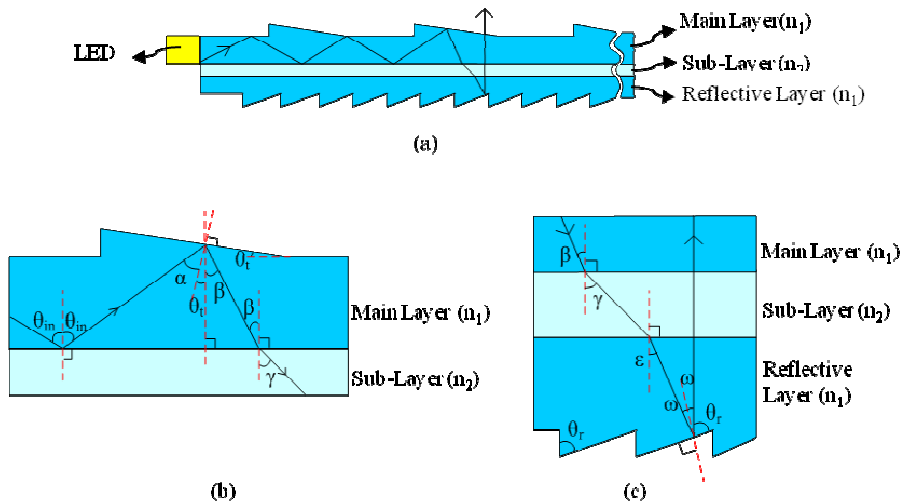


Fig. 1. (a) The schematic of the HLGP. (b) The function of the microstructures on the main layer and (c) the function of the microstructures on the reflective layer.

3. Optical design and simulation

The hybrid backlight module was constructed by LightTools [12]. This model had 18 LEDs (Nichia NxSW155). These LEDs were the typical planar Lambertian source. Locations of the LEDs were on the edge of main layer. Size of the HLGP was 10.1 inch (16: 9). The HLGP's thickness, materials, and angles for the microstructures are shown in Table 1. The designs of the prism micro-structure are easy to fabricate by imprint process [15].

The microstructures on the main layer had the function of conventional LGP's microstructures that could destroy the TIR of rays in LGP. We controlled the illuminance uniformity by adjusting the density of the microstructures on the main layer. After adjusting the density of the microstructures, we achieved a HLGP with good illuminance uniformity. The illuminance chart is shown in Fig. 2, and uniformity of the backlight module was 80% under nine points measuring method [16]. However, rays with high angle may not TIR in the

light-guide, and there is hot spot on the side of the light-guide near the LED. We sacrifice the light-guide's area of 2mm*223.6mm to get good illuminance uniformity.

Table 1. The Conditions of Each Layer in the HLGP Simulation.

Geometrical aspect				223.6 mm × 125.7 mm	
Layer	Thickness	Material	Index	Angle of prism micro-structure	Pitch of prism micro-structure
Main Layer	1.4 mm	PMMA [13]	1.49	$\theta_t = 2.1^\circ$	50 μ m
Sub-Layer	0.1 mm	Teflon [14]	1.35	N/A	N/A
Reflective Layer	0.1 mm	PMMA [13]	1.49	$\theta_r = 60^\circ$	50 μ m

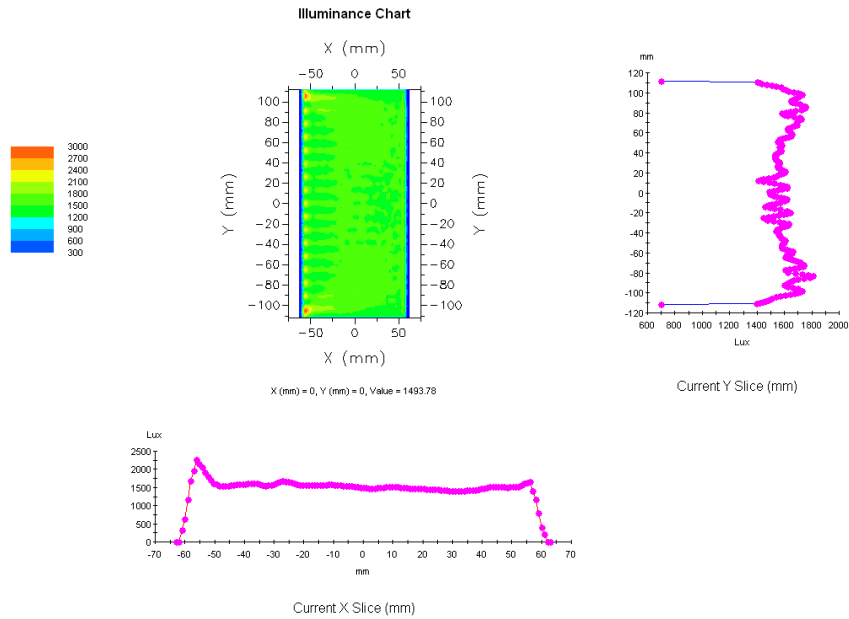


Fig. 2. Illuminance chart of the HLGP whose microstructures on the main layer are adjusted for the uniformity of the illuminance.

