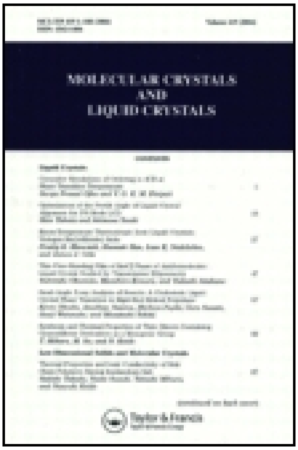

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Grating-Based Luminance-Enhancement Film for LCD Backlights

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LCD backlights have to meet two contradictory requirements: high luminance and uniform emission. Utilizing the characteristics of diffraction gratings, we have developed micro-patterned optical films which provide highly collimated emission and good uniformity at the same time. The design strategies, optical characteristics and high-precision patterning of the grating-based luminance-enhancement films will be presented.

Keywords: backlight; grating; liquid-crystal display; optical film

INTRODUCTION

Backlights (BL) for liquid-crystal displays (LCD) have to meet two contradictory requirements: high luminance and uniform emission. Figure 1(a) schematically depicts how a typical BL works. White light emitted from the light-emitting diode (LED) is spread within the light guide (LG), confined by total internal reflection (TIR). At certain point the light is emitted from the LG in a canted direction. Finally, the light is bend to the normal direction by the optical film. The principal roles of the optical films are: (1) to bend the light toward the normal

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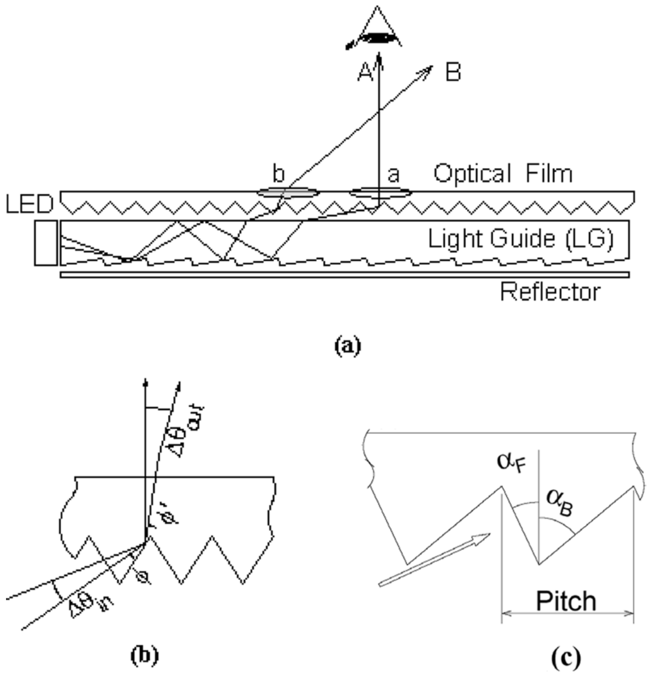

FIGURE 1 (a) A schematic drawing of a typical backlight. (b) The characteristic of currently used prism-array film. The prism-array bends the incident light by total-internal reflection at one prism surface. Since $\phi' = \phi$, the change in the incident- and emission angles ($\triangle\theta_{\mathrm{in}}$ and $\triangle\theta_{\mathrm{out}}$) are almost the same. (c) Definition of the geometry of a grating film. The white arrow roughly indicates the direction of the incident light.

direction of the BL, (2) to collimate the light to enhance the luminance, and (3) to improve the uniformity of the luminance.

The first successful optical films are ‘BEF’ (made by 3 M [1]), which have prism array on the upper side and are used in pairs. Although they show good uniformity, the requirement of pairwise usage prevents reducing the thickness of BL, and their luminance-enhancement ability is poor. To improve the latter, several attempts have been made [2–5]. Their key feature is to use a film with a prism array on the lower side (prism-array film, PAF) [2], in combination with highly directional LG which is, *e.g.*, equipped with micro-deflectors [3] or made of highly scattering optical transmission polymer [4,5]. This type of PAF simply bends the incident rays by TIR (Fig. 1(b)). As the result, the emission angle changes just the same amount as the incident angle. An actual LG emits light with emission angle slightly different from position to position, as shown in Figure 1(a). The rays that follow path A reach the eye, and thus the region-a looks bright. The region-b looks darker as the rays miss the eye. This emission-angle variation is one of the major causes that impair the uniformity. Currently, this type of non-uniformity is overcome by scattering the emitted light by diffuser films, spoiling the luminance.

Utilizing the characteristics of diffraction grating, we have developed micro-patterned optical films which provide highly collimated emission and good uniformity at the same time. In this article, we mainly describe the former subject.

