Patterned Glass Diffuser (PGD) for Automotive White LED Backlights

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Abstract
Patterned glass diffusers (PGDs) have been demonstrated to reduce backlight thickness and LED count, and increase luminance when used with an optimal film stack in blue mini-LED backlights. However, they encounter challenges when used in automotive white LED backlights. We report our PGD solution to dimensionally and thermally stable automotive white LED backlight that has an LED pitch of 13 mm.

Author Keywords
Automotive backlight; White LED backlight; Mini-LED backlight; HDR backlight; High dynamic range; 2D local dimming; Glass diffuser; LCD backlight

1. Introduction
A few years ago, the trend towards thin liquid crystal displays was enabled by edge-lit backlight units (BLUs) using light-guide plates (LGP) with LED sources coupled into one or more sides [1]-[4]. Contrast can be enhanced using lenticular lenses on the front surface of the LGP to confine the light from the LEDs in one dimension and allow 1D local dimming. Several designs for 2D local dimming in edge-lit backlights have been demonstrated, but so far they cannot achieve the performance of direct-lit BLUs [5] – [8]. However, direct lit BLUs are typically much thicker due to the larger optical distance (OD) required to achieve the desired luminance uniformity.

We have reported on a backlight design as thin as an edge-lit backlight, yet capable of 2D local dimming as a direct-lit backlight, based on the use of a glass LGP with holes [9]. This design, although promising, is presently limited by the unavailability of in-plane all-side emitting LEDs. We also reported a thin backlight that relies on bonding LEDs to a glass light guide plate [10].
With the recent adoption of mini-LEDs [11]-[16], direct-lit BLUs become more attractive than edge-lit BLUs, because they maintain the advantages in luminance and local dimming control while closing the gap in the total thickness.

Typical mini-LED backlights, like direct-lit backlights using regular-sized LEDs, mainly rely on three approaches to convert point-like light sources into a uniform surface light source: 1) using a thick plastic diffuser plate; 2) using a large air gap between the light sources and the diffuser plate; and 3) using a large number of the light sources (at a reduced light source pitch). Approaches 1 and 2 result in undesired large total thickness, while approach 3 leads to higher cost.

We have reported the use of a patterned glass diffuser (PGD) in a mini-LED backlight to reduce the total thickness [17] or to reduce the LED count [18] while maintaining the luminance and uniformity, to increase the luminance while reducing the total thickness, and to provide an improved match in coefficient of thermal expansion with a glass circuit board (GCB) [19][20].
In this paper, we report the challenges when the PGD is applied in a white LED backlight and our progress in overcoming the challenges. We demonstrate a uniform backlight in an automotive white LED backlight with a pitch of 13 mm.

2. Patterned Glass Diffuser (PGD) for Automotive White LED Backlight
2.1 Automotive white LED backlight vs. mini-LED backlight: Both automotive white LED backlights and mini-LED backlights are direct-lit using a two-dimensional array of discrete LEDs. However, they differ in two important aspects in addition to different sizes of the LEDs. Firstly, the automotive white LED backlight is package-on-board, with green and red phosphors packed over a blue LED chip, and it does not contain a separate color conversion film such as a quantum dot (QD) film or KSF film. In comparison, the mini-LED backlight is usually chip-on-board, with blue mini-LEDs mounted on a light board, and it includes a color conversion film. Secondly, the automotive backlight usually includes only one

prismatic film such as brightness enhancement film (BEF) that concentrates the light angular distribution in the vertical direction and preserves the wide light angular distribution in the horizontal direction, while the mini-LED backlight includes two crossed prismatic films to increase luminance for applications such as monitors. Because of these differences, the automotive white LED backlight tends to have less recycling than the mini-LED backlight and is more challenging for a patterned glass diffuser to provide a spatially-uniform light distribution.

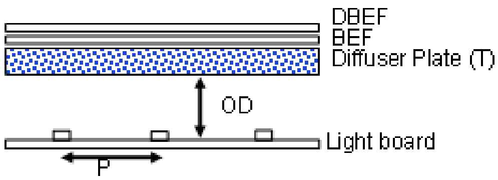


Figure 1. Cross-section of an automotive white LED backlight.

Figure 1 shows the cross-section of a typical automotive white LED backlight that includes white LEDs mounted on a light board, a plastic diffuser plate, a BEF, and a reflective polarizer such as a dual brightness enhancement film (DBEF). Typical automotive white LED backlights achieve targeted luminance and color uniformity by selecting a sufficiently large optical distance or sufficiently thick diffuser plate for a given LED pitch.

2.2 PGD As discussed previously [17][18][19], the PGD is made of a Corning glass sheet and has a proprietary pattern on one or both surfaces. The pattern is referred to as a variable diffusive pattern (VDP) when it varies in space, and as a uniform diffusive pattern (UDP) when it does not vary in space.

The main function of the VDP is to spatially modulate reflection, transmission, and scattering to suppress transmission near the LED and reflect or scatter that light out at a distance further from the LED. The VDP can create uniform illumination in a smaller OD via multiple reflection or scattering events, provided that the VDP is registered with each LED within certain horizontal and vertical alignment tolerances. The VDP can vary in opening aperture and/or in height profile. It can be located on the top or bottom surface of the PGD.

