A Novel Light Guide Plate with Micro-prisms for an Edge-lit LED Backlight

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Abstract

We propose a novel light guide plate for an edge-lit LED backlight. Properly designed micro-prisms enable light to go out of the LGP in near vertical direction and luminance fluctuations in front of the LEDs to be invisible.

1. Introduction

Recently, laptop computers with a light-emitting diode (LED) backlight are introduced in the market and attract public attention. An LED backlight enables computer battery to last longer and the module design to be slimmer. According to a forecast by Display Search, the share of LED backlights will rise up to 70% in 2011[1]. Despite the hopeful view for fast growth of LED backlights, they must overcome two major problems to realize such high market share. The problems are luminance fluctuation near light source and high cost compared to CCFL backlights. The luminance fluctuation near LEDs, which is called “hot spot”, is originated from the shape and placement of LEDs. Because the LEDs are placed in a row with spacing wider than their light emitting area, the array of bright regions appears along the location of LEDs. Although there have been many efforts to eliminate the hot spots, the problem is not yet clearly solved [2-4]. The hot spot may get worse when the number of LEDs and/or optical sheets decreases for cost reduction of LED backlights.

To meet the demands for good appearance and low cost, we propose a new light guide plate (LGP) that requires only two sheets, a normal diffusing sheet and a normal prism sheet. Compared with a conventional LED backlight with 3 or 4 sheets, the new backlight with a proposed LGP requires fewer sheets while the level of hot spot remains almost same. The shape, size and pitch of the LGP patterns were designed considering the usage of a normal diamond tooling and a normal injection molding. In this paper we introduce the idea and the experimental results.

2. Design and Experiment

For a cost reduction of backlight, we removed one of the prism sheets which have the roles of redirecting light to vertical direction and screening hot spots. Therefore, the LGP in the proposed backlight should play the same roles of the removed prism sheet. To make the LGP emits light into the vertical direction, we imported a V-groove pattern that has been developed for CCFL backlight. The V-grooves, which are located on the bottom surface of the LGP, redirect light in near vertical direction by total internal reflection.

The V-grooves simply reflect light like a mirror without diffusing or scattering. Therefore, the image of light source is clearly visible and becomes intensive hot spots. This is the reason that the V-groove pattern had not been applied to LED backlights.

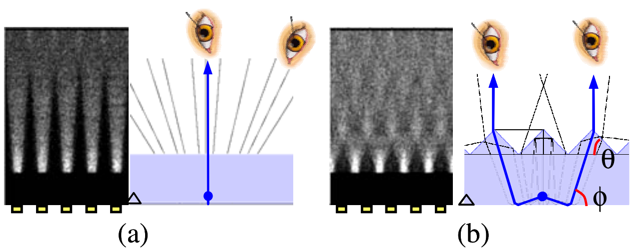

Fig.1. Hot spots of V-groove LGPs with (a) flat top surface and (b) prism-patterned top surface

In a V-groove patterned LGP with flat top surface, the hot spot appears in the form of a gradually broadening line (Fig.1.a). The hot spot line is due to the closely arranged V-grooves. When the top surface is filled with prism patterns, the inclined surface changes the direction of light. Accordingly, the latitude angle (ϕ in the figure) for vertical emission is defined by the prism angle θ. Because the prism is symmetric, both of the lights with (+)ϕ and (-)ϕ go out of the LGP in vertical direction and two symmetric hot spot lines are generated (Fig. 1.b).

From these results, we found an idea to eliminate hot spots. If the prism angles are randomly varying, the hot spot lines will be split into many lines and may not be distinguishable each other. Instead of varying each prism angles, varying the tangential angle of a single pattern will be a more effective and easier solution.

Prior to design and experiment, we simulated the backlight system using a ray tracing simulator, LightTools® ver. 6.1.