The angle of microstructures on the main layer θ_t was designed to determine the half-luminance angle in horizontal direction. Maintaining the light field to be on-axis, as we increased the angle of microstructures on the main layer θ_t , the half-luminance angle in horizontal direction increased, and the on-axis luminance decreased with the expansion of the light field. The Fig. 3 shows the relationships between them.

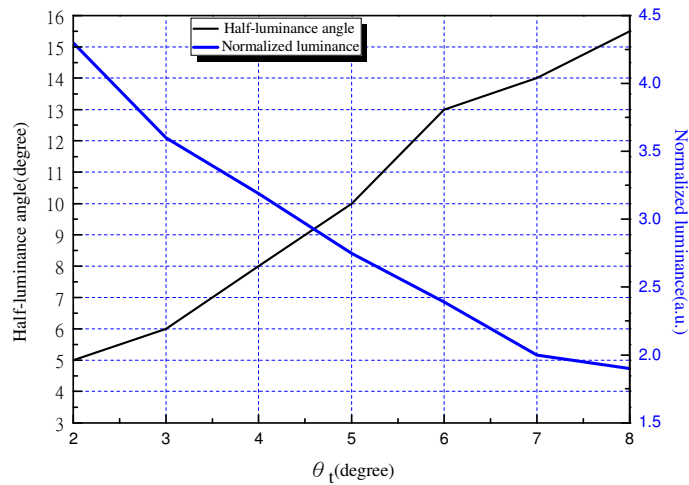


Fig. 3. The relationships between θ_r , the half-luminance angle in horizontal direction and the normalized on-axis luminance.

The microstructures on the reflective layer were coated with silver [17]. By designing a corresponding prism angle θ_r , output rays were collimated. The microstructures on the reflective layer had hybrid functions with both a conventional backlight's reflector and a BEF.

By the description above, we understood the working function of the HLGP. The rays were collimated in horizontal direction with 5 degree at half-luminance angle. However, in the crossed dimension, there was no micro-structure to control the rays in this dimension. The half-luminance angle in vertical direction kept at 25 degree as shown in Fig. 4. Thus we added a BEF [18] above the HLGP. The BEF was used to collimate the rays in the vertical direction. As a result, the half-luminance angle was reduced to 17 degree. The on-axis luminance increases simultaneously.

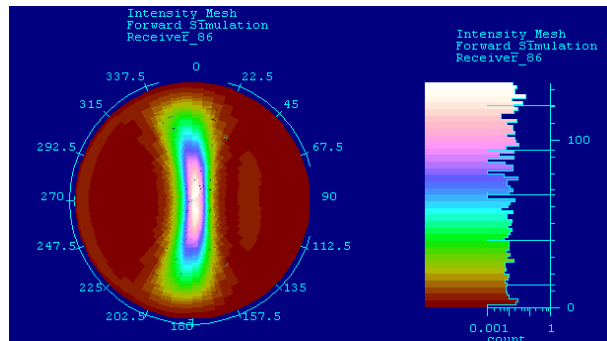


Fig. 4. 3D intensity chart of the HLGP.

Finally, we completed the design of the hybrid backlight module. The rays coming from the hybrid backlight module were highly collimated under the hybrid light guide plate and a BEF sheet.

4. Comparison between the Hybrid and the Conventional Backlight Module

We used the conventional backlight module as our comparing reference. The conventional backlight consists of a wedge-LGP, a reflector, a down diffuser, crossed BEF, and a top

diffuser. The optical films are supported by Optical Research Associates (ORA) as shown in Table 2. This backlight module is widely used for the laptops in the world. Fig. 5 shows 3D intensity charts of the conventional and the hybrid backlight module. Obviously, we found that the rays were much more collimated for the hybrid backlight module.

Table 2. The Model Names of the Optical Film.

Reflector	Down diffuser	Crossed BEF	Top diffuser
3M-Vikuiti™ ESR [19]	KeiwaOpalusBS-530 [20]	3M-Vikuiti™ BEF II 90/50	Tsujiden D117VG [21]

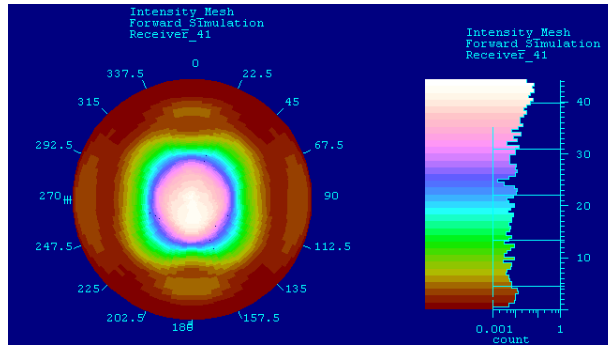


Fig. 5. (a) 3D intensity chart of the conventional backlight module.

