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# Design of Slim LED Coupler for Collimated Light Source

Chun-Hao Sun, Tun-Chien Teng*

Department of Mechatronic Engineering, National Taiwan Normal University, Taipei, Taiwan.

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## Abstract

This study proposed a slim coupler to collimate the light emitted from an LED, which can be used as a collimated light source. The coupler is substantially a 2-D compound parabolic collector (CPC); its bottom surface has longitudinally extending V-groove microstructures thereon. The parabolic side walls reflect the propagating light to converge only in the transverse direction, but the V-groove microstructures reflect the light and make its propagating direction gradually rotates around a central axis of the CPC. Therefore, the angular distribution of the light finally converges after several times of reflection on both side walls and V-groove microstructures. Moreover, the illuminance distribution on the outlet of the V-groove CPC becomes more uniform than a CPC without V-groove microstructures. The effects of V-groove microstructures on both angular and illuminance distributions of the light emerging from the outlet of the CPC is analyzed, and the feasibility of providing a uniform collimated light source is verified by conducting simulation.

**Keywords**: collimation, Coupler, LED, compound parabolic collector, illumination

## 1. Introduction

The liquid crystal display (LCD) needs an extra planar light source such as a backlight. As energy-saving is paid more attention an ultra-collimated planar light source (UCPLS) becomes an attractive solution to raise energy efficiency of the LCD. The UCPLS concentrates the light toward the observer to avoid waste of energy. Moreover, it is essential for achieving some advanced functions to greatly raise energy efficiency. Several typical designs of UCPLS were proposed. The first is to fabricate a light guide plate (LGP) with special microstructures thereon that directly reflect the light propagating within the LGP into the normal direction [1]. The second is to form grating dots on the LGP surface to diffract the light propagating within the LGP into the normal direction. [2]. The third is to utilize an LGP composed of a stack of multiple layers of different refractive index to make the inner light emerge with narrow vertical angular distribution [3]. The fourth is to pre-collimate the light emitted from an LED by an extra optical component before it enters an LGP and then to reflect the collimated light into the normal direction through microstructures on the LGP [4]. Among those designs, using an extra pre-collimating component is a simpler way but needs thicker or wider volume to accommodate the component, which is adverse to a slim backlight. Thus, we proposed a UCPLS design, in which a slim LED coupler was used to pre-collimate the light emitted from an LED and the overall thickness was 5 mm [5]. In this paper, we further analyze the effects of parameters of the coupler on both spatial and angular distribution of the output light to attain the optimal condition.

## 2. Principle

The LED coupler used in the backlight must account for both light mixing and light-collimation. The coupler has a profile of the CPC to convert divergent light entering a small area (inlet) into collimated light emerging from a large area (outlet). The relationship between the angular distribution range (i.e., the “half-angle”) of the light entering the inlet and that of the outlet of CPC can be expressed as follows:

$$\frac{t_1}{t_2} = \frac{n_2 \sin\theta_2}{n_1 \sin\theta_1} \tag{1}$$

$$\frac{A_1}{A_2} = \frac{(n_2 \sin\theta_2)^2}{(n_1 \sin\theta_1)^2} \tag{2}$$

* Corresponding author. Email: walter.teng@ntnu.edu.tw

Eq. (1) is applicable for the 2-D case, where t1 and $t_2$ is the thickness of the inlet and outlet of the CPC, respectively; Eq. (2) is applicable for the 3-D case, where $A_1$ and $A_2$ is the area of the inlet and outlet of the CPC, respectively; and $n_1$ and $n_2$ respectively represent the refractive index of the medium surrounding the inlet and outlet. The two equations indicate that the degree of collimation of the light emerging from the outlet depends on the ratio of the outlet area to the inlet area. As the ratio increases, both width and thickness of the CPC outlet become larger, thus adverse to backlight application. Moreover, output a uniform collimated light beam is another focus if we intend to transversely connect multiple of the CPCs side by side to form sufficiently wide and uniform collimated light source for the LGP.

For a CPC that can be accommodated in a slim backlight whose space is relatively wide but very thin, the horizontal angular distribution of the output light of the CPC would be relatively narrow, but the vertical angular distribution would be relatively wide. To solve this issue, an approach combining a CPC with V-groove micro- structures was proposed. The coupler was designed as a thin and long CPC with a rectangular cross-section, and an array of V-groove microstructures longitudinally extended along the z-axis was form on its bottom surface as shown in Fig. 1. The light propagating along the z-axis within a thin but wide CPC exhibits a narrow horizontal angular distribution (projected on the x-z plane) and a relatively wider vertical angular distribution (projected on the y-z plane). When a light beam with a narrow horizontal angle but comparatively wider vertical angle is incident to the slope facet of the V-groove microstructures, it is reflected by total internal reflection (TIR), and then continues propagating conversely with a narrow vertical but comparatively wider horizontal angle. Such a light beam with a wider horizontal angle is more likely to hit the curved surface on the left or right side of the CPC. Consequently, it is reflected by TIR, and then continues propagating with a narrower horizontal angle; in other words, the beam becomes more collimated. After many similar cycles, the original light propagating within the CPC converges both vertically and horizontally. In the process, the length of the CPC and the angle of the apex of the V-groove microstructures have effects on both spatial and angular distributions of the output light.

