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Anti-glare LED projection lamp based on an optical design with a confocal double-reflector

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A new optical design of a confocal double-reflector, for white LED lighting, performing uniform illumination with a specific projection angle has been presented and demonstrated. In addition, the anti-glare design with double-reflector prevents direct view of the LED, and the measured veiling luminance is much lower than that in general LED-based projection lamps.

1. Introduction

Lighting and display based on human factor is one of the most important branches of technology in the beginning of 21st century. In lighting, the impact is from the growth of solid-state lighting device such as light emitting diodes (LEDs), which enable more color saturation, life time, design freedom, and environment benefit [1,2]. However, owing to high luminance and intensity of an LED, serious glare occurs when the optical design is just for providing the necessary of illuminance rather than addressing human eye factor. One of the appropriate approaches to prevent glare effect is to enlarge the effective area of light emitting. One of the useful ways to enlarge the exit face of the light source is an approach similar to backlight for liquid crystal display/television, where the backlight module is to transfer a line/point light source to a plane light source [3–5]. The difference between the requirement for the lighting and backlight display is the appropriate illuminance level in the lighting case and the uniformity of luminance in the display case. Another important request for both cases is to hold the optical efficiency as large as possible. The difficulty arising in the lighting with the backlight scheme is that the design is not suitable to light projection to a specific angle. Thus a new design for LED lighting with low glare and an appointed projection angle is demanded. An effective way to reach the demand is to design a structure with avoiding direct view of the light source. There could be two options. The first is to let the light source face to the reflector, and the light source must be located at the center of a reflector. The second is to let the light source face outward, and the light source is located at the bottom of the reflector. Besides, a second reflector should be used to reflect the light back to the main reflector [6–12]. Both approaches can avoid direct view of the light source. However, the first approach is difficult in heat dissipation for LEDs since the light source should be floated within the reflector. In this paper, we present a study of an optical design for the second approach, with a confocal double-reflector to reduce the glare factor. Our design not only enlarges the effective light source area for low glare effect but also projects light at a specific angle with an uniform illuminance.

2. Optical modeling

The optical design starts from the selection of an appropriate LED as the light source. To the aimed lighting, we select a 4-in-1 package white LED by CREE named as XC-E [13]. Its flux was measured around 430 lm with an injection current of 350 mA. To perform a precise design, an optical model of the LED is necessary. Here we did it with the mid-field model, where all verifications were done in the mid-field region of the light source [14–16].

The geometry of the LED is shown in Fig. 1. After figuring out the most important optical parameters including the surface reflectivity, absorption coefficient and weighting factor of the emitting area, we simulated the optical pattern through a Monte-Carlo ray tracing program such as ASAP [17]. The angular light

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patterns were verified at different distances in the mid-field, which was at a range shorter than the 10 times of the largest lateral dimension of the LED [18]. The simulated light patterns and the corresponding measurement were similar to each other at several selected midfield distances, and the normalized cross correlations (NCC) between the two light patterns were always larger than 99.5%. Such values are proven accurate enough for providing the light source for a precise lighting design.

3. Optical design and verification

Three main tasks of the luminaire will be done in the optical design. The first is to enlarge the effective light source area and to reduce the glare effect. The second is to control the projection angle of the light pattern. The last is to make a uniform illumination. In traditional optical designs, it is difficult to perform all three desired properties simultaneously [19–22]. Here we propose a double-reflector to solve the problems. The first reflector near the LED is to reflect the lights to the second (or primary) reflector. The other role of the first reflector is to prevent direct view on the LED by human eyes, and thus to reduce the glare effect. The geometry of the double-reflector is shown in Fig. 2(a). The primary reflector is used to collimate the incoming lights from the first reflector. In order to collimate the incoming light, a confocal design is proposed.