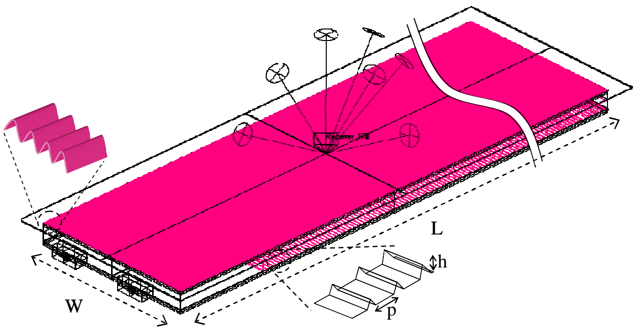

Fig. 2. Optical simulation of the LED backlight

The target model was a 15.4inch backlight with 60 LEDs. To reduce simulation time while increasing the accuracy, we reduced the dimension of model as shown in the Fig. 2. Instead of full size modeling, we narrowed the backlight width so that the only two LEDs are remained. The modeled backlight consisted of LEDs, a reflection sheet, an LGP and detectors. A diffusing sheet and a prism sheet comprised in the proposed backlight were not modeled in the hot spot simulation because they might blur out the small change in the level of hot spots. The LEDs are assumed as 550nm single wavelength sources although they emit white light over broad wavelength range. The reflection sheet was modeled considering the bidirectional reflectance distribution function (BRDF) (Fig. 3) [5].

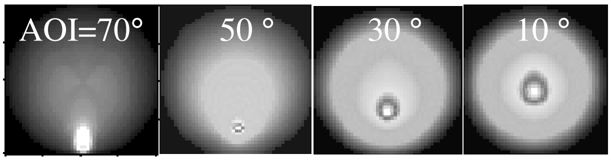

Fig. 3. BRDF distributions of the reflection sheet for different angles of incidence (AOI).

The detector planes were placed above the LGP with 0.5mm spacing. The detector planes were divided into small meshes of which dimensions are 0.2mm×0.2mm for hot spot modeling and 1mm×1mm for luminance modeling. In the case of hot spot modeling, the spatial luminance meters were placed at every 30 degree intervals along the longitudinal and latitudinal directions, respectively.

At first, we optimized the top surface pattern that defines the level of hot spots. Among many possible shapes, an ellipse shape was chosen considering its accessibilities in diamond tooling. We optimized the parameters of the ellipses and the combination of several different ellipses. The optimized pattern is the combination of two ellipses as shown in the Fig. 4.

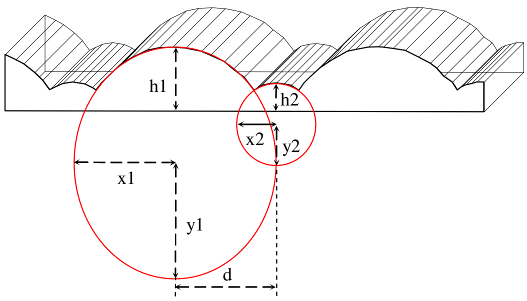

Fig. 4. Optimized top surface pattern

The hot spots before and after optimizations are shown in the Fig. 5. Before optimization, the LGP had 90 degree prism patterns on the top surface as the V-groove LGP for CCFL. The hot spots before optimization were very strong and were not hidden even with a diffusing sheet and a prism sheet. After optimization, the LGP with patterns of Fig. 4 showed dramatically improved hot spots. When combined with a diffusing sheet and a vertical prism sheet, the proposed LGP showed almost no hot spots.