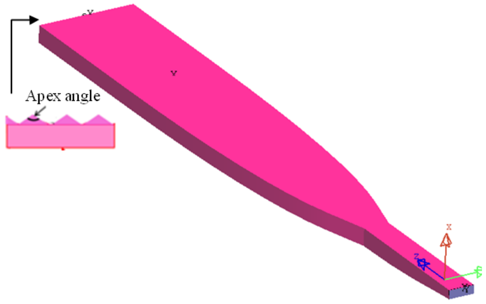


Fig. 1 CPC with V-groove microstructures

## 3. Results and Discussion

In this study, we established an optical model whose related parameters are detailed as follows. A CPC was made of polymethyl methacrylate (PMMA), whose dimensions of its inlet and outlet were $3.6\times1.2$ (mm) and $13.82\times2.4$ (mm), respectively; its length was 50–70 mm. A series of simulations were performed for different conditions such as: apex angles of V-grooves and types of the profile of the CPC. Apex angles included 90°, 110°, 130°, and 150°; types of the profile had three: width and thickness simultaneously increasing (Case A); width increasing first and then thickness (Case B); thickness increasing first and then width (Case C).

Table 1 Uniformity of illuminance vs. apex angles

| | Case A | Case B | Case C |
|---|---|---|---|
| 0° | 0.80/0.87 | 0.88/0.90 | 0.83/0.85 |
| 90° | 0.69/0.76 | 0.79/0.90 | 0.69/0.85 |
| 110° | 0.92/0.94 | 0.97/0.98 | 0.95/0.95 |
| 130° | 0.84/0.99 | 0.98/0.99 | 0.80/0.97 |
| 150° | 0.89/0.98 | 0.98/0.99 | 0.78/0.93 |

Table 1 lists uniformity of illuminance in the three cases under the conditions of different apex angles. Uniformity is defined as the ratio of minimal illuminance to maximal. Angle of zero means the bottom of the CPC is bare flat; the uniformity data behind the slash are those of the CPC that is extended by an extra length of 20 mm with a constant cross-section. The results indicate that the apex angle of 90° is adverse to uniformity for the three cases; apex angles of 110°, 130°, and 150° improve uniformity for Case A and B; only the apex angle of 110° improves uniformity for Case C. Case B performs the best uniformity; Case C performs the worst. However, all the uniformity is improved for the three cases when the CPC is extended.

 

Angular distributions of output light of the CPC for Case A, B, and C are shown in Fig. 2. The left insets are those in the vertical direction; the right insets are those in the horizontal direction. The effects of apex angles of V-groove microstructures on angular distribution are demonstrated. The V-groove microstructure narrows the angular distribution in the vertical, and up to 47% at most as compared with the CPC without microstructures. However, it also slightly broadens the angular distribution in the horizontal. Among the three cases, Case B has narrower and smooth vertical angular distribution, but its horizontal angular distribution is wider. Considering uniformity of illuminance, Case B is an optimal solution.

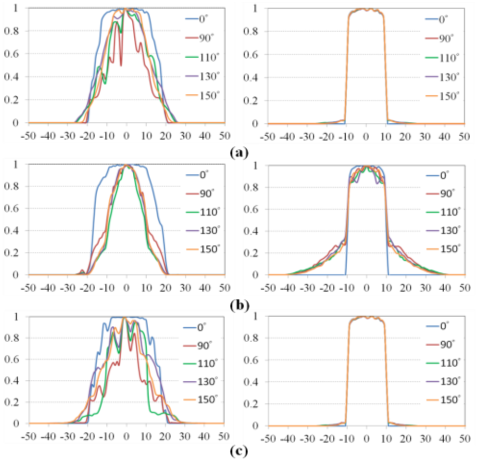


Fig. 2 Angular distributions of output light of the CPC: (a) Case A; (b) Case B; Case C

## 4. Conclusions

In this paper, effects of V-groove microstructures on both angular and illuminance distributions have been demonstrated for the three types of CPCs. In the slim volume, the vertical angular distribution and illuminance uniformity of the output light is narrowed and improved, respectively. The CPC of the profile with width increasing first and then thickness is an optimal solution for a slim coupler providing a uniform collimated light source because of its smooth angular distribution and excellent illuminance uniformity.

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