Development of Light Collecting Optical Sheet for LCD Backlight

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Keywords : LCD backlight, light collecting, brightness enhancement

Abstract

Present research is devoted to the development of optical sheet intended to be used inside LCD Backlight unit in order to improve output axial Luminance. It deals with refractive by nature optical sheet having relief embossed top surface (microlenses array). Patterned reflecting layer can be coated on flat bottom surface.

1. Introduction

Axial Luminance – or Normal Luminance (NL) – is crucial characteristic of the LCD Backlight Unit (BLU). NL can be improved by means of either light shaping (changing the Luminance Spatial Angular Distribution (SAD)) or polarization optimization. Light shaping (or light collecting) can be accomplished by specific optical sheet (or film, or plate). In our research we explored how light collecting properties of the refractive by nature optical sheet can be improved by patterned reflecting layer coated on its bottom surface.

2. Experimental definition of BLU reflectance

In order to carry out computer simulation on performance of optical sheet according to our approach, we have to compute Light Recycling (LR) performance. For that we have to know the reflectance of the internal part of considered BLU ρ_{BLU}.

We can define ρ_{BLU} as follows:

$$\rho_{BLU} = \frac{1 - t \cdot L_0 / L_{BEF}}{\rho}, \tag{1}$$

where L_0 is NL provided by the internal part of BLU (back reflector, CCFLs and Diffusion Plate (DP)), L_{BEF} is NL provided by this with the prism sheet (BEF) added over it, t is transmittance of BEF in normal direction, ρ is total reflectance of BEF – for specific SAD of incident light (fig. 1).

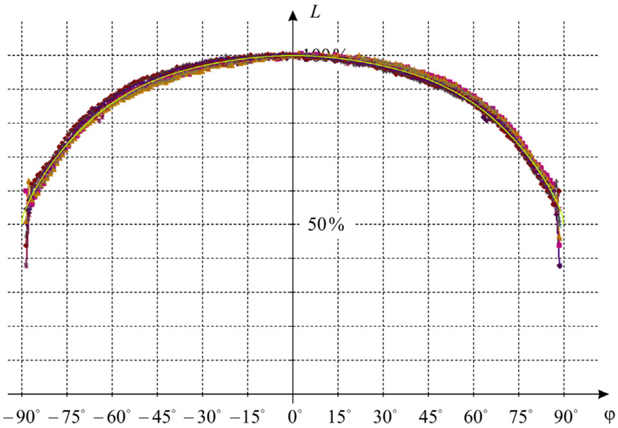


Fig. 1. Measured by ELDIM EzContrast SAD after DP and approximation that we built (green line)

The measurement gave following value of Normal Luminance Increase (NLI):

$$L_{BEF} / L_0 = 1.67 \pm 0.02\,. \tag{2}$$

According to simulation performed using original software based on precise dendritic ray tracing algorithm, for prism sheet made from PC resin (refractive index $n = 1.586$)

$$t = 0.909 \pm 0.003\,, \tag{3}$$

$$\rho = 0.536^{+0.003} \tag{4}$$

(0.003 here means computation error – or unaccounted remainder – inevitably presented in simulations of this kind).

According to expression (1) we found following:

$$\rho_{BLU} = 0.850 \pm 0.020\,. \tag{5}$$

This is exactly the value, which we have used for all simulations presented below.

3. Prevalent light-collecting optical sheets

Now we can proceed to the simulations on light-collecting performance of optical sheets, using value (5) to calculate the increase in input Luminous Flux due to LR:

$$F_{input} = \frac{1}{1-\rho\cdot\rho_{BLU}}\,, \tag{6}$$

Let's assume that these sheets are made from PET resin ($n = 1.575$). To represent the SAD of input light let's use approximation shown on fig. 1.

Let's investigate first of all the light-collecting performance for prevalent optical sheets – from prismatic to the based on cylindrical microlenses array. We will represent lens profile (or cross-section of unit cylinder) by quadratic curve. We will specify quadratic profile shape by vertex angle β, and by ratio between profile height h and vertical semi-axis of quadratic curve b : $q = h/b$. For parabola $b = \infty$ and $q = 0$, we also assumed q to be negative for ellipse and positive for hyperbola. We depicted 17 profiles different in value of parameter q on fig. 2.

