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Analysis and Improvement of Spectrum Defects in Prism Film by Optical Simulation

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Spectrum defects such as hot band and rainbow spectra on back light unit (BLU) composed of prism film and diffusing film have been examined by optical analysis. Hot band and rainbow phenomenon could be resulted from rapid luminance decrease and fluctuation in spectra at viewing angles in the range of 30–40° and 50–70°, respectively. By optical simulation with modification in prismatic structure, it is suggested that spectrum defects could be diminished or eliminated in both calculated simulation and practical prism pattern when the plane structure of prism is changed from straight to slow curved.

Keywords Hot band; optical simulation; prismatic structure; rainbow; spectrum defects

1. Introduction

Generally, back light unit (BLU) in liquid crystal display (LCD) is classified into a edge type and a direct type according to light sources. Direct type is commonly used in order to get more uniformity and higher luminance of light. Direct type BLU is composed of optical materials such as a reflecting film, a light diffusing plate, a light diffusing film, a bright enhancement film (BEF) and a protective film. The BEF, also called ''prism film'' has an important role in collecting the diffused light through diffusing plate and sheet and enhancing the LCD panel's luminance. Up to date, lots of researches have been studied improvement on BLU performance to achieve higher luminance, better luminance uniformity and wider viewing angle [1–6]. But these studies were focused on the effects of refractive indices, pitch length or peak angle of prism film. In light of a performance upgrade and a cost down, many attentions and attempts to remove a protective film have been attracted and tried continuously in BLU industries. However in this case, various kinds of spectrum defects have been

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encountered resulting in different luminance behavior and disturbance of the luminance uniformity. It has been suggested spectrum defects should be controlled in BLU system composed of prism film and diffusing sheet and such spectrum defects could be anticipated and controlled by the design of optical films or configuration through optical simulation and analysis. Wilson *et al.* [7] have investigated that the micro lens array provided the ability to hide defects and resistance to moiré. Olczak *et al.* [8] have also reported that the randomization of the micro pyramid array was necessary to reduce moiré patterns derived from interference caused by periodicity of micro-pyramids. However, there have been hardly reports on the hot band and rainbow phenomena of prism film. Hot band and rainbow phenomena were reduced by using the additional diffusing film such as protective film, but this system resulted in high thickness of BLU and high cost.

Therefore, in order to improve the spectrum defects of prism film without additional protecting film system, the correlation of prism structures and spectrum defects had been investigated and the most suitable prism film was prepared based on optical analysis and simulation in this study.

2. Experimental

Investigation of Hot Band and Rainbow Phenomenon

Diffusing film (DF), protective film (PF) and two kinds of prism films such as lenticular type (Lenti) and normal type (LC107) were supplied from KOLON Co. To investigate the spectrum defects, prism film was installed after equipping a diffusing sheet on 22 inches of wide BLU device. Luminance was measured at the range of viewing angle from -80° to $+80^\circ$ by BM 7 (Topcon Co.). Rainbow and hot band phenomenon were observed in the range of specific angles and photographed by digital camera.

Theoretical Interpretation of Hot Band and Rainbow Phenomenon

Basically when white light passes on a prism, refraction and reflection of light occurs according to Snell's law [9] which means various wavelength spectra happen due to the difference in refractive index of each wavelength of light. Hot band is a phenomenon appeared in a wide yellowish band of BLU bottom area in which luminance is not uniform. Rainbow means phenomenon of fluctuation area in which dark and bright part happens repeatedly. Figure 1 shows a general photograph of hot band and rainbow phenomenon in prism film with peak angle 90°, pitch 50 um and height 25 um on 22 inches of wide BLU device composed of lamp, light guiding plate and diffusing film.

