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Study on the Simulation Model for the Optimization of Optical Structures of Edge-lit Backlight for LCD Applications

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The optical performances of 15-inch edge-lit backlight were simulated by using a Monte Carlo ray-tracing technique. The backlight model was built by combining a wedge-type light guide plate, a diffuser sheet, a tubular fluorescent lamp with a lamp reflector, and two crossed prism sheets. Angular distributions of the luminance on each optical component obtained from simulation were consistent with those obtained from experiments on a real 15-inch backlight. The constructed backlight model was used to evaluate the optical performances of a micro-pyramid film. It was found that the on-axis luminance gain on the pyramid film is higher than that on one prism film but much lower than that on the two crossed prism films. These results suggest that a reliable simulation model can be used to develop new hybrid films and to optimize the optical structure of edge-lit backlight in order to reduce the developmental period.

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I. INTRODUCTION

Recent FPD (Flat Panel Display) technology has been led by LCD (Liquid Crystal Display), a representative non-emissive display among various FPDs. LCD thus needs an independent light source called BLU (Backlight Unit) which supplies LCD with homogeneous, bright, visible light, mostly white light. BLU consists of many components such as light sources, optical films, mold frames, etc. [1-2] Light sources generate visible light having an appropriate spectrum, while optical films transform the generated light into a two-dimensional, homogeneous, collimated flat light source. Since LCD controls the transmission and spectrum of the visible light supplied by BLU, the picture quality of LCD is substantially affected by the electro-optic properties of BLU. It is thus of paramount importance to revolutionize the BLU technology for improving the competitiveness of LCD from the point of view of performance as well as cost.

One of the most important factors in the improvement of BLU technology is to develop new optical films in order to integrate several optical functions into a smaller number of films and thus to reduce the number of optical films required in one BLU. Recently, extensive efforts have been made for the development of new collimating films for better optical performances and/or hybrid films incorporating both the diffusing function and the collimating function [3-5]. However, it normally takes a long time of the order of at least a few months to design, fabricate, measure, feedback the experimental results, redesign and finalize the development of new optical films for backlight applications. It is thus highly necessary to speed up the development of new hybrid films by adopting some indirect methods. Optical simulation can be a powerful tool for this purpose, because it can be used to predict the optical performances of new films without the need of fabrication of prototype samples. Optical simulation using the ray tracing technique has thus been widely used to check the optical performances of new-concept optical films and shorten the developmental time [6-7]. However, optical performances of a certain film may vary depending on the specific conditions under which the simulation has been carried out [8]. Therefore, it is highly necessary develop a simple, general BLU model into which new optical films can be integrated and tested. The simple BLU may not reflect all the minute structural details of real BLUs used for LCD but should include their essential optical characteristics. The present study is devoted to the development of a simple edge-lit BLU model which can reproduce, at least, important viewing-angle characteristics as well as relative luminance gains on each optical film included in it. In order to confirm the reliability of the simple BLU model, a micro-pyramid film was inserted and simulated. It was found that the luminance gain obtained from micro-pyramid film in the edge-lit BLU is comparable to that of one prism film in spite of its higher luminance gain as a single film put over a Lambertian light source [6].

II. EXPERIMENT

A typical edge-lit BLU consists a light source, a lamp reflector, a light guide plate (LGP), a diffuser film (or a lens film), collimating films such as a prism film, and a protection film. In order to construct a reliable BLU model for optical simulation, it is necessary to compare simulation results with the optical properties of real BLUs. For this purpose, a 15-inch wedge-type edge-lit BLU (model 154w01-TCD1, LG) was investigated. Viewing-angle characteristics on the LGP, a lens film (UTE25, MNTech), and two crossed prism films (SOF-M02, Sangbo Co.) were investigated by using a luminance colorimeter (BM-7, Topcon). The luminance on each component was measured as a function of the viewing angle along the parallel and perpendicular direction with respect to the tubular axis of the fluorescent lamp. Before the measurement, the BLU was aged enough in order to prevent any change in luminous efficacy caused by temperature effect.