To draw each profile we used following general equation of second-order curve (or its branch):

$$z = h - \frac{cx^2}{1+\sqrt{1-(1+K)\cdot c^2x^2}}\,, \tag{7}$$

where

$$h = \frac{1}{2}\cdot ctg\frac{\beta}{2},\quad c = 2\cdot(2+q)\cdot ctg\frac{\beta}{2},\quad K = -1-\frac{q}{2+q}\cdot tg^2\frac{\beta}{2}. \tag{8}$$

At that pitch p is assumed to be equal 1 and x have to be changed in range $-0.5 < x < 0.5$.

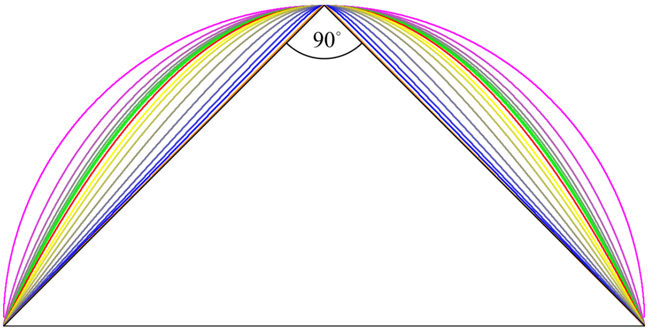
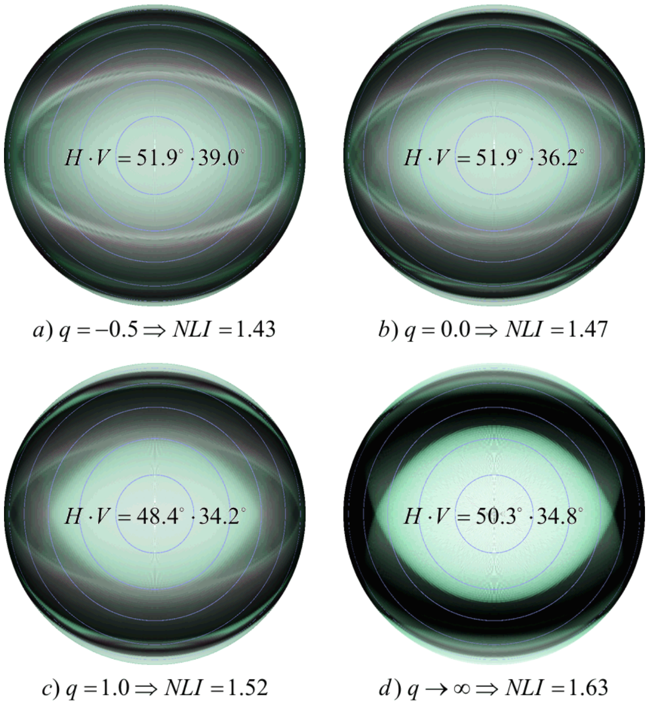


Fig. 2. Quadratic profiles having vertex angle $\beta = 90^\circ$: elliptical with $q = -2^{-0.5\cdot k}$, $k = 0, 1, ..., 6$ (from magenta to green), parabolic (red), and hyperbolic with $q = 2^n$, $n = -2, -1, 0, ..., 5$ (from yellow to blue) and $n = 7$ (orange)

The results of simulation performed using original software based on dendritic ray tracing algorithm are depicted on fig. 3, where we represented output SAD and its main characteristics: NLI and viewing angles (or, rather, Half-Width on Half-Maximum (HWHM) of SAD sections by horizontal and vertical planes).

We have to explain the origin of naming ray tracing as 'dendritic'. The point is that at the interaction with interface between two media one incident ray can be split on two rays – transmitted and reflected. (Intensity of each ray can be defined according to Fresnel equations). In order to perform simulation precisely, we have to take into account further propagation of both rays. Later, each of them can be split again by adjacent interface. Thus, rays form 'tree-like' or 'dendritic' structure.

Sure, number of elements in this structure can not be infinite, so we have to limit Admissible Number of Splittings (ANS). We used $ANS = 7$ to obtain prism sheet characteristics (3) and (4) and $ANS = 3$ in simulations presented on fig. 3. In both simulations we used the same limitation for Admissible Number of Interactions (including Total Internal Reflections (TIR)) – $ANI = 100$. Using these limitations ($ANI = 100$ and $ANS = 3$) we got the values of unaccounted remainder Rem lying in range $0.011...0.015$. This causes inaccuracy of our simulations on the level about $0.8\%...1.2\%$ according to expression (6). This correction was already taken into account on fig. 3.