The main function of the UDP is to widen the angular distribution of the LED light when the UDP is placed on the bottom surface of the PGD, while it is to increase the alignment tolerance when the UDP is placed on the top surface of the PGD.

The PGD can take a variety of forms depending on the location of the UDP and VDP.

2.3 Challenges in PGD-based automotive white LED backlights

igure 2 shows the cross-section of a PGD-based automotive white LED backlight that uses the same white LEDs, prismatic film, and reflective polarizer as shown in Figure 1, with the PGD replacing the diffuser plate to reduce the optical distance and increase the thermal and dimensional stability.

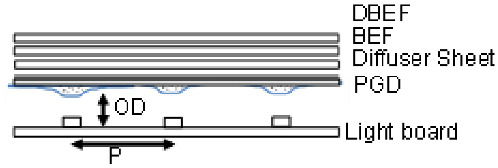
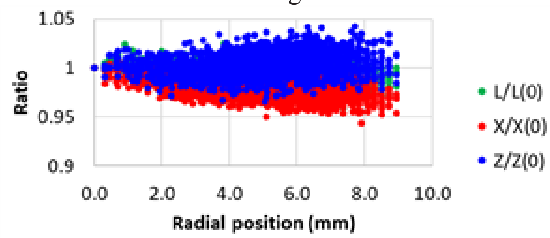
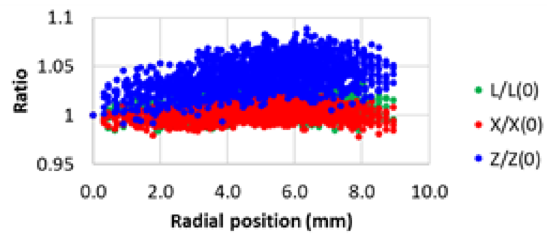


Figure 2. Cross-section of a PGD based automotive white LED backlight.



(a)



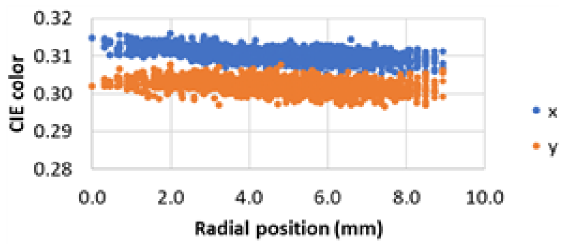
(b)

Figure 3. Measured normalized ratios vs. radial position. (a) Z is relatively flat; (b) X and L (Y) are relatively flat.

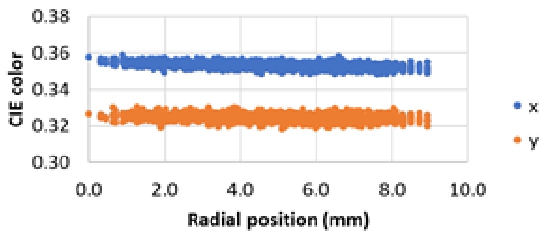
Because the spectral transmittance and reflectance of the PGD are wavelength dependent, it's relatively easy to achieve good spatial uniformity for one of the tristimulus values X, Y (the same as luminance L), and Z, but not for the three values simultaneously. This is not a problem for the previous PGD-based blue mini-LED backlight applications, because the PGD must only achieve good spatial uniformity for the blue light (Z). The good spatial uniformity of the red (X) and green (Y) light can be subsequently achieved by the color conversion film acting upon the uniform blue light. However, this is a challenging problem in the automotive white LED backlight which emits white light and does not benefit from the color conversion film.

Figure 3 shows measured normalized spatial results for X/X(0), L/L(0) (the same as Y/Y(0)), and Z/Z(0) vs. radial position in a single LED zone. The radial position is measured as a distance of the measurement location relative to the center of the LED [17][18][19]. In Case (a), tristimulus value Z is relatively flat, indicating a good spatial uniformity for Z, while tristimulus values X and L (Y) are downward and separated from Z, indicating a less optimal spatial uniformity for X and Y. In Case (b), tristimulus values X and L (Y) are relatively flat, while tristimulus value Z is upward.

The consequence of the above results is that the backlight may have a good spatial luminance distribution, but its color, represented by the CIE 1931 color coordinates x and y, will vary in space, shown as a color mura.



(a)



(b)

Figure 4. Measured 1931 CIE color coordinates x and y vs. radial position. (a) Corresponding to Figure 3(a); (b) Correspnding to Figure 3(b).

Figure 4 shows measured CIE 1931 color coordinates x and y vs. radial position, corresponding to Figure 3(a) and Figure 3(b), respectively. In either Case (a) or Case (b), color coordinates x and y vary in space and decrease with increasing radial position. The change in x within a single LED zone is larger than the change in y in both cases. With radial position increases from 0 to 9 mm, x decreases from about 0.315 to about 0.307 in Case (a) or from about 0.360 to about 0.352 in Case (b). The absolute change in x is about 0.008 in both cases. If we define the uniformity = min/max, the ratio between the minimum and maximum values, the uniformity in x is about 0.98.

