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The Multi-shadow Analysis of LED Secondary Optics

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Abstract

Due to these advantages, small size, low heat radiation, long life time, and high luminous efficiency, the light-emitting diodes (LEDs) have been used widely to the varied lighting in recent years. However, the LEDs have the higher intensity of light in central region and the scattering in the surrounding during lighting, so it is necessary to modify the LED projection by the secondary optical lens. The extra secondary optical lens can enhance the light collection efficiency of LED, but it will readily induce the multi-shadow phenomenon during lighting, which has a significant impact on the human vision. In this study, the LED illumination module with/without secondary optical lens, total internal reflected (TIR) lens or reflection mirror cup, can be simulated by the Apilux® optical software. The result indicates that the approach can identify the level of multi-shadow images according to the deviations in light intensity, and will be new performance criteria of LEDs for users.

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Keywords: LED, multi-shadow, total internal reflection (TIR), secondary optical lens

1. INTRODUCTION

Light emitted diodes (LEDs) have many advantages for industry application, such as smaller volume, lower thermal radiation and power consumption, long life time and high speed response. The LED's are widely applied to indicating light and signal lamp, back light module of large size, and so on [1-3]. From the ITRI's IEK report, the white LED's will gradually be adopted in the lighting market, and the output value of white LED's will reach 1.6 billion US dollars in 2012 [4].

During the packaging of LED lamps, in first, they need the specific optical lenses to cover the LED chips. In general, the light divergence angles of specific lenses have to be designed from 120 to 160 degrees. However, the LED has the higher light intensity in its center; therefore, it needs to be covered by a second optical lens to uniform light intensity and meet the lighting requirement [5]. In addition, for satisfying the varied illumination requirements, the LED has different layout of array type. The LED lamps comprise a several LED chips, so it will induce the glare and the multi-shadows of object while lighting [6], shown in Fig. 1.

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The glare and multi-shadow phenomenon makes the human eyes feel tired after a period of observation, which is the important problems need to be solved. There are many research have been studied, including the glare angle and glare index formula [7-9]. In 2005, Sammarco et al. [10] discussed the relationships between the glare phenomenon and the LED's cap wearied by different height people. Tsuei et al. [11] analyzed the light efficiency and illumination of LED lamps and fluorescent tubes and indicated that the glare of LED lamps could be reduced by coupling the diffuser. In addition, Trotter [12] had proposed the ten methods to reduce the glare, but he never mentioned about the multi-shadow phenomenon. Furthermore, The LED light source covered with the convergence secondary lens caused the worse ghosting and visual fatigue [13].

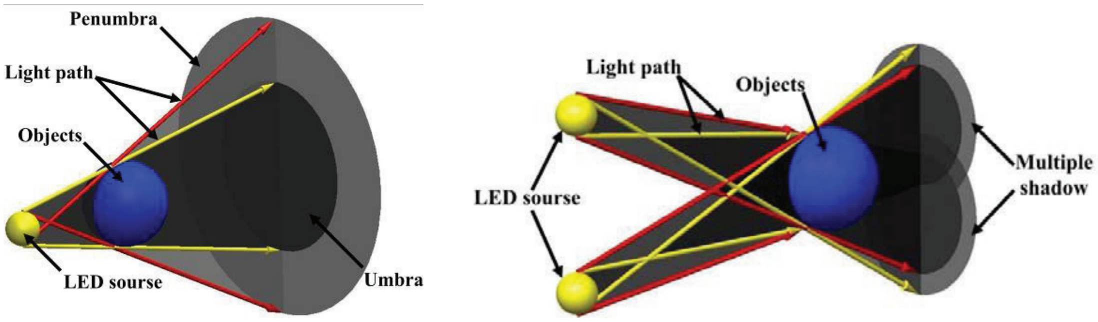
The performance of LED lamp can be evaluated by its illumination, divergence angle, glare angle, illumination distribution, color temperature range and distribution, but there is no effective approach to evaluate the multi-shadow phenomenon. The article presents the simulation and analysis of LED illumination module with/without secondary optical lens (TIR lens or Reflection lamp) by the Apilux® optical software. And then, based on the deviations in light intensity of LED lamp, we can define the degree of multi-shadow images and create a new criterion for LEDs performance.