Simulation for Optimum Prismatic Structure

At first, luminance data of diffusing film (DF) was observed at first in the range of viewing angle from -80 to $+80^\circ$, followed by inputting the data into the simulation program called "Light Tools" (Optical Research Association Co.) and angular distribution of light source was confirmed as base. After the parameters of normal prism structure such as peak angle (90 deg), pitch (50 um), peak height (25 um), and refractive index ($n = 1.60$) were input into the program, the simulation data were

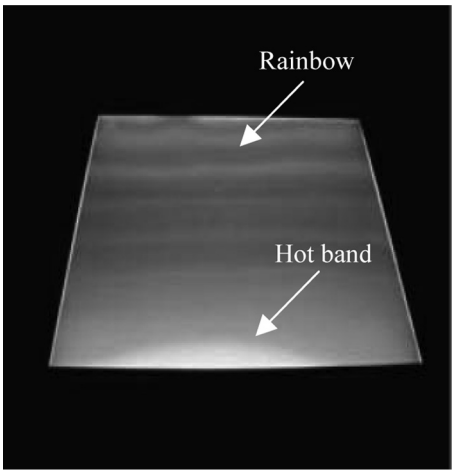

Figure 1. Spectrum defects of hot band and rainbow.

compared with the real data of prism film. Thereafter the simulation with objective parameters proceeded on the light source.

3. Results and Discussion

In combination of prism and diffusing film, various optical phenomena have been occurred by different prism structures [7,8,10,11]. The photographs of hot band and rainbow phenomenon in the range of viewing angles from -80° to $+80^\circ$ are shown in Figure 2. Hot band and rainbow phenomenon happened simultaneously when a prism film was located on a diffusing film. While normal prism film (LC107) showed a strong rainbow phenomenon, Lenti film showed no defect in photograph. In order to diminish the hot band, an additional protective film might be necessary by diffusing the light through a prism film resulted in smoothing down the viewing angle profile. Also lenti film might be necessary to reduce the spectrum defects. But it was found that the luminance of both cases decreased to 10% and 20% compared to prism film, respectively. From these results, it was assumed that spectrum defects such as hot band and rainbow phenomenon could be happened by penetration of light in the different surfaces and it might be caused by the delicate difference of prismatic structures. Figure 3 shows the normalized luminance

Figure 2. Photographs of prism combinations on BLU of (a) DF + LC107, (b) DF + LC107 + PF, and (c) DF + Lenti film.

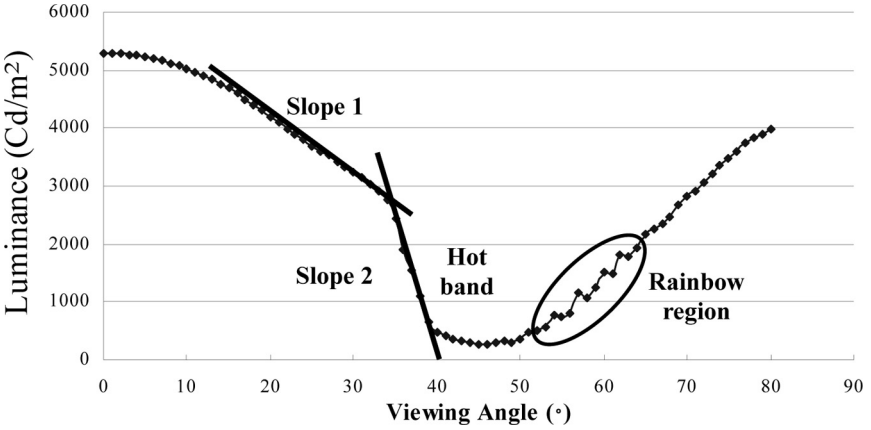

Figure 3. The expression of hot band and rainbow phenomenon in a luminance-viewing angle graph.

behavior of normal prism mentioned in Figure 1 in viewing angle range of 0° to 80°. The hot band and rainbow phenomenon could be assigned to the corresponding spectrum at viewing angle from 30° to 40° and 50° to 70°, respectively. If "slope 1" and "slope 2" were defined as slopes of slow decrease and rapid decrease region of luminance respectively, it is explained that hot band in other words "yellow band" started to be seen from the intersection position of "slope 1" and "slope 2". From this, we were able to know that the yellow band strength became much stronger as the slope 2 increased. Rainbow phenomenon is also assigned to the fluctuation spectrum in the range of viewing angle above 50°. As shown in Table 1, when slope 2 values of the prism systems in Figure 2 were calculated, normal prism film (LC107) showed the highest value of 0.071 and lenticular film (Lenti) showed the lowest value of 0.035. It is expected that the value of slope 2 lower than 0.050 should be needed to decrease the hot band.