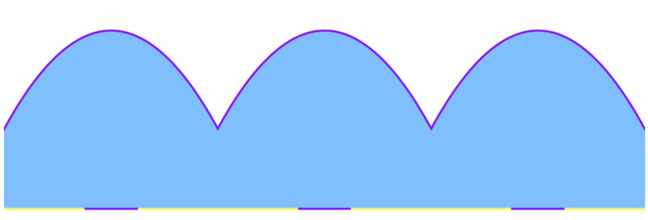
$a)\ q = -0.5 \Rightarrow NLI = 1.43$ $b)\ q = 0.0 \Rightarrow NLI = 1.47$

$c)\ q = 1.0 \Rightarrow NLI = 1.52$ $d)\ q \to \infty \Rightarrow NLI = 1.63$

Fig. 3. Output SAD for sheets with different profiles

4. Modified light-collecting optical sheets – comprising patterned reflective layer

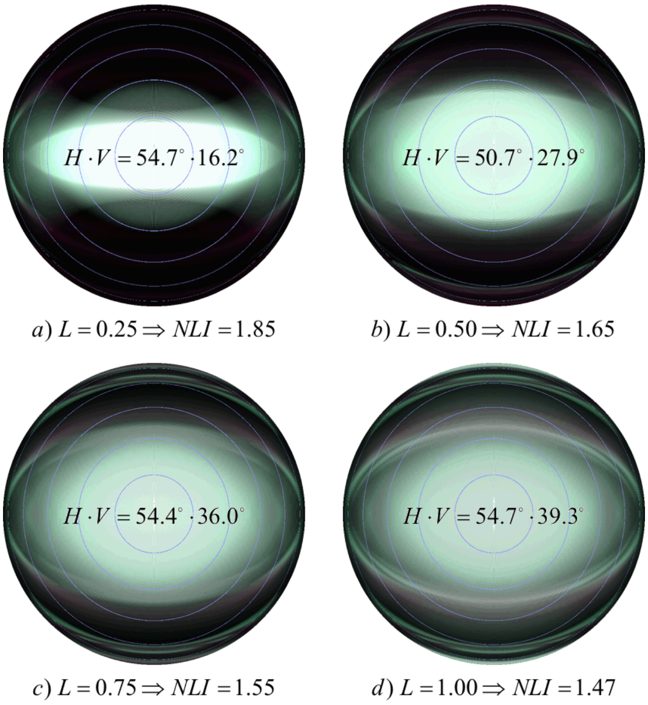
In this section let's explore how light-collecting properties of considered optical sheet can be improved by patterned reflecting layer coated on its bottom surface. If top surface of the sheet is array of cylindrical surfaces (1D case) then the pattern of reflective coating has to be just the array of identical equidistant stripes (fig. 4).



$\beta = 95^\circ, q = 0;\ z_0 = 0.375;\ L = 0.25$

Fig. 4. Cross-section of the modified sheet

We'd like to know first of all the influence of aperture size (width) L on light-collecting properties of the sheet. Simulation gave us the answer as depicted on fig. 5. At that we considered that reflective layer material reflects specularly 95% of light energy, and absorbs remaining 5%.



$a)\ L = 0.25 \Rightarrow NLI = 1.85$ $b)\ L = 0.50 \Rightarrow NLI = 1.65$

$c)\ L = 0.75 \Rightarrow NLI = 1.55$ $d)\ L = 1.00 \Rightarrow NLI = 1.47$

Fig. 5. Output SAD for sheets with different size of aperture in reflective layer

Let's consider now different case (2D) – when top surface of the sheet is array of spherical surfaces united with plane (fig. 6). In this case we will consider diameter of the circle formed by intersection of unit sphere with base plane to be equivalent of the pitch and equal 1.

