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# LED Light Coupler Design for a Ultra Thin Light Guide

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A LED light coupler is proposed for coupling light from a mini side LED of 0.4 mm height to a very thin (~0.3 mm) light guide. Due to the ultra thinness of the light guide, conventional light couplings between LEDs and light guides do not provide adequate coupling efficiency. The designed LED coupler is a compound lens of 3.5 mm length, 1.2 mm height, and 3.3 mm width. The coupler first collimates the light from the LED and then concentrates the light in a manner similar to a compound parabolic concentrator (CPC) into the light guide. The exit surface of the coupler is additionally textured to have micro patterns in order to control the radiance profile.

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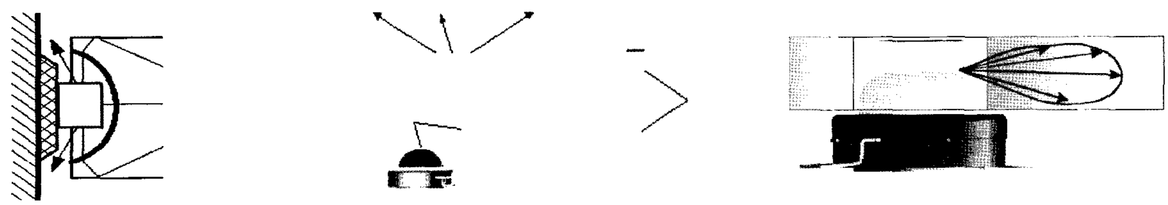
## I. INTRODUCTION

Conventional LCD backlights are generally composed of a light source(s), a light guide, and optical films such as a reflector, a diffuser, and two prism sheets. The light source can be an incandescent light bulb, one or more light-emitting diodes (LEDS), an electroluminescent panel (ELP), and one or more cold cathode fluorescent lamps (CCFL) or hot cathode fluorescent lamps (HCFL). Due to recent development of LEDs with increased efficiency, luminous flux and brightness, LED backlights, which use LED(s) as a light source, are becoming more common [1-4]. Furthermore, many studies have been performed in efforts to increase the efficiency and uniformity of LED BLUs by tailing light guide flow-lines or optimizing the location/size/pattern of micro-structures or diffusive dots on the light guide [5-12].

LED BLUs have been applied to not only large size displays but also small size displays. For small size displays, LED BLUs typically have LEDs located on the edge of the light guide in order to reduce the total thickness of the BLU. Currently, there are three ways to couple light from edge-LEDs into a light guide, as shown in fig. 1. The first method is to orient the light guide such that a smooth and concave surface is facing the LED. The second is to employ reflecting optics that guide the light from the LED to the light guide [13]. The third is to utilize a cap lens on the top of the LED; this lens redirects the LED light to the side directions [13, 14]. The coupling efficiencies of these methods are respectively about 72%, 85%, and 82% and a light guide as thin as 6 mm and 3 mm, respectively, for the first two and the last methods can be applied [13].

Nagasawa and Nufjsawa presented an ultra slim backlight system using an optical patterned film, a



(a) LED + Concave surface (b) LED with a reflector (c) LED with a cap lens

FIG. 1 Three coupling methods from an edge LED to a light guide.

schematic cross-sectional view of which is shown in Fig. 2 [15]. Incident light from the light source propagates by total reflection in the light guide, and light reaching the contact points between the light guide and the optical patterns is picked up toward the film. However, the issue of coupling between the LED and the light guide arises, since the light guide (~0.3 mm) is thinner than any commercially available LEDs.

This paper presents a LED light coupler that couples light from a mini side LED of 0.6 mm height, the thinnest commercially available LED, into a very thin (0.3 mm) light guide. The coupler is essentially comprised of a collimator and a concentrator lens. The coupler first collimates the light from the LED and then concentrates the collimated light into the light guide. The exit surface of the coupler is additionally textured to have micro patterns in order to control the radiance profile.

## II. LED Coupler Design

The LED coupler employs a combination of refraction, reflection and internal reflection to organize light from a light source into the thinner light guide. The first part of the coupler, i.e. the primary optics, collimates light from the LED without significant losses and the collimated light is then concentrated by secondary optics. The secondary optics is effectively a compound parabolic concentrator but adopts total internal reflection instead of reflection for ease of manufacture. The exit area of the secondary optics is textured to have micro-structures in order to enhance the light efficiency. The whole LED coupler can be molded from the same material (PMMA) into a single compound lens. This section describes the LED coupler design.

### 2.1 LED Selection

A mini side white LED (LW Y3SG) from OSRAM [16] was selected as a LED candidate since its thickness (0.6 mm) is the smallest among currently available commercial LEDs. The LED is shown in fig. 3. The illuminating area is of 0.4 mm height and 1.6 mm width.