2.4 Solutions to the color nonuniformity in PGD based automotive white LED backlight

In the following, we discuss our solution of using a patterned color material to compensate the non-uniformity of the current PGD materials.

Figure 5 shows measured normalized spatial results for X/X(0), L/L(0), and Z/Z(0) vs. radial position in a single LED zone, with an optimized PGD including a patterned color material in an automotive white LED backlight.

Noticeably, all the three tristimulus values X, L (Y), and Z overlap and are flat, indicating a good spatial uniformity for red, green, and blue colors. Our visual inspection also concludes that little spatial color variation is present.

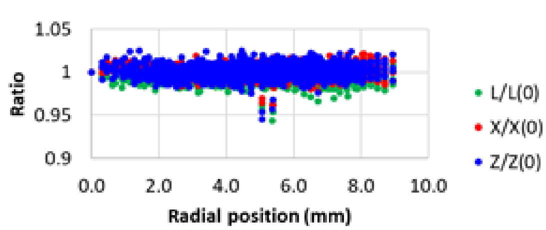


Figure 5. Measured normalized ratios vs. radial position in an optimized PGD enabled white LED backlight.

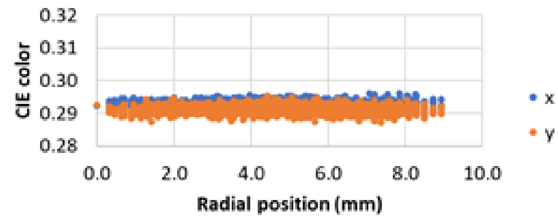


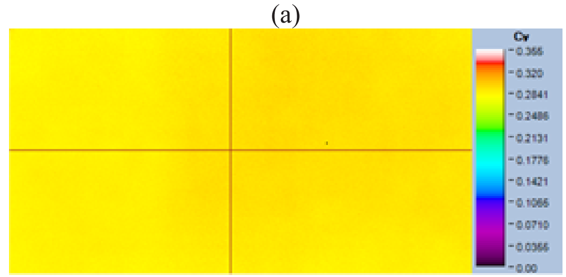
Figure 6. Measured 1931 CIE color coordinates x and y vs. radial position in the optimized PGD enabled white LED backlight.

Figure 6 shows measured CIE 1931 color coordinates x and y vs. radial position for the same optimized PGD including a patterned color material in an automotive white LED backlight. Compared to the spatial uniformity curves shown in Figure 4, the spatial color uniformity measured by the CIE 1931 x and y are significantly improved. With radial position increases from 0 to 9 mm, the changes in x and y are less than about 0.002, much smaller than the change of 0.008 as shown in Figure 4. The uniformity in x and y also improves to about 0.993 from the prior uniformity of about 0.98 before the patterned color material is used.

2.5 Demonstration of PGD in an automotive white LED backlight with an LED pitch of 13 mm

We have built a light board using automotive white LEDs, arranged in a rectangular array, with LED pitches of 13 mm ×13 mm. Using the above method, we have successfully demonstrated a PGD that has achieved good luminance and color uniformity across 13 ×24 LEDs.

(a)



(b)

Figure 7. Good spatial uniformity in the 1931 CIE color coordinates spatial distributions across 13 ×24 LEDs, with LED pitches of 13 mm ×13 mm. (a) CIE x; (b) CIE y.

Figure 7 shows good spatial uniformity in the CIE 1931 color coordinates x and y spatial distributions across 13 ×24 LEDs. A faint vertical line in Figure 7(a) is due to slightly different driving conditions to the LEDs across the vertical line.

2.6 Value of the PGD:

As demonstrated previously [17], the PGD is able to reduce the total thickness of the mini-LED backlight using the same light board on which the pitches of the LEDs are fixed.

The PGD is also able to reduce the number of the LEDs if the total thickness is fixed or reduced to a less degree, resulting in cost savings associated with the LED cost, LED driving circuit, and the yield of the light board [18].

The PGD is also able to increase the luminance of the backlight when used with a thin diffuser plate and a blue light transmitter, and also reduces the usage of the expensive color converter materials [19].

The PGD does not only work for mini-LED backlights with a color conversion film, but also work with automotive white LEDs. Compared to conventional plastic-based solutions, a glass-based PGD solution further provides desired dimensional and thermal stability. Glass from Corning Incorporated can have much smaller humidity swell (nearly 0), smaller coefficient of thermal expansion (CTE) (about one tenth), and higher Young's modulus (more than 20×) compared to typical plastics [3]. These attributes make the glass more suitable when high luminance, small total thickness, narrow border, and a large size are required.

3. Summary and Impact

In summary, we have demonstrated that the PGD concept not only works with blue mini-LED backlights that include a color conversion film, but also with white LED backlights that do not use a color conversion film. This demonstration widens the application space of the PGD into automotive backlights and other applications.

Combined with the demonstrated thickness reduction and LED count reduction, the PGD technology offers design flexibility to enable slim designs, low-cost designs, and innovative designs in-between.

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