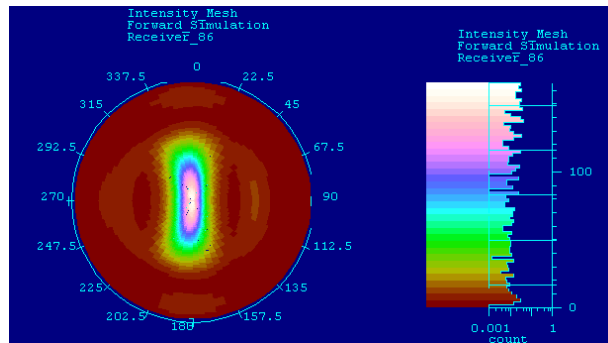


Fig. 5. (b) 3D intensity chart of the hybrid backlight module.

We defined the optical efficiency as percentage for the flux of the backlight to the flux of the LED light source. The optical efficiency is 35.5% for the conventional backlight and 45.9% for the hybrid backlight. Comparing with the conventional edge-lit backlight module, the optical efficiency improved to 1.3 times for the hybrid backlight module as shown in Fig. 6. With the increase of the output flux and the collimation of the light field, the on-axis luminance was increased substantially.

The dependence of the normalized on-axis luminance and the off-axis angle are plotted as Fig. 7. We normalized the luminance data by the on-axis luminance of the conventional backlight module. Comparing with the on-axis luminance of the conventional backlight module, the on-axis luminance of the hybrid backlight module was increased to 3.7-times. The half-luminance angle decreased from 21 degree to 17 degree in vertical direction, and decreased from 21 degree to 5 degree in horizontal direction.

For the hybrid backlight module with high efficiency and luminance, the main reason is the ray tracing of the light in the HLGPs follows the principle we have proposed. Therefore, we

could control the light field well in one dimension. We could effectively make the rays be collimated without much energy loss. For the conventional backlight module [22], most rays do recycling between the two BEFs and the light-guide, so there is more energy loss coming from the absorption and the Fresnel loss.

This hybrid backlight module had high degree of collimation. Compared with the conventional backlight module, if we used the hybrid backlight module to provide the same on-axis luminance, the power consumption of the LED light sources was reduced to 27%. As a result, we significantly reduced the adoption of LED light source number. It reached the goal of cost-down, energy saving, and carbon reduction.

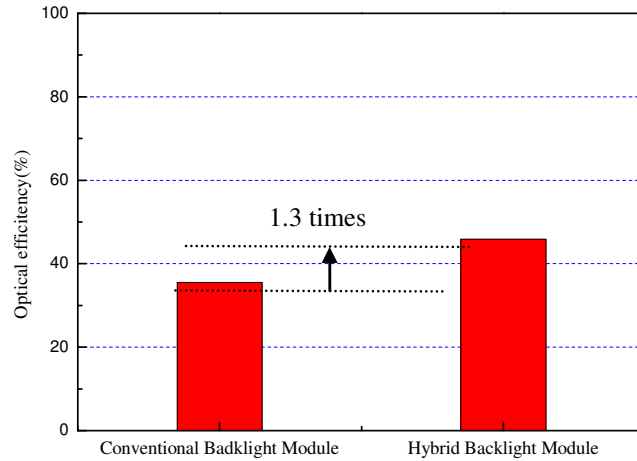


Fig. 6. Output flux of a hybrid backlight and a conventional backlight.

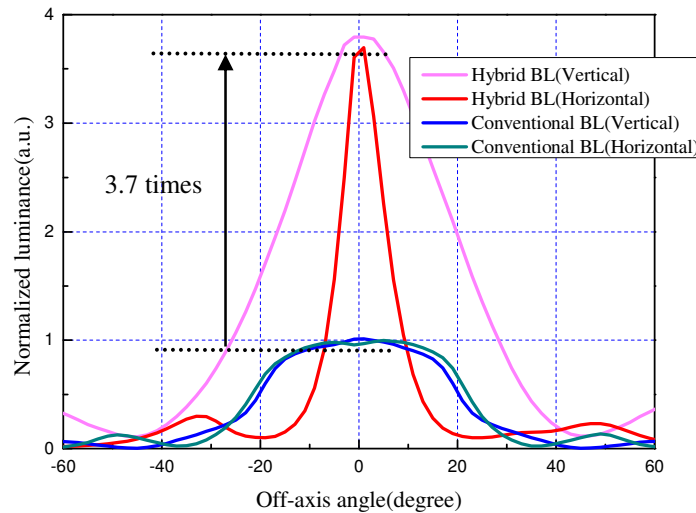


Fig. 7. The dependence of the luminance and the off-axis angle for the hybrid backlight and the conventional backlight.