### 2.2 Primary Optics Design: Collimating Part

The primary optics is a compound lens made of an optical plastic material (PMMA), which comprises the inner refractive wall, the outer reflective wall, and the first entrance surface having an entrance aperture at a recess in which the LED is situated. Figure 4 shows the 3D modeling process and a cross-sectional view of the primary optics. The inner refractive wall and outer reflective wall are conic aspheric surfaces designed by a conventional lens optimization technique using commercial software [17]. Their role is to collimate any rays departing from the entrance aperture, as shown in fig. 5. A similar LED collimation optics was patented

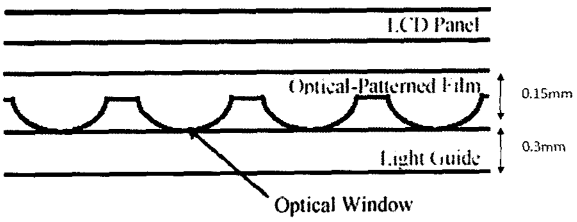



FIG. 2. Schematic of an optical patterned film backlight of less than 0.5 mm total thickness [15].

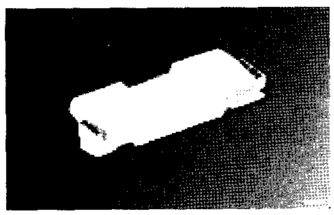


FIG. 3. A picture of the selected mini side LED (LW Y3SG) [16]

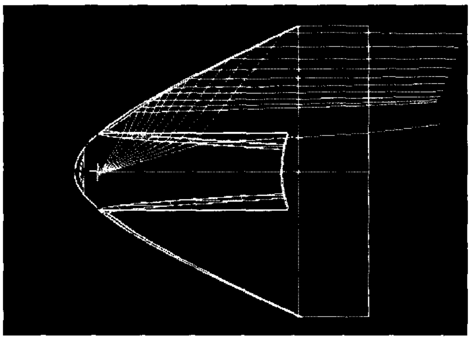

(a) 3D model (b) Cross section

FIG. 4. 3D model and cross-section of the primary optics.

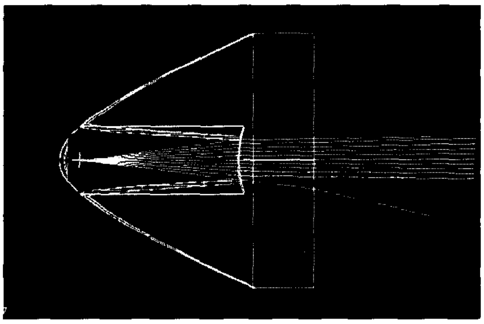
for a rotationally symmetric LED [18]. Figure 6 shows the normalized radiance intensity.

### 2.3 Secondary Optics Design: Concentrating Part

The secondary optics is essentially a compound parabolic concentrator (CPC), a well known device for etendue limited collimation of light [18]. This device transfers light from a source to a target with the same etendue. A sufficient condition for light transfer without any losses is given by the edge ray theorem [19], as given by



(a) Rays going via an outer reflective wall



(b) Rays going through an inner refractive wall

FIG. 5. Cross-sectional views of the primary optics with some rays.

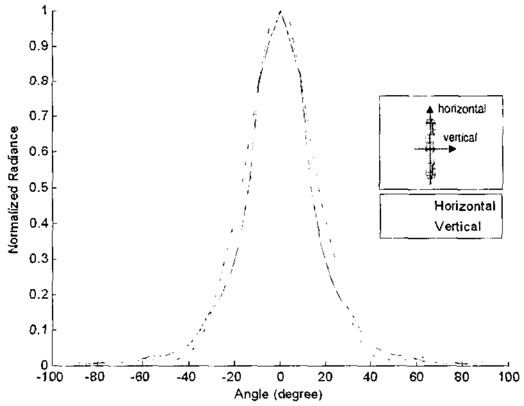


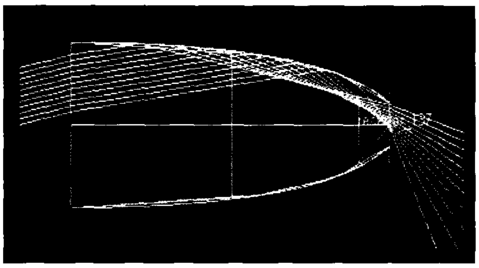

FIG. 6. Normalized radiance intensity after the primary optics.

$$\theta < \sin^{-1}\left(\frac{D}{d}\right) \quad (1)$$

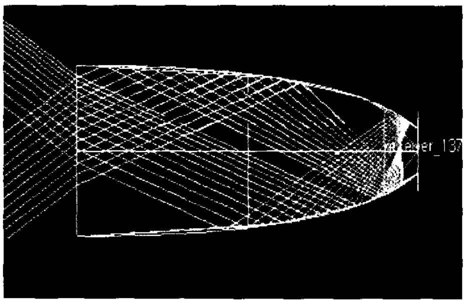
where D is the diameter or height of a source or entrance aperture and d is the diameter or height of a target or exit aperture. For D = 1.2 mm and d = 0.3 mm as specified in sections 2.1 and 2.2, the edge ray angle should be smaller than 14.5°. For rays with a collimation angle larger than 14.5° might travel back to the source, as shown in fig. 7 (b). A conventional CPC is a reflective device but the secondary optics is a refractive CPC-like lens. The material of the secondary optics is the same as that of the primary optics, i.e. PMMA. Figure 6 shows that more than 80% of radiance is within a ±14.5° collimation angle. The detailed profile of the secondary optics is designed by commercial software [20].