The side-view of the first reflector S_1 is an elliptic curve and that of the primary reflector is a parabolic curve in the S_2 area with a focus at F_2 and another parabolic curve in the S_3 area with a focus at F_1. The focal point F_2 is the common focal point for $S_1$and S_2 so the two reflectors are regarded as a confocal pair, where the lights hitting on the first reflector can be collimated by the primary reflector in the S_2 area. The rest of lights hit the primary reflector in the S_3 area and then can be collimated by the primary reflector. Such a design will enable the reflectors to collimate the lights to a small projection angle or other specific angle. The double-reflector with confocal design keeps the etendue of the effective light source so that the projection angle can be controlled. However, the illumination pattern could not be uniform due to the dispensing of the phosphor on the four separated dies in the LED or possible manufacture/alignment error in the reflectors. To solve the problem, the primary reflector is designed to equip multiple segments shown in Fig. 2(b), where each segment contains a curve surface to enlarge the projection angle at a limited range and introduce a localized blur function. Thus the projection light pattern can be regarded as a convolution between the collimating one and an effective blur function so that the light distribution becomes smoother and the light pattern becomes more uniform.

The 3-D diagram of the double-reflector is shown in Fig. 3, where the double-reflector height is 20 mm, the diameter is 50 mm, and the reflectivity is set 90%. Such a design causes a 71.4% of optical efficiency and a uniform illumination pattern. In the simulation, the illumination at a distance of 1 m is around 193 lx at the center of the projection spot, where the central spot is a circle with a diameter of around 150 cm.

The prototype of the designed reflector was fabricated through CNC (computer numerical control) machining The illumination pattern at 1 m distance is shown in Fig. 4, where the diameter of the projected central spot was around 150 cm as in the design, and the illuminance at the center was 183 lx which was also close to the design. The comparison of the projection angle at 1 m between the design and real sample is shown in Fig. 4(b and c). The projection angle at full width half maximum (FWHM) in the

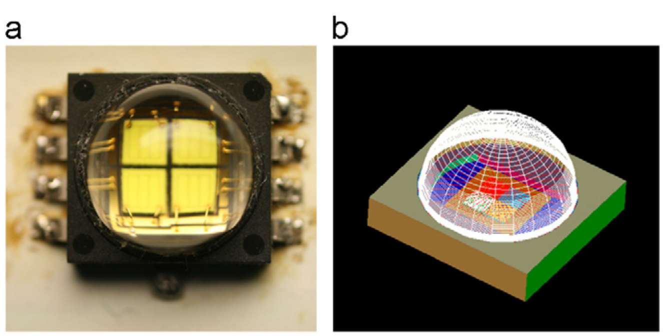

Fig. 1. (a) Photo of the 4-in-1 white LED. (b) Geometry model for simulation.

Fig. 3. Optical design of the collimating reflector.

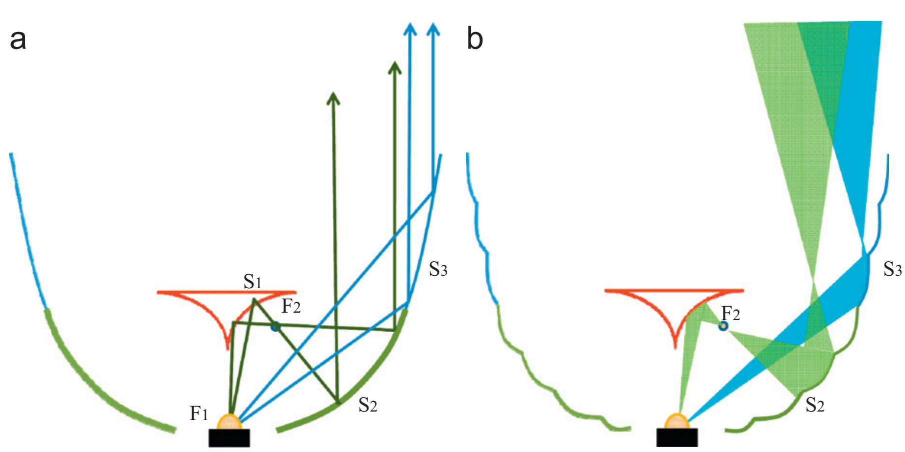

Fig. 2. (a) Geometry of the double-reflector. (b) Schematic diagram of the multiple- segment reflector.