Fig. 1 Multi-shadow Phenomenon

2. Research Methods and Process

2.1 Multi-shadow of Object

Light travels in straight line in space, and when it is blocked by non-transparent objects, it will generate a 2D gray area in the projection plane. The gray area is so called "shadow". The shadow is divided into two parts; umbra and penumbra, shown in Fig. 2(a). When two or more light source project on the same object, it will produce several overlapping shadows (multi-shadow), and also result in a lot of volatility in illuminance, shown in Fig. 2(b). In order to effectively identify the multi-shadow, this study presents a novel simulating method of multi-shadow by small change in illuminance.



(a) (b)

Fig. 2 Schematic of a) the shadow (umbra and penumbra) and b) multi-shadow

2.2 Simulation and Analysis of Multi-shadow

Figure 3 shows the flowchart of multi-shadow simulation. We create a new method to evaluate the multi-shadow of object by the Apilux® and Solidworks® software. In the experiment, there are three light source modules; (a) only bare light source, (b) total internal reflection (TIR) lens and (c) reflective lamp are applied to the multi-shadow simulation of object. In addition, the comparison of all simulations is discussed.

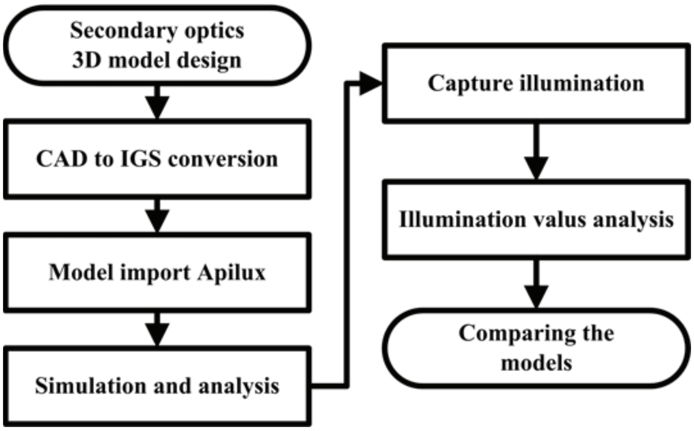


Fig. 3 The flowchart of multi-shadow simulation

2.3 Layout of LED light source array

In the article, the LEDs (Philips Lumileds LXHL-PW09) are adopted for the analysis of the illumination distributions of single/dual array module, shown in Fig. 4. The lumens value of LED light source is 80 lm /W and it is divergent lambertian type. The other optical parameters of LED are shown in Table 1. During the simulation by Apilux®, there are three main parameters need be determined:

(1). Power: the power and lumens value of LED.

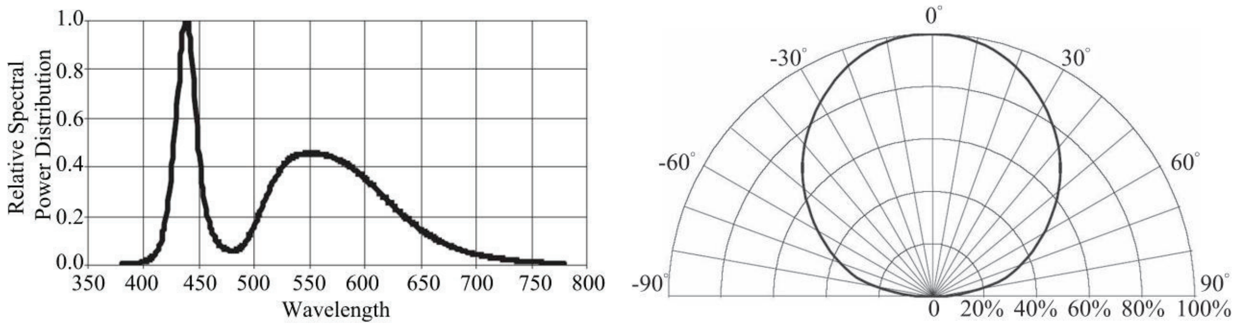
(2). Spectrum: the light spectrum of LED. The wavelength of LEDs, which are applied in the experiment, is 390 to 780nm (Fig. 5 (a)).

(3). Light type and diverge angle: the Light type and diverge angle of LED can be measured based on the standard of "CIE-127 measurement of LED" [14]. The divergence angle of LED, which is applied in the experiment, is 120 degree (Fig. 5(b)).

