JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 17, No. 1-2, January – February 2015, p. 62 - 66

Designing and optimizing of spherical lenses for LED illuminance

J. LIU[a], H. YANG[a*], P. JIANG[a], M. YU[a], Y. HUANG[a], J. YANG[b]
[a]School of Physical Electronics, University of Electronic, Science and Technology of China, Chengdu 610054, China
[b]School of Electronic Information, University of Electronic Science and Technology of China Zhongshan Institute, Guangzhou Zhongshan 528402, China

A new kind of lenses system is proposed in this paper for LED illuminance, it can improve the utilization rate of light energy properly. Non-imaging optics proposed a number of methods for secondary optic design of LED. In this paper, geometrical optics theory is used for the optic design of LED.A kind of spherical lenses system is designed to collimate the LED beams and distribute its light flux so to meet the requirements of illuminate in our daily life. For the characters of LED source and desired illumination, we set geometric model and simulate by optical software Zemax.

(Received June 27, 2014; accepted January 21, 2015)

Keywords: Geometrical optics, Spherical lens, Optical system design

1. Introduction

Light-emitting diodes(LEDs) have been widely used in various fields as a new light-emitting devices[1][2]. As illumination source possesses many advantages, including high energy conversion, small physical size, long service life. High-brightness LED device developed rapidly makes it possible to apply white LED in a lighting field[2]. Due to its lower power consumption, LED can replace traditional lamps in many occasions, such as street light, display, indoor light ,etc[3].

LEDs used in modern illumination systems require the usage of secondary optics[4]. There are many methods for this design, include simultaneous multiple surface(SMS),differential equation,parameters optimization method[5]. Secondary optics is a refractive optical element which is placed over the LED and intended to redirect the light flux emitted by the source into illuminated area.

To be used in illuminating or other field, as a light source, we must do the collimating firstly.

To take the optical feature of LED, we proposed an aspherical system to collimate the beams. The system is composed of a parabolic reflector ,a spherical lens. The simulation has been made for a single LED device.

To meet the require of illuminate ,we set lens after the collimating lens to redistribute the light energy. The LED illuminance array is shown as Fig.1(a).Then we set array of these system for our daily illuminance, it is shown in Fig.1(b).

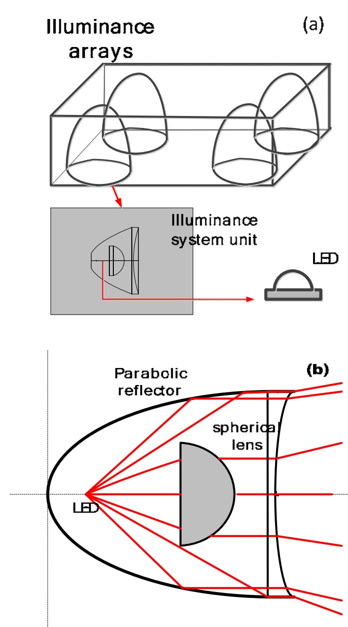


Fig .1. The illuminance system

2. Design one unit of the Collimation Optical System

2.1 Parabolic Reflector

Considering that the LED is a small Lambertian emitting surface. To collimate all the light emitting from the LED, we made up of the reflective device and refractive device, which is shown in Fig.2.

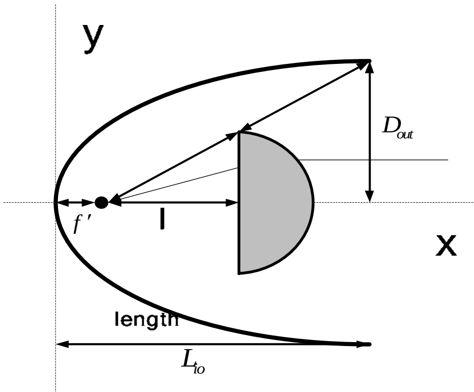


Fig. 2. Parabolic Reflector

The parabolic reflector is trimmed by its focal plane at the apex of the reflector, where the LED device is mounted, with its emitting surface orienting along the optical axis.

According to the geometric knowledge, the function of the parabolic reflector is shown as:

$$y^2 = 2px \tag{1}$$

The focal point is $(p/2, 0)$.

Consider the limitation of the real systems, the angle between the rays emitted from the LED surface and the surface normal is define as θ.The proportion of the light that can be collimated by this reflector is reflector is relevant to the diameter of the output aperture D_{out} and depends on the focal length f' and the depth of the reflector L_{io} .The relationship between L_{io}, f' ,and D_{out} is

$$L_{io} = \frac{D_{out}}{8f'} \tag{2}$$

Where $f^{'}$ is the focal length.