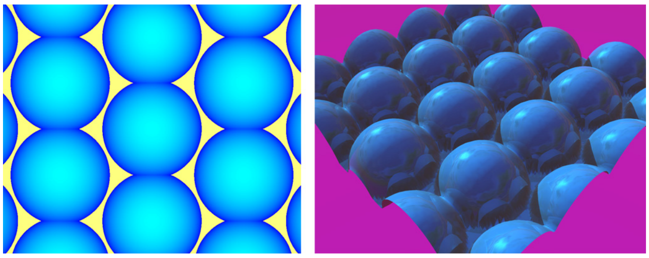
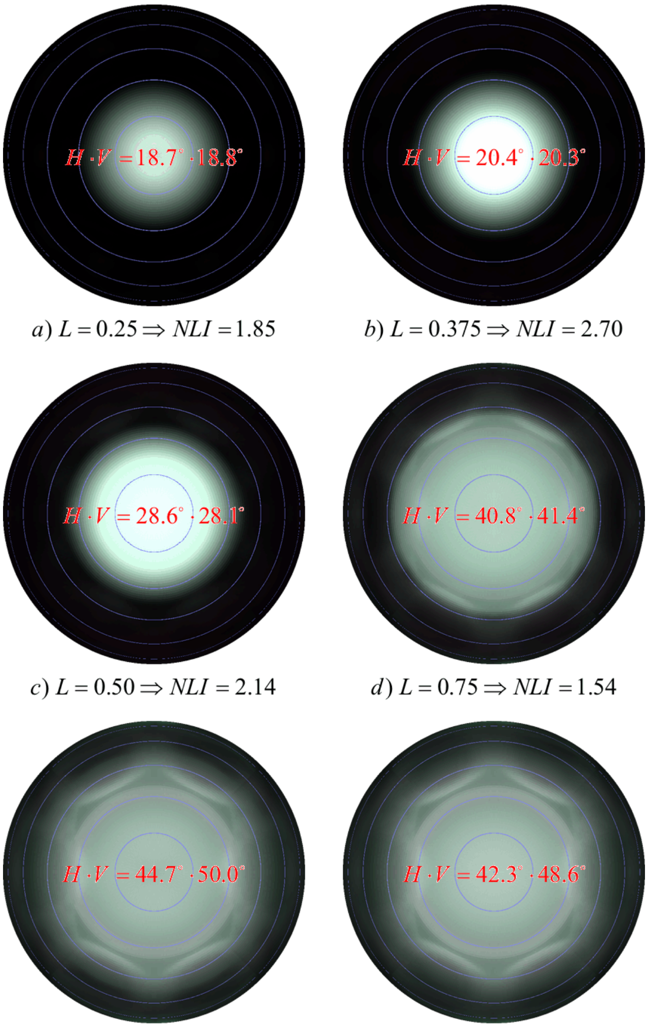


Fig. 6. Top and Perspective views on array of spherical microlenses with $\beta = 95^\circ$; $p_x = p_y = 0.925$

In 2D case reflective coating should have identical circular openings, which centers coincide with lenses centers. Again we'd like to investigate the influence of aperture size (diameter) L on light-collecting properties of modified sheet. The results are presented on fig. 7 (value 1.156 of aperture size is minimum value corresponding to total absence of reflective layer). We can see that if we have to meet our rigid specific requirements for viewing angles ($H \cdot V \geq 40^\circ \cdot 36^\circ$) then both in 1D and 2D cases we can get just moderate values of NLI. Indeed, by means of reflective layer we can improve NLI just from 1.47..1.48 to 1.54..1.55, i.e. just on ~5%. At that sheet with prismatic profile provides ~5% higher NLI (1.63) and almost meets the requirements for viewing angles.



$a)\ L = 0.25 \Rightarrow NLI = 1.85$ $b)\ L = 0.375 \Rightarrow NLI = 2.70$

$c)\ L = 0.50 \Rightarrow NLI = 2.14$ $d)\ L = 0.75 \Rightarrow NLI = 1.54$

$e)\ L = 1.00 \Rightarrow NLI = 1.35$ $f)\ L = 1.156 \Rightarrow NLI = 1.48$

Fig. 7. Output SAD for sheets (2D case) with different size of aperture in reflective layer

So, this specific application is not the one where optical sheet with patterned reflective layer can come in handy, especially if we'll remind that manufacture of patterned reflective layer costs a lot. Indeed, it's hard to produce thin high-reflective coatings; it's also hard to print apertures precisely, i.e. to provide their coincidence with the microlenses at the top of the sheet. However, if requirements for viewing angles are not so strict then considered modification can be of use. Indeed, one can get NLI values up to 1.85 (for 1D case) and 2.70 (for 2D case), what is certainly higher than possible by means of ordinary prismatic sheet. Such a modified sheet (2D case) can successfully substitute two crossed prismatic sheets, assuring higher NL gain (2.70 as against 2.20…2.30).

5. Summary

Applications that accept narrow viewing angles are the range of use naturally peculiar to sheets based on microlenses array and patterned reflective layer. Exactly for these applications modified sheets can provide high gain in Normal Luminance (up to 2.70) and show some additional advantages.

They can provide good stray light control, what means that they transmit almost no light in tangential directions in contrast to the prismatic sheets, which transmit ~5% of incident light (or ~12% of total transmitted light) into side lobes [5].

They also offer precise control over the viewing angles. One can provide almost any desired SAD for light emitted by BLU.

High performance and design flexibility of concerned brightness enhancement optical sheets comprising reflecting layer makes them quite attractive for applications in relevant sector of LCD backlights technology.

6. References

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