III. MODEL CONSTRUCTION

Figure 1 (a) is a schematic edge-lit BLU constructed for the evaluation of performances of new optical films. This BLU model is composed of a tubular lamp, a lamp reflector, a wedge-type LGP, a reflection film, a lens film, and two crossed prism films. The wedge-type LGP having a thickness of 0.5 mm and an area of 9×6 mm^2 was used for guiding the light incident from the light source. The tilt angle of the lower surface of the LGP was 2° with respect to the horizontal plane, and the refractive index of the LPG was set to be 1.49. One tubular lamp with a diameter of 3 μm and a length of 6 mm was put beside the LGP, which was combined by an elliptic lamp reflector as shown in Fig. 1 (b). The emitting distribution from the lamp was Lambertian, and the wavelength of the emitted light was 550 nm. The lens film, which was put on the LGP and played the role of a typical diffuser film, consisted of hemispherical lenses of a diameter of 30 μm arrayed in a two-dimensional square lattice on a PET (polyethylen terephthalate) substrate having a thickness of 125 μm. The lattice constant was the same as the diameter of the lenses. The refractive indices were set to be 1.572 and 1.59 for the substrate and the microlenses, respectively. The prism films were formed on the same PET substrate with an apex angle of 90° and a pitch of 50 μm. The refractive indices were set to be 1.572 and 1.59 for the substrate and the micro-prisms, respectively. Two prism films were crossed on the lens film as shown in Fig. 1. Finally, the reflection film was put under the LGP in order to recycle the light directed downwards from the LGP. The reflecting property of this film did not have any substantial effect on the viewing-angle characteristics of the BLU and thus a mirror reflector with a reflectivity of 100% was used.

One of the most important properties which BLU should maintain is the uniformity of the emitted light on BLU. The distribution of the emitted light from LGP is controlled by the distribution of the reflecting/scattering dots printed on the lower surface of the LGP. These reflecting structures break the condition of the total internal reflection for the guided light in the LGP and extract it toward the LCD panel. The areal density of scattering dots normally increases with increasing distance from the light source resulting in enhancing extraction efficiency, which should be compromised with the decreasing light power available for the scattering events on the dots. The reflecting property of the scattering dot was modeled by the bi-directional reflection distribution function (BRDF) of typical white PET films of E60L (Toray). The BRDF of this reflection film was

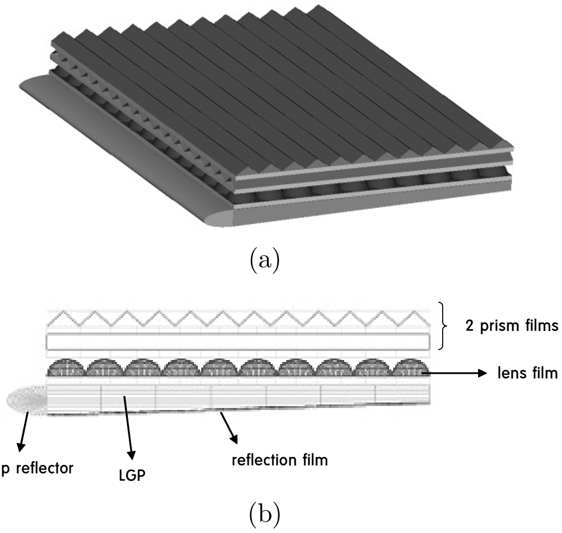


FIG. 1. (a) A schematic figure of a simple edge-lit BLU constructed in the present study (b) A cross-section of the BLU shown in (a).

measured and modeled by the Harvey scattering model, which was incorporated into the software used in the present study. In the present study, the diameter of dots located at the farthest side of LGP from the light source was fixed to be 0.1 mm, while the diameters of the rest were adjusted to decrease linearly as a function of the distance from the light source. This procedure was repeated until the illuminance uniformity on the LGP was optimized. Figure 2 shows several examples for different diameter ratios of m:n. In this case, m and n indicate the diameters of dots located at the nearest and farthest sites on the LGP with respect to the lamp, respectively. Allowable uniformity was obtained at the condition of m:n = 2:3 and used for the simulation. The three side surfaces of LGP except one toward the lamp were mirror coated for preventing light losses.