In order to investigate the effect of prismatic structures on luminance and spectrum defects, computer simulations such as changes of prism angle and plane shape were carried out. As shown in Figure 4, all slope 2 values showed over 0.083 and rainbow region still existed not only to obtuse angle but also to acute angle of prism peak. Furthermore luminance became decreased in both cases.

For the purpose of changing the prism plane in this study, the quadratic equation defined by Borysov *et al.* [12] had been introduced. They have specified a prismatic profile as cross-section of unit cylinder with vertical angle (β) as follows.

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

Table 1. Slope 2 values of BLU composed of diffusing film (DF), prism film (LC107), protective film (PF) and lenticular film (Lenti)

	DF + LC107	DF + LC107 + PF	DF + Lenti
Slope 2	0.071	0.050	0.035
Rank of hot band strength	1	2	3

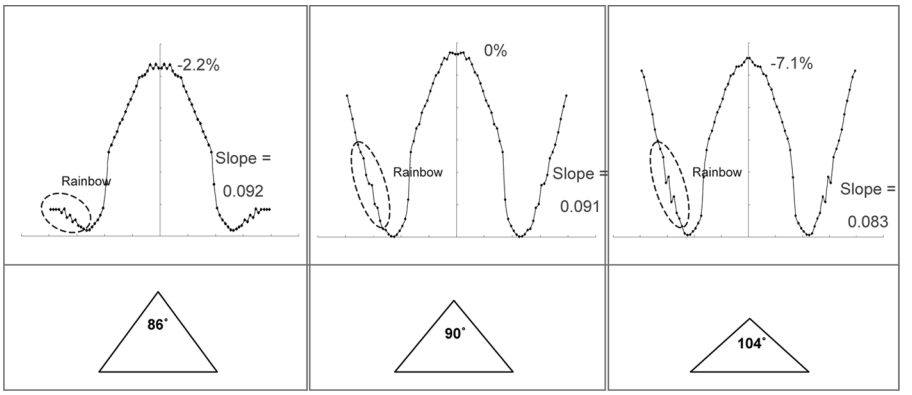

Figure 4. Luminance profiles versus viewing angle with the peak angle of prism (X = Luminance (Cd/m^2), Y = Viewing angle (Degree)).

Where

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

Various quadratic profiles could be depicted with the parameter of "q" in this equation. In right angle ($\beta = 90$), as "q" value decreases, the radius of curvature become smaller, which means prism plane becomes hyperbolic.

Figure 5 shows the simulation results on pattern shapes and their luminance graph with viewing angles when the "q" values were applied. At high "q" values (q = 16, 8) the slope 2 values were −0.055, −0.051 respectively, but the luminance

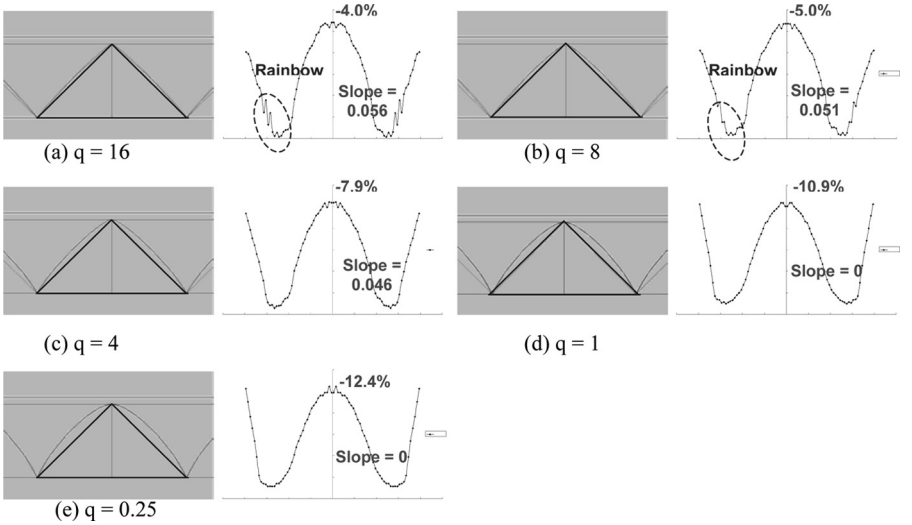

Figure 5. The pattern drawings and luminance profiles by optical simulation of prism structure with various q values (X = Luminance (Cd/m^2), Y = Viewing angle (Degree)).

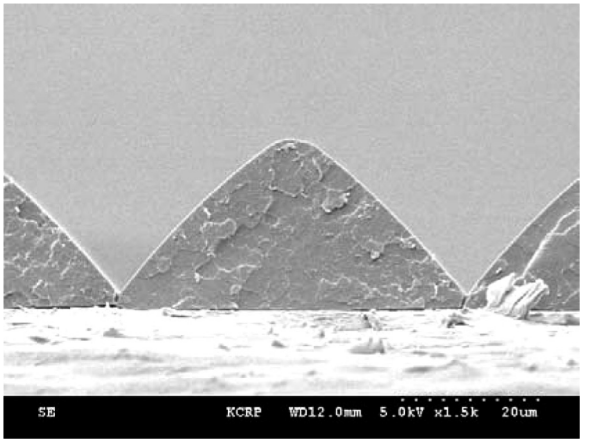

Figure 6. SEM image of prepared prism pattern with curvature.

fluctuation corresponding to rainbow phenomenon was found. At low "q" values ($q = 1, 0.25$), even though all the slope 2 values were zero and no fluctuation existed, luminance decreases over 10% were forecasted. From simulated modification of prism structure, it is concluded that peak angle of prism is not a critical factor of spectrum defects but the curvature of prism plane has an important role for eliminating hot band and rainbow phenomenon.

According to the simulation results, real prism pattern was prepared by imprinting and UV curing of varnish through the engraved pattern roll with the parameters of peak angle (90°), curved plane ($q = 4$), pitch (50 um) and peak height (25 um). Figure 6 shows SEM image of prepared prism pattern with slowly curved plane ($q = 4$). Figure 7 shows the luminance results of modified prism pattern in Figure 6 and normal prism pattern in Figure 1. It was found that the modified prism showed no hot band and no rainbow spectrum compared to a normal prism and the simulation result corresponded to that of practical prism consequently.

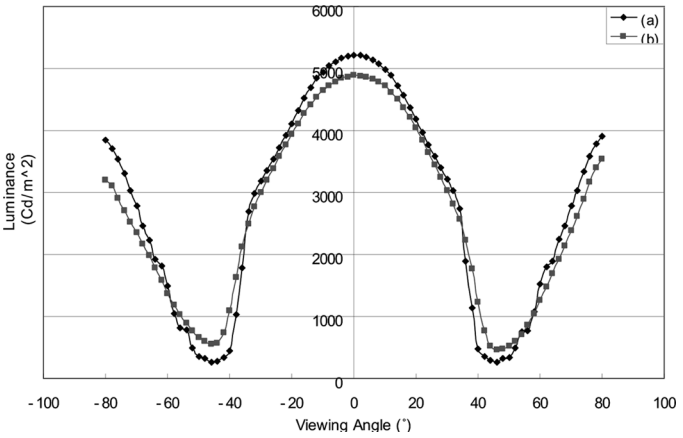

Figure 7. The luminance behaviors of (a) normal prism with straight plane and (b) prepared prism with curved plane ($q = 4$).

4. Conclusion

The spectrum defects such as hot band and rainbow phenomenon could be assigned through luminance-viewing angle graph in optical analysis. Hot band and rainbow spectrum were occurred at the viewing angle of 30–40°, 50–70° respectively. According to optical analysis and simulation results, it is concluded that spectrum defects always happened in all of prism structures with straight plane regardless of peak angle but could be eliminated or diminished introducing the curved plane in prism structure. Finally, preparation of practical prism film was possible with a significant decrease or elimination of hot band and rainbow phenomenon according to optical simulation approaches and controls.

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