EXPERIMENTAL

The geometry of a GF is defined by the parameters in Figure 1(c). The calculated emission angle (θ_{cal}) was calibrated by experimental values to give corrected angle (θ_{cor}): $\theta_{cor} = 0.956\,\theta_{cal}$-5.8. The GF's were replicated from mold plates patterned on NiP plating, using specially synthesized urethane-acrylate UV-resin [6]. The SEM images of the GF's were measured with an XL30 (Phillips). The incident-angle dependence of the emission angle of the optical films were measured using a BM-5 luminance meter (TOPCON) and NSCW335 as the light source. The emission characteristics of the BL were measured by a 3D-emission-distribution evaluator RISA COLOR/MC (Hiland Co. Ltd.). As the standard sample, a PAF with the edge angle of 63° and pitch $= 30\,\mu m$ was used.

RESULTS AND DISCUSSION

The simulation results are shown in Figure 2. Among the shape-defining parameters, α_B has large influence on the emission angle (Fig. 2(a)). The emission angle changes about 2.7° when α_B changes 1°, while the peak intensity stays almost constant. On the contrary, α_F and the pitch has similar effect on the optical properties (Figs. 2(b), (c)), namely, the emission-peak intensity increases as the parameters decrease, while the emission angle is hardly affected. Summarizing the results, the emission angle can be controlled by α_B without affecting the intensity. The peak intensity can be maximized by reducing α_F and the pitch. In reality, the fabrication of the mold and the replication are more difficult for smaller α_F, therefore, the peak intensity is preferably enhanced by reducing the pitch while α_F is remained at a relatively large value. Since the color-separation effect of the GF becomes prominent as the pitch is decreased, the pitch should not be less than $4\,\mu m$, above which we have confirmed that the separation is comparable to the PAF.

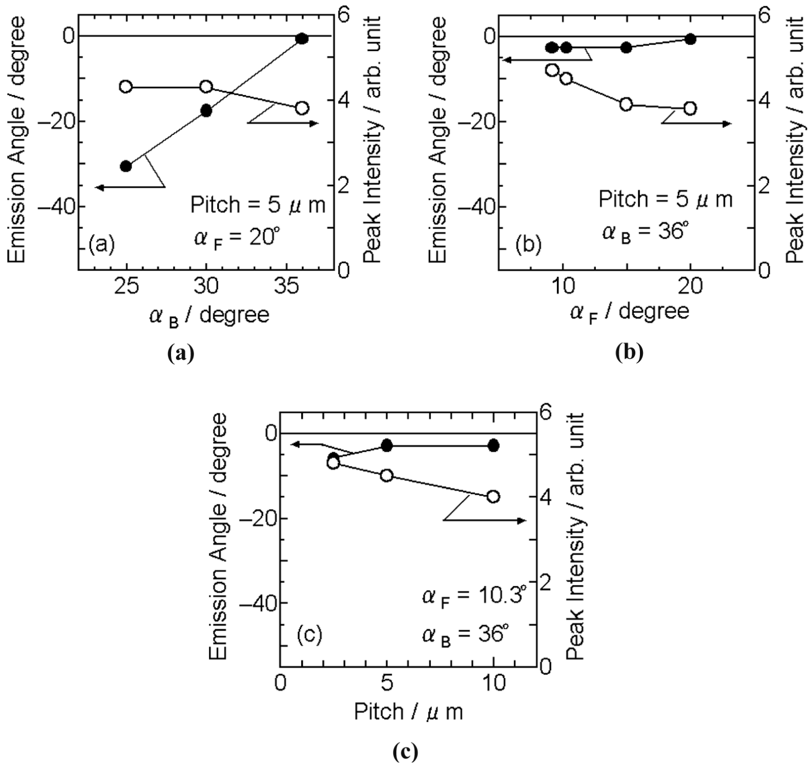

FIGURE 2 Simulation results for grating films. The definitions of α_B, α_F and the pitch are given in Figure 1(c). Figures (a)–(c) respectively represent the α_B-, α_F- and pitch dependencies of the peak intensity and the emission angle. The emission angles are corrected by the equation in the text.

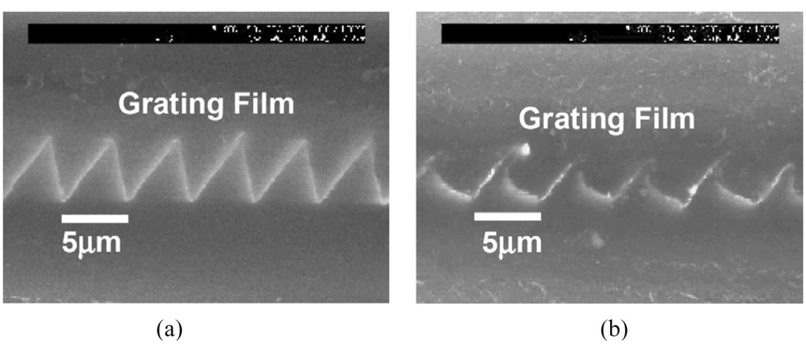

FIGURE 3 The SEM images of the cross-section of the grating films. (a) Saw-tooth shape. (b) Wave shape.