To avoid the reflected light being blocked by the sequent aspherical lens, the actual length of the parabolic surface is

$$L_o = L_{io} - f' \tag{3}$$

Among all rays collimated by the reflector, it is obvious that the maximum aperture angle $\theta_{\max}$ is $\pi/2$,and the minimum angle $\theta_{\min}$ is determined by :

$$\theta_{\min} = \arctan(\frac{D_{out}}{2L_o}) \tag{4}$$

Therefore, the reflected rays range from $\theta_{\min}$ to $\theta_{\max}$ .After calculating, we get the focus length $f = 35mm$,the length $L_{io} = 125mm$. And the $Dout = 90mm$.

2.2. Spherical lens

According geometrical optics, for arbitrary angle of incidence of light as the incident angle is $\alpha = \alpha_0$, the incoming light and lens on the node $M(x_1, y_1)$,and exit on the node $N(x_2, y_2)$,which is shown in Fig.3.

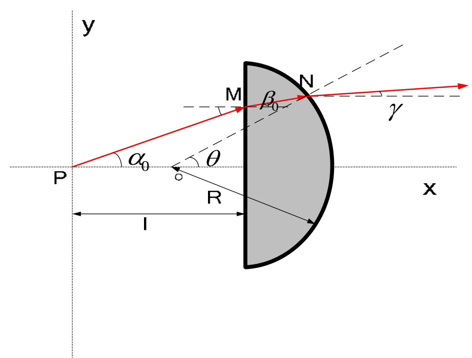


Fig.3 spherical lenses to collimate LED beams

According to the Snell's law we get equation as follows:

$$x_1 = R - d \tag{5}$$

$$y_1 = l \cdot \tan\alpha_0 \tag{6}$$

$$x_2 = \frac{\sqrt{8\times[\tan\beta_0\cdot\tan\alpha_0\cdot l - \tan^2\beta_0\cdot(R-d)]^2 - 4(\tan^2\beta_0+1)\{[l\cdot\tan\alpha_0 - \tan\beta_0\cdot(R-d)]^2 - R^2\}}}{2(\tan^2\beta_0+1)} - \frac{2\times[\tan\beta_0\cdot\tan\alpha_0\cdot l - \tan^2\beta_0\cdot(R-d)]}{2(\tan^2\beta_0+1)} \tag{7}$$

$$y_2 = l \cdot \tan\alpha_0 + \tan\beta_0 \cdot [x_2 - (R-d)] \quad (8)$$

Then we can get the exit angle equation as follows:

$$\gamma = \theta - \arcsin[n \cdot \sin(\theta - \beta_0)] \quad (9)$$

Where

$$\theta = \arcsin(\frac{y_2}{R}) \quad (10)$$

We set a point source at the focal point of the sphere lens,it has been simulated by Zemax in this design.Considering the size of the parabolic reflector,we obtained the curvature radius of the lens : $R = 42\text{mm}$,and $D = 42\text{mm}, l = 15\text{mm}$ .The refractive index of the lens is 1.574.

The collimation results that point source through the sphere lens we designed, it is shown in Fig. 4.

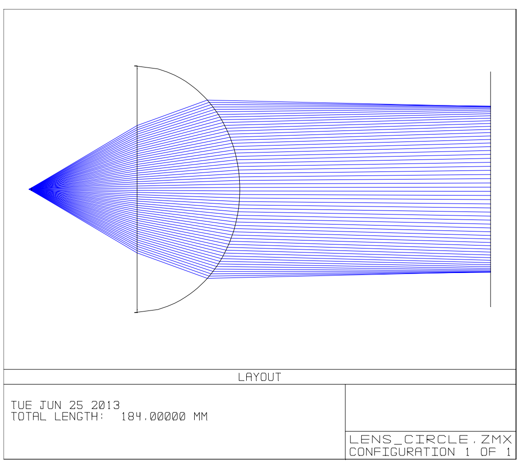


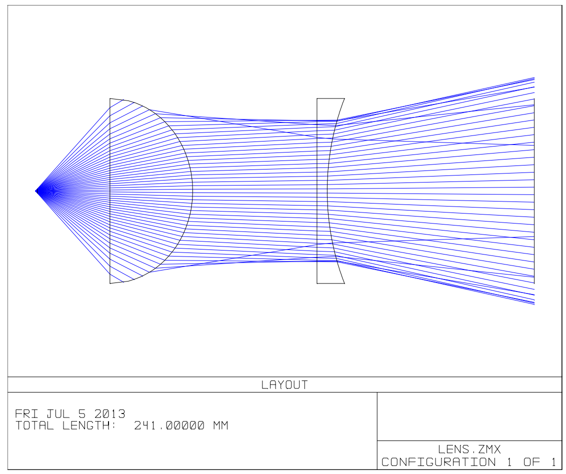
Fig.4 Ray tracing of spherical lens

From Fig.4, we can see the divergence angle is very small. Its value lies in the range of 0.8 to 2 degree.