Fig. 4 The Lumileds LXHL-PW09 LED

Table 1. Summarize the parameters of LXHL-PW09

Characteristics	LXHL-PW09
Power (W)	2.59
Color Temperature (K)	5900
Luminous Flux (lm @ 700mA)	65
Average Life-time (h)	~100,000



(a) (b)

Fig. 5 a) Spectrum and b) intensity distribution of LXHL-PW09 LED

2.4 The design of secondary optical element and simulation architecture

Refer to the collimator lens series of Philips Lumileds LUXEONR, we design a secondary optical element comprised a collimation lens and reflector. The target of divergent angle is 30 degree. Based on the consideration of uniformity of LED lights pot, we decide to use the parabolic curve for designed base line. The architecture of simulation comprises the LED light source, secondary optics elements, shelter and the observation surface. The distance between two light sources is 60 mm, the shelter size is 80 mm × 20 mm × 20 mm, and the observation surface is 500 mm square. In addition, the resolution for simulation is 1pia/mm, the numbers of ray tracing are 10 million and the distance between the light source and the observation surface is 800 mm, shown in Fig. 6.

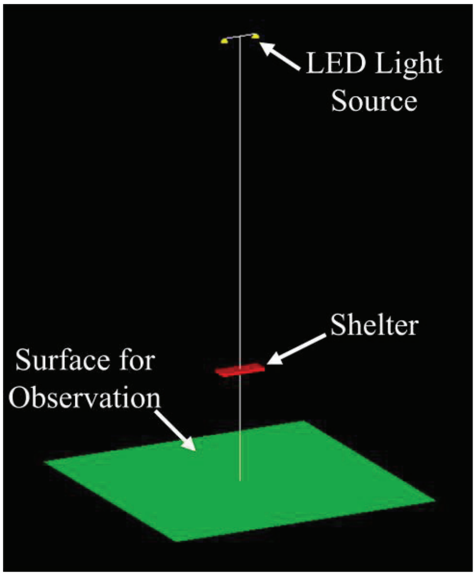


Fig. 6 The system layout of LED Simulation

3. Experimental results and discussion

In this study, we perform the projection simulations of LED by three different modules, shown in table 2.The single light has no multi-shadow phenomenon, so its illumination can be thought of the evaluating standard of multi-shadow phenomenon. To obtain the illumination values from the observation plane, the simulation conditions are given in the following:

(1). The illumination plane is a 500 x 500 matrix.

(2). The multi-shadow phenomenon appears in A zone (160 cm x 50 cm), shown in Fig.7.

(3). The first-order derivative of illumination can be used to evaluate the degree of multi-shadow, shown in Fig. 7(b). The Y-axis and X-axis indicates the illumination value and the projected position, respectively. The simulation results are expressed in table 2.

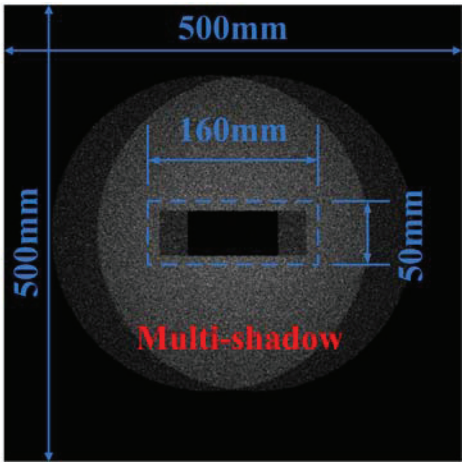


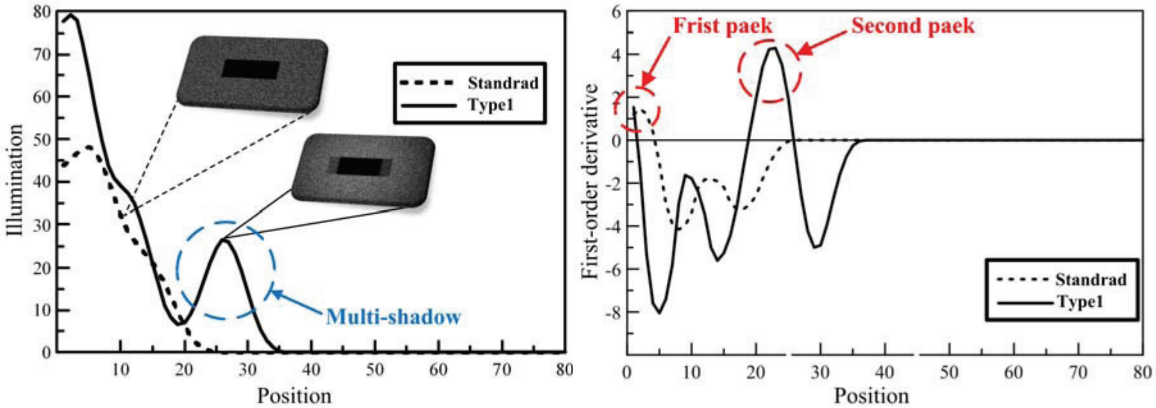
Fig. 7 Obtain the illumination values from the observation plane