Figure 3(a) shows the cross-section of a GF with total edge angle of 49°. The contraction of the resin upon solidification is ca. 5%. Figure 3(b) shows a replica of a deformed mold. Due to the high-precision

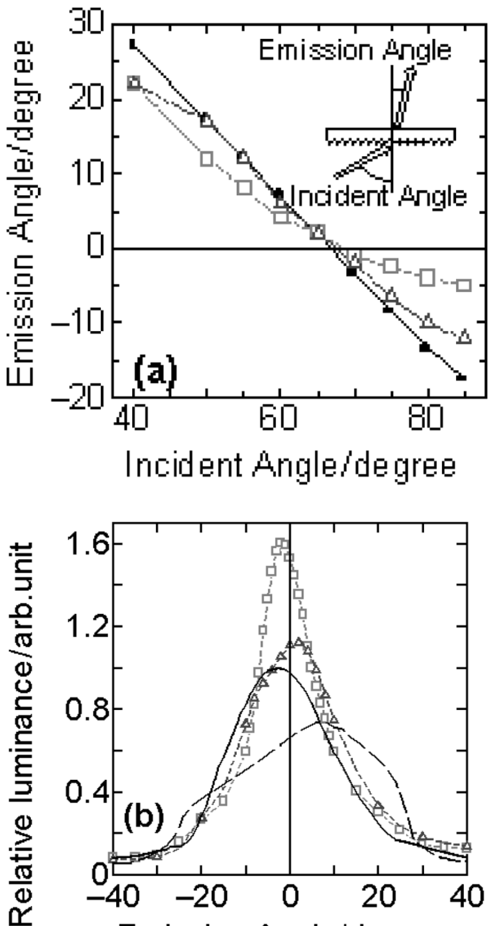

FIGURE 4 Comparison of optical properties of the optical films. The triangles and squares represent the data for the grating films with pitch of 8 and 4 μm, respectively. The edge angles of the grating films are $\alpha_F = 16.5$ and $\alpha_B = 34.6°$. The solid and dashed lines represent the data for the prism-array film and BEF, respectively. (a) Incident-angle dependence of the emission angle. The incident light is a collimated one emitted from a white light-emitting diode. (b) Angular distribution of the emission from backlight units equipped with various optical films.

replication ability of the UV-resin, even the undercut part of the wave-like shape can successfully be replicated.

When irradiated by collimated light, the emission angle of the PAF changes precisely the same amount as the incident angle (Fig. 4(a)), due to the mechanism shown in Figure 1(b). This incident-emission relationship is, as previously mentioned, one of the major causes of uniformity impairment.

In contrast to the PAF, the 8 μm-pitch GF shows smaller change in the emission angle than that in the incident angle, especially for incident angle between 70 to 85°. As the pitch is reduced, the incident-angle range of emission-angle anomaly becomes large. For the 4 μm-pitch GF, the anomalous incident-angle region is 50–85°. In this region, the total change of the emission angle (15°) is less than half of that of the incident angle (35°). This result clearly demonstrates that the GF's have strong collimation ability absent in the PAF's. The tolerance to the incident-angle change gives the GF's such versatility that it can be incorporated in various kinds of BL without changing the design. The collimation effect also improves the uniformity by reducing the emission-angle variation as shown in Figure 1(a).

Figure 4(b) is the angular distribution of the BL emission intensity. The 8 μm-pitch GF shows slightly higher peak luminance than the PAF, and *ca*. 50% higher than the BEF. As expected from the simulation results, the peak intensity increases as the pitch is decreased. When the pitch is 4 μm, the GF shows the peak luminance *ca*. 60% higher than that of the PAF. While the integrated emission intensities are nearly the same for each optical films, the full-width at half-maximum are 45.1 for the BEF, 28.9 for the PAF, 26.5 and 15.5° for the GF's with 8 and 4 μm pitch, respectively. Therefore, the enhancement of the peak luminance is due to the collimation effect intrinsic to the grating films.

CONCLUSION

We have established the design strategy for grating-based optical films that provides high-luminance backlight. We also have developed an urethane-acrylate UV-resin that can replicate complicated micro-structure to fabricate grating films. The grating films thus designed and manufactured show prominent collimating ability, which is absent in conventional prism-array films. Thanks to the collimating ability, the grating film enhances the luminance of the backlight by 60% compared to that of the conventional backlight with prism-array film.

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