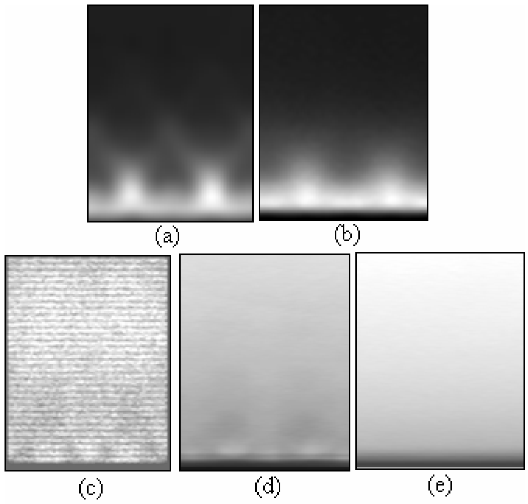

Fig.5. Hot spots before optimization (a) without sheets and (b) with sheets (both are measured). Hot spots after optimization (c) without sheets (simulated), (d) without sheets (measured) and (e) with sheets (measured).

Luminance and luminance uniformity are mainly defined by V-grooves. The design parameters of the V-groove are angles and heights. The east angle (θ1) facing incident light defines the radiation angle of the LGP and the west angle (θ2) defines the rate of recycling rays. The vertical angle (θ3) is restricted due to the burr which is formed during diamond tooling. At the condition of restricted θ3, we optimized the angles of the V-groove. Fig.6 shows the experimentally measured the angular radiation profile of the optimized LGP. The results show that the LGP emits light in near vertical direction. After passing through a diffusing sheet and a vertical prism sheet, the radiation profile becomes similar to that of the conventional backlight with 3 or 4 sheets.

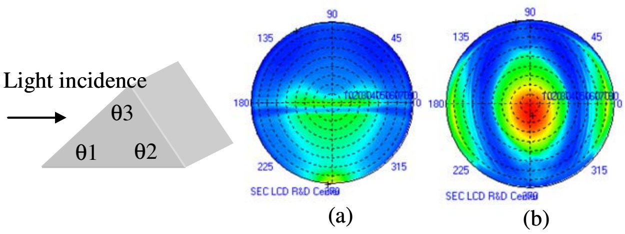

Fig. 6. V-groove angles and measured angular radiation profiles ((a) LGP and (b) backlight)

Finally, we optimized the height of V-grooves which defines the light extraction efficiency. The available total flux is highest at the front edge of LGP and falls off with increasing distance from the LEDs. To obtain maximum and uniform luminance profile, the height of V-groove must increase with the distance and its increasing function should be optimized. Fig. 7 shows the optimized height profile and resultant luminance distribution when the optimized profile was applied. The simulated and experimented luminance distributions were well matched each other and were in satisfactory levels.

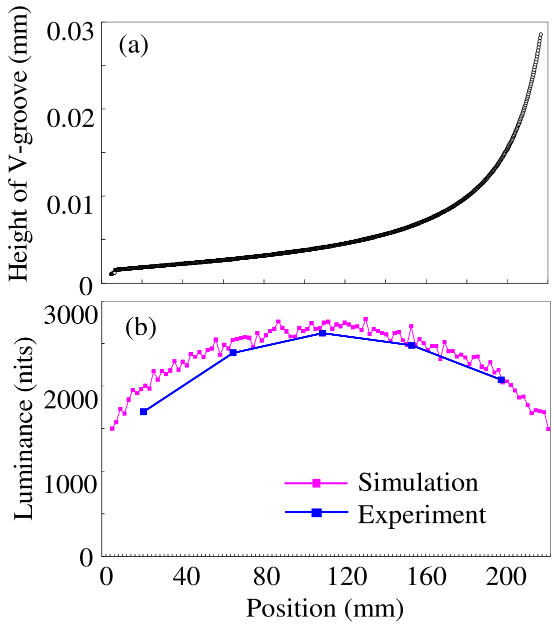

Fig. 7. (a) Optimized height profile of V-groove. (b) Simulated and experimentally measured spatial luminance distributions

3. Summary

In this paper, we introduced a novel double-sided micro-prism LGP. We also proved that a cost effective backlight with good appearance can be made using the proposed LGP. We believe that the proposed technology will accelerate the penetration of LED backlights.

4. References

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