5. Tolerance

Considering the injection manufacture, we analyzed the tolerance for microstructures' draft angle. Fig. 8 shows the schematic of the microstructures with draft angle on the main and reflective layer. We simulated the draft angle from 0 to 5 degree. The dependence of the draft angle θ_{d1} , θ_{d2} and the normalized on-axis luminance is as Fig. 9. We found that the influence to the on-axis luminance was very small with the draft angle of microstructures on the main layer, because the microstructures on the main layer were used to destroy TIR of the rays in the HLGP's main layer. Draft angle θ_{d1} for the microstructures on the main layer didn't influence the performance of the HLGP.

However, for the microstructures on the reflective layer, draft angle θ_{d2} influenced the on-axis luminance. This was due to the rays reflected by the right side of the HLGP was going to strike the microstructures of the reflective layer as shown in Fig. 10. And then the rays were reflected by the surface A and surface B sequentially. When there were no draft angle θ_{d2} , the rays were collimated off the HLGP, and the on-axis luminance could be the maximum. When there were draft angle θ_{d2} , the light field was expanded, and the on-axis luminance decreased compared to the microstructures on the reflective layer without draft angle. The data in Fig. 9 indicates that the on-axis luminance decrease 15% when the draft angle θ_{d2} is greater than 2 degree. In general, the draft angle isn't greater than 1 degree [15], so the tolerance in the manufacturing is acceptable.

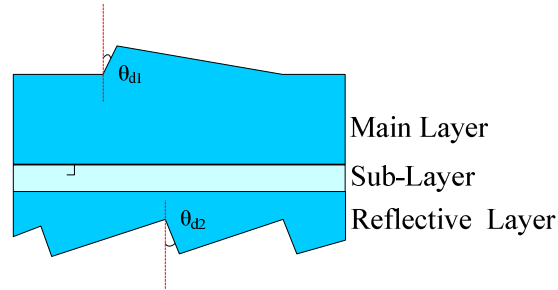


Fig. 8. The microstructures on the main and reflective layers with draft angle.

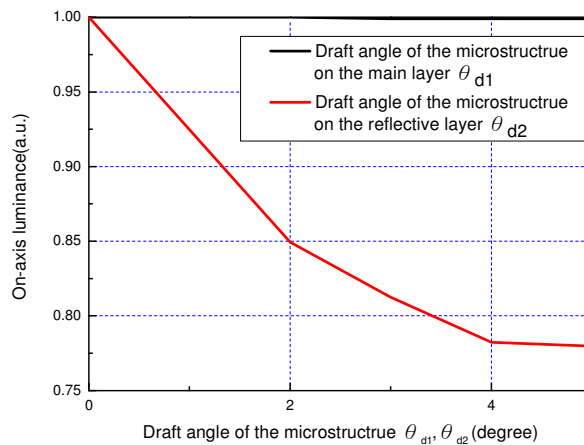


Fig. 9. The dependence of the normalized on-axis luminance and the draft angle θ_{d1} , θ_{d2} of the microstructures.

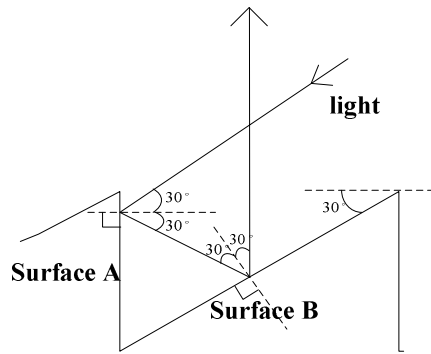


Fig. 10. The schematic of ray trace reflected by the right side of the HLGP.

6. Conclusion

In this paper, we propose a hybrid backlight module with a hybrid light guide and a BEF. After designing corresponding microstructures on the reflective layer, we can get a backlight module with high collimation. Compared with a conventional edge-lit backlight module, the optical efficiency improves to 1.3 times and the normalized on-axis luminance improves to 3.7 times. This hybrid backlight module can be used in products that require high brightness, such as small size laptops, tablet PC, and 3D displays module. It can also be used in the display devices that are more energy-saving and carbon reduction due to efficiency increasing 1.3 times. The hybrid backlight module has a non-symmetric light distribution. The broad light distribution in the vertical direction can be used to share displaying information with others. And the narrow light distribution in the horizontal direction can be applied for anti-peep without additional optical film. This is a breakthrough because anti-peep is achieved by adding special film above the conventional backlight module.

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