### 2.4 Micro-texture design

The primary and secondary optics are made of the same material, i.e., PMMA, and thus they can form a moldable compound single lens. Figure 8 shows a 3d model of the compound LED coupler. Figure 9 shows the normalized radiance of the LED coupler. The figure shows that the radiance is concentrated along the light guide (i.e. 90 latitude degrees in fig. 9). This significantly reduces the efficiency of the BLU, since the major portion of the light directly passes to the other end of the light guide. In order to increase the efficiency, the exit surface of the coupler was textured with micro-



(a) When the edge ray theorem is satisfied.



(b) When the edge ray theorem is not satisfied.

FIG. 7. Collimated light transfer from a source into a target via the secondary optics.

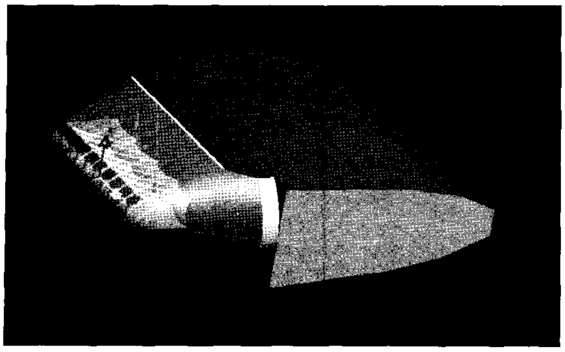


FIG. 8. 3D model of the compound LED coupler.

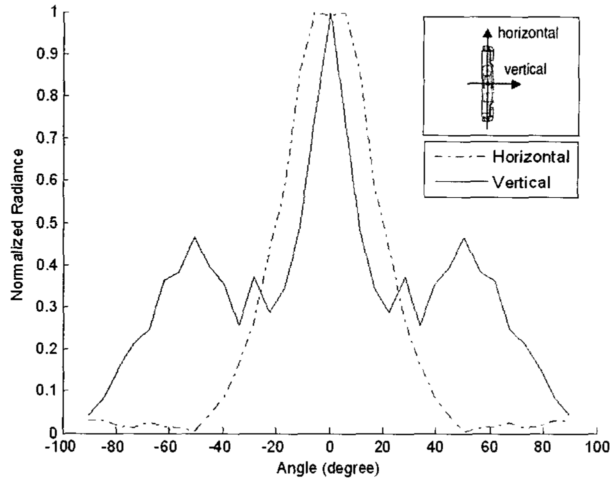



FIG. 9. Normalized radiance intensity after the LED coupler with no micro-structured texture.

structures to change the light radiance. Among micro-structures of cylindrical, spherical, prism, and pyramid character, micro-structure characterized by prisms with 30 micron height and width was found to provide a no-center-peak radiance profile, as shown in fig. 10.

## III. Discussion & Conclusion

We present a single compound LED coupler comprised of the same material, PMMA. The LED coupler of 2.4 mm height, 3.5 mm length, and 3.3 mm width is comprised of a compound collimator and a CPC-like concentrator. The primary optics (collimating part) collimates any light from the LED and the secondary optics transfers the collimated light into a small exit aperture by using etendue conservation. The exit surface is textured with micro-structure in order to increase the efficiency. The coupling efficiency is improved from 66% without any couplers to 86% with the proposed LED coupler.

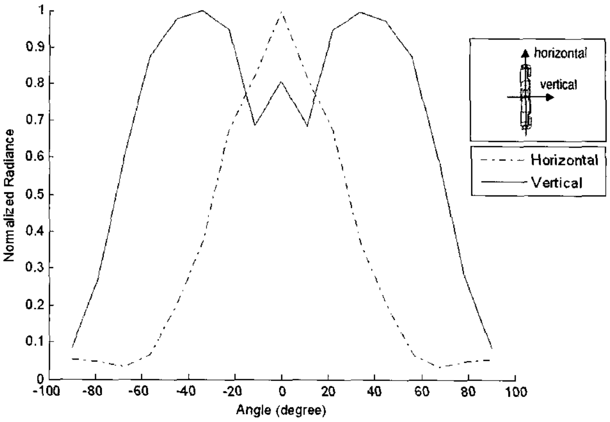



FIG. 10. Normalized radiance intensity after the LED coupler with a micro-structured texture.

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