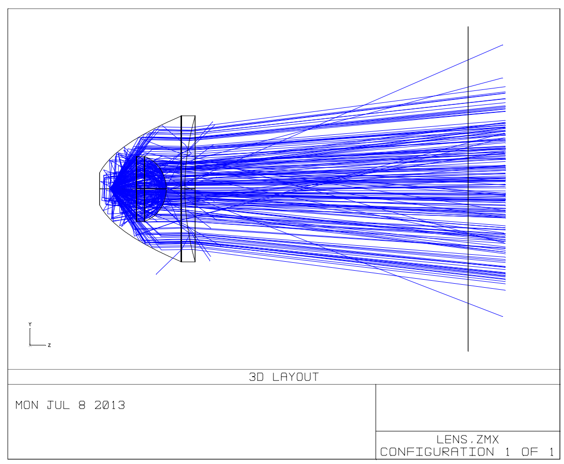
3. Secondary tailoring

All rays can be transferred to parallel rays after the collimation system, resulting in a circular shape beam, with its beam diameter coinciding with the reflector diameter.

As is shown in Fig.5,we set a secondary tailoring lens after the collimation system to redistribute the light energy. As LED is a kind of Lambertian light source, the beam energy is concentrated at the center of the circular beam. So the highly concentrate must be diverged and redistributed.



(a)



(b)

Fig. 5(a) Light energy distribute (b) ray tracing for the whole system

Fig.5 (a) shows the ray tracing that a point source through the two lenses.Fig.5 (b) shows the beam through the whole system. In this design, we set the size of LED device is $1cm \times 1cm$,and the power is 7.6watt.

The luminance distribution simulation results are shown in Fig. 6.

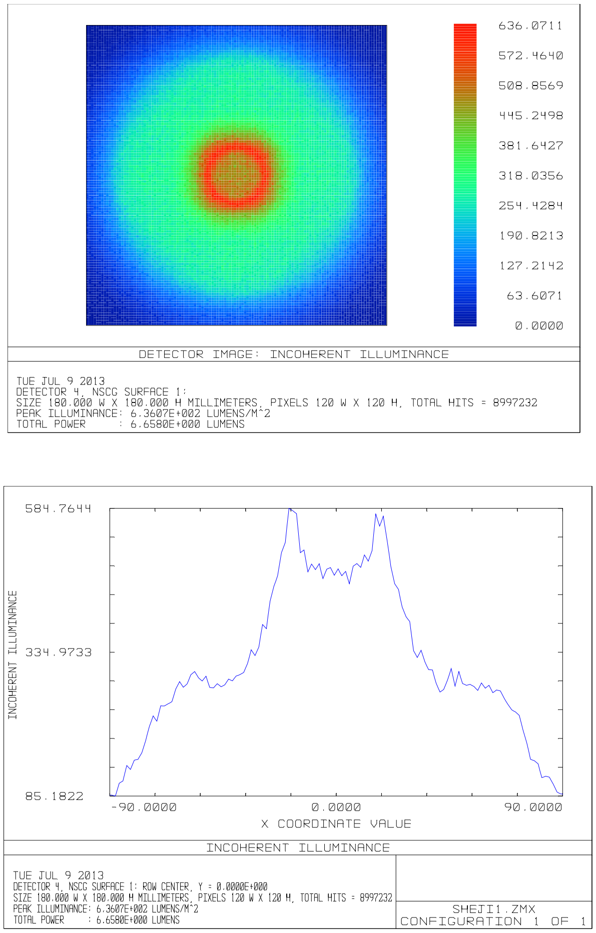


Fig .6. The inensty of illumination

For a single unit, simulation results (Fig.6) indicated that the light intensity distribution concentrate in the centre. According to this result, we can dorepeated addition,through three or four LED unit to get the illumination uniformly.

4. Arrays for illuminance

This part we design LED illuminance arrays as shown in Fig.7 ,and we analysis the light intensity distribution in the distance of 2.5m.In this part, the distance between each unit is designed as 24cm. And the power of the LED device is 7.6watt.