Table 2 Summary of the simulation results

Model	Standard	Type 1	Type 2	Type 3
Optical component	N/A	N/A	TIR LENS	Reflection
Number of light source	Single	Multi-source	Multi-source	Multi-source

3.1 The definition of multi-shadow

Figure 8(a) shows the comparison of the illumination distributions of standard and type 1 light source model. In the standard model, when light is blocked by the shelter, the illumination values decreases from the position of 5 mm to 25 mm. In addition, the illumination value of standard model is zero after the position of 25 mm. In the type 1 model, when light is blocked by the shelter, the illumination value decreases from the position of 3 mm and increases from the position of 19 to 26 mm, shown in Fig. 8(a). From the Fig. 8(b), the multi-shadow appears when the first-order derivative of illumination is positive, except the first peak.

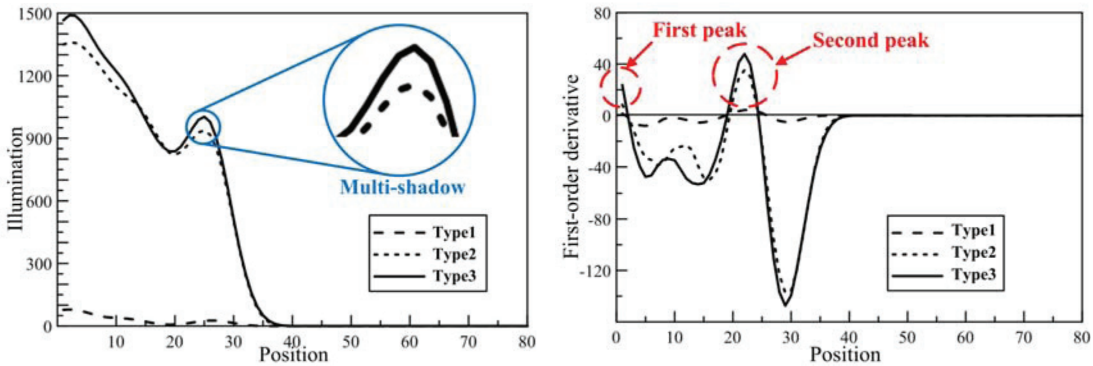


(a) (b)

Fig. 8 a) The illumination distributions of standard and type 1 model and b) their first-order derivative

3.2 The impact of the secondary optics on multi-shadow

In this section, we discuss with the distribution of the secondary optics for the multi-shadow of type 1, type 2, and type 3 modules. From the above section, the multi-light source induces readily the multi-shadow phenomenon. Therefore, the multi-shadows appear in the simulation of type 2 and type 3 modules, shown in Fig 9(a). But the degree of multi-shadow in the type 2 and type 3 modules will be enhanced by their secondary optics element, shown in Fig.9 (a). However, the secondary optics can improve the illumination value, but the degree of multi-shadow is also worse. Figure 9 (b) shows the first-order derivative of illumination. From the Fig.9 (b), the second peak value of type 3 module is bigger than type 2 and their second peak width are about the same.



(a) (b)

Fig. 9 a) The illumination distributions of type 1, type 2 and type 3 models and b) their first-order derivative

4. Conclusions

From the simulation, the article presents the multi-shadow phenomenon could be induced by the multi-light source. Except the first peak, if the first-order derivative of illumination is positive, the multi-shadow phenomenon will appears. In addition, the peak value of first-order derivative of illumination can be used to evaluate the degree of multi-shadow. If the peak value is higher, the degree of multi-shadow is more seriously. Furthermore, the contribution of reflection lamp for multi-shadow is larger than TIR lens; therefore, the secondary optics could increase the illumination values of LED, but they will enhance the multi-shadow phenomenon.

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