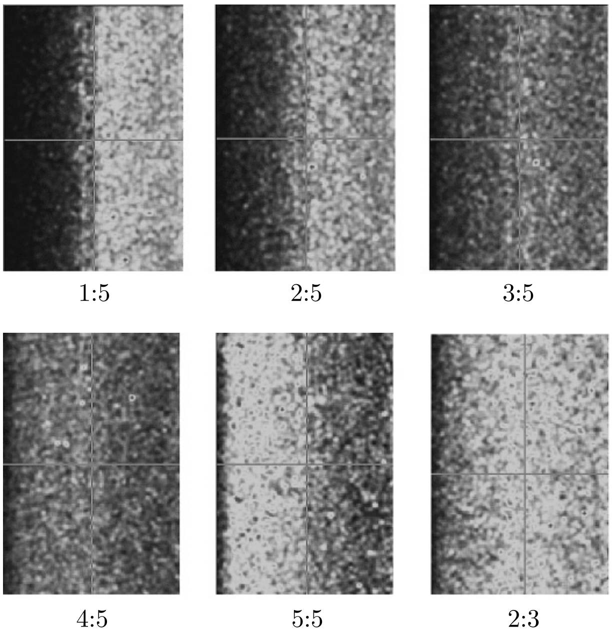
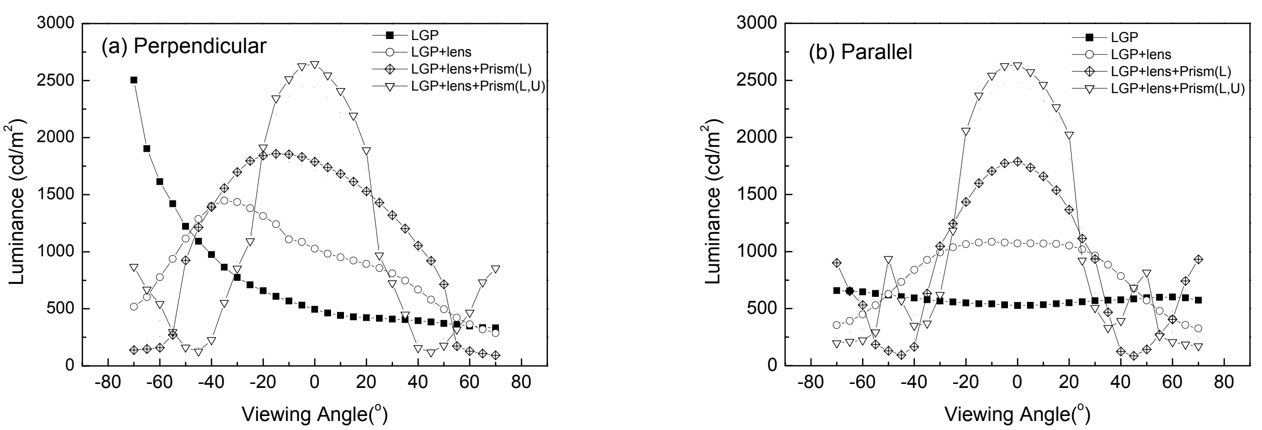

1:5 2:5 3:5
4:5 5:5 2:3

FIG. 2. The uniformity of the illuminance on the LGP of the edge-lit BLU at several ratios of m:n which denote the diameters of dots located at the nearest and farthest sites on the LGP with respect to the lamp, respectively.

Ray tracing technique using the ASAP software (Advanced Systems Analysis Program, Breault Research Org., 2006 V2R1) was adopted for the simulation of the edge-lit BLU [9]. Normally, more than 10 million rays were used to simulate the BLU at one condition. The illuminance distribution as well as the viewing-angle characteristics on each film were investigated by using a virtual detector put over the corresponding optical component.

IV. RESULTS AND DISCUSSION

Figure 3 (a) and (b) display the angular dependence of the luminance along the perpendicular and parallel directions with respect to the lamp axis, respectively, obtained from the experiment described in section II. The luminance distribution on LGP is almost Lambertian along the direction parallel to the tubular light source, while along the other direction the rays tend to be emitted toward opposite directions of higher viewing angles with respect to the lamp side. This is due to the specular nature of the reflection of scattering dots printed on the lower surface of LGP. The inclined rays are gradually directed toward the normal direction via successive refraction on the lens film and the two crossed prism films. This process is also the one via which the rays are collimated toward the LCD, resulting in a much narrower angular distribution of the luminance on the upper prism film as can be seen

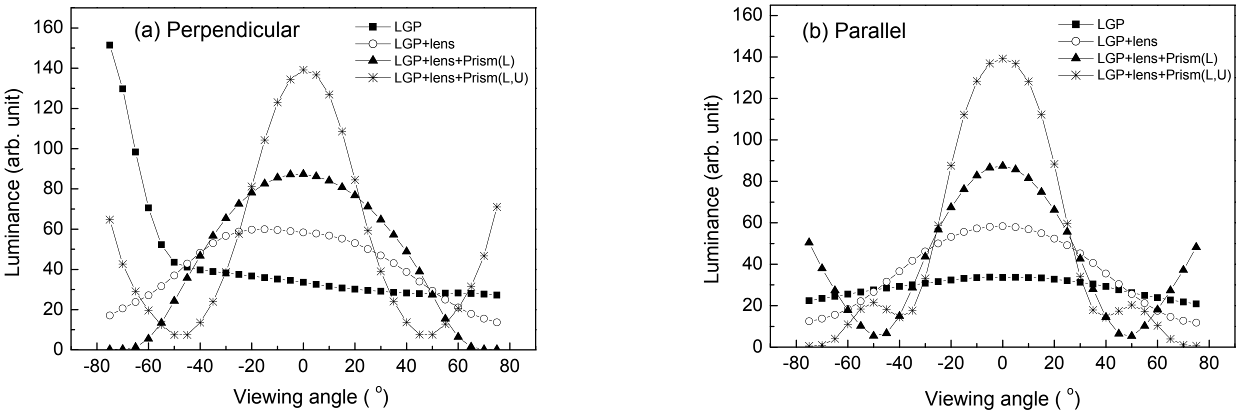


(a) (b)

FIG. 3. The angular distribution of the luminance along the (a) perpendicular and (b) the parallel directions with respect to the lamp axis, respectively, obtained from the experiment. ("lens", "Prism(L)", and "Prism (U)" indicate the lens film, the lower prism film, and the upper prism film, respectively.)

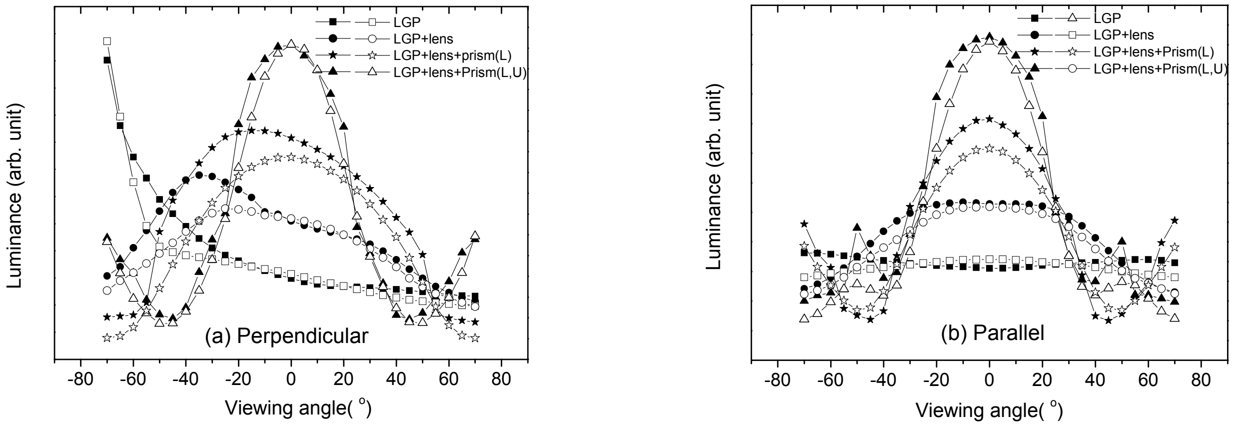
from Fig. 3. This condition is suitable for one-person-use display such as Note-PC or mobile phone.

Figure 4 (a) and (b) show the angular dependence of the luminance along the perpendicular and parallel directions with respect to the lamp axis, respectively, obtained from the simulation carried out on the BLU model described in Fig. 1. Overall viewing-angle characteristics are similar to the experimental results shown in Fig. 3, although slight differences in the angular distribution can also be noticed. In order to compare the two results in more detail, two data sets from the simulation and the experiment were plotted in the same graph as shown in Fig. 5 (a) and (b). The ordinate scales were adjusted in a way that the luminance values on the upper prism film along the normal direction (i. e., 0°) from the two data sets are the same. It is noticed that the angular distribution of the luminance on the LGP and the lens film from simulation shows departures in the angle between -60° and -10° from that obtained from experiment. Moreover, the distribution on the lower prism shows a relatively large difference between the experiment and the simulation. This inconsistency is not surprising because the output distribution on the LGP and succeeding distribution on each lens film are very sensitive to the detailed structure of the scattering dots in addition to their reflecting properties. The present simple model does not include the real dot pattern and its scattering property of the BLU used for the experiment because the present study is aimed at constructing a general, simple BLU model which can be useful in evaluating optical performances of new hybrid films. Although there are some differences



(a) (b)

FIG. 4. The angular distribution of the luminance along the (a) perpendicular and (b) the parallel directions with respect to the lamp axis, respectively, obtained from the simulation carried out on the BLU model in Fig. 1. ("lens", "Prism (L)", and "Prism (U)" indicate the lens film, the lower prism film, and the upper prism film, respectively.)



(a) (b)

FIG. 5. The comparison of angular distribution of the luminance between the simulation (open symbols) and the experiment (solid symbols) along the (a) perpendicular and (b) the parallel directions with respect to the lamp axis, respectively. ("lens", "Prism (L)", and "Prism (U)" indicate the lens film, the lower prism film, and the upper prism film, respectively.)

in the viewing angle and the location of the side lobes, the final distributions on the upper prism film of two results are very similar indicating that the present model reflects important, major optical processes occurring in the real BLU. It can thus be concluded that the simple BLU model constructed in the present study reflects major viewing-angle characteristics on each component of edge-lit BLU, which can thus be used to evaluate optical performances of new hybrid films before the real fabrication and measurement.

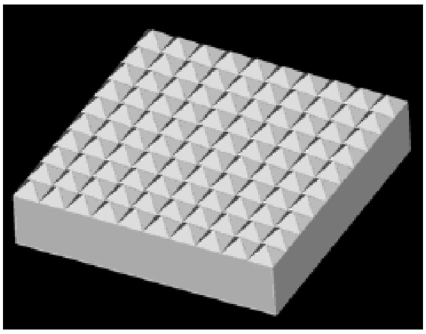
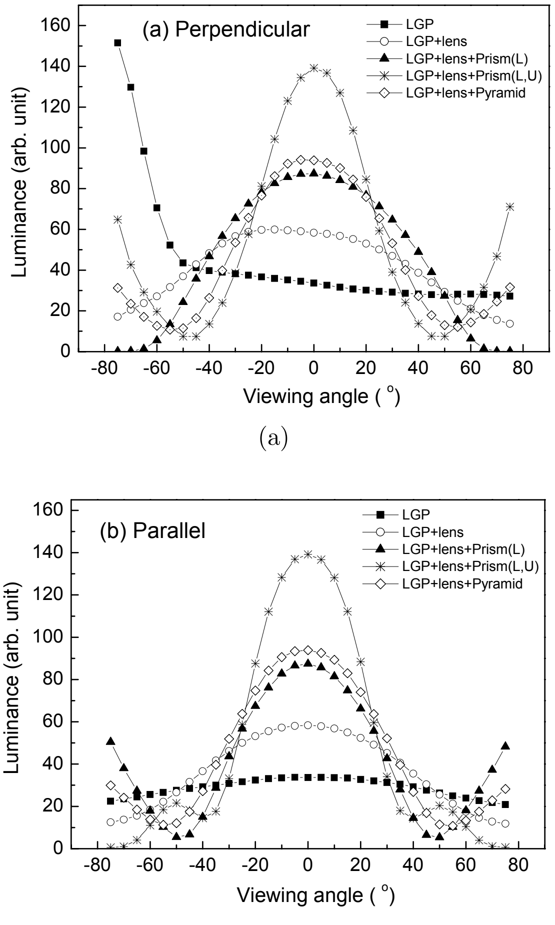


FIG. 6. A 3-dimensional figure of the micro-pyramid film used for the simulation.



(a)

(b)

FIG. 7. The angular distribution of the luminance along the (a) perpendicular and (b) the parallel directions with respect to the lamp axis, respectively, obtained from the simulation carried out on two kinds of BLU model. ("lens", "Prism (L)", "Prism (U)", and "Pyramid" indicate the lens film, the lower prism film, the upper prism film, and the pyramid film, respectively.)

From this point of view, it seems appropriate to simulate one collimating film of a new concept instead of the conventional prism film by using the present simple BLU model. The micro-pyramid film shown in Fig. 6 may be one candidate because it was reported from a simulation study [6] that the on-axis luminance gain on the pyramid film may become higher than that of the prism film in a specific condition. Micro-pyramids having a tetrahedral shape were made on the same PET substrate as was used for the lens film and the prism film. The apex angle and the refractive index of micro-pyramids were 90° and 1.59, respectively. The pitch was 60 μm, and thus the height of each micro-lens was 30 μm. The two crossed prism films in the model BLU were replaced by this pyramid film, and then the optical characteristics on it were investigated. The results obtained from this new BLU model are shown in Fig. 7. For comparison, angular distributions obtained from the previous model with crossed prism films are also plotted. It is clear from this comparison that the on-axis luminance on the pyramid film is higher than that on the lower prism film by about 7% but much lower than that on the two crossed prism films. Figure 8 displays the relative on-axis luminance gain on each film from experiment as well as simulation. These results clearly indicate that the pyramid film cannot replace the two crossed prism films used in the conventional BLU for small-size LCDs if the same performances should be achieved. Instead, pyramid-film-based edge-lit BLU may be applied to some LCDs where moderate brightness and viewing-angle characteristics are enough for the device performances.

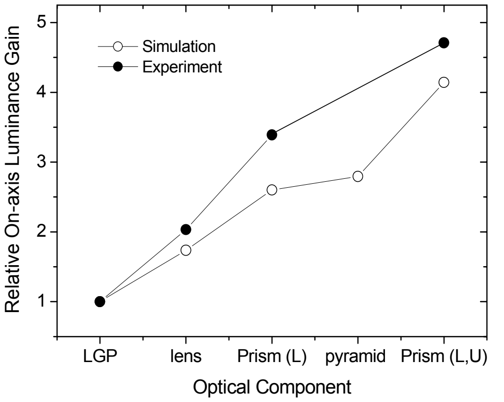


FIG. 8. Relative on-axis luminance gain on each film from experiment and simulation.

The micro-pyramid film has been believed to be one candidate for replacing two prism films because of its refracting/collimating properties along both parallel and perpendicular directions in contrast to the one-dimensional collimation function of the conventional prism film. However, present study revealed that this is not possible. For one-dimensional prism film, the rays which have not been collimated on the micro-prisms are normally reflected downwards via two total internal reflections at the inclined surfaces of the prisms and then diffusely reflected upwards resulting in further collimation. This kind of recycling process does not seem to be effective in the pyramid-film-based BLU because the rays which are not collimated on the micro-pyramids may have more chances to be emitted to directions at higher viewing angles rather than to be doubly reflected downwards for recycling owing to the quantized, discrete structure of micro-pyramids. It was recently found that the collimating power of a micro-cone-based collimating film is also much lower than that of two crossed prism films irrespective of the aspect ratio of micro-cones and thus cannot replace two crossed prism films in the edge-lit BLU [10]. All these results indicate that the recycling mechanism of reflected rays from the collimating film should be carefully considered and analyzed when the optical structure of new hybrid films should be optimized for achieving better performances and thus replacing conventional prism films.

V. CONCLUSION

A ray tracing technique has been used to develop a simple, general backlight model which can be used for the evaluation of optical performances of new hybrid films. The constructed model consisted of a tubular lamp combined by a lamp reflector, a wedge-type LGP, a reflection film, a hemispherical lens film, and two crossed prism films. The angular distribution of the luminance on each component from the simulation was consistent with the result obtained from measurement on a 15-inch wedge-type backlight. Therefore, the simple BLU model constructed in the present study reflects major viewing-angle characteristics on each component of edge-lit BLU, which can be used to evaluate optical performances of new hybrid films before the real fabrication and measurement. As one example, two crossed prism films were replaced by one micro-pyramid film in the BLU model and then simulated to obtain the optical performances. It was found that the on-axis luminance gain on the pyramid film was higher than that on one prism film but much lower than that on the two crossed prism films. The present study suggests (1) that a reliable simulation model can be used to develop new hybrid films and to optimize the optical structure of edge-lit backlight in order to reduce the developmental period, and (2) that the recycling mechanism of reflected rays from the film should be carefully considered and analyzed when the optical structure of new collimating films should be optimized for achieving better performances and thus replacing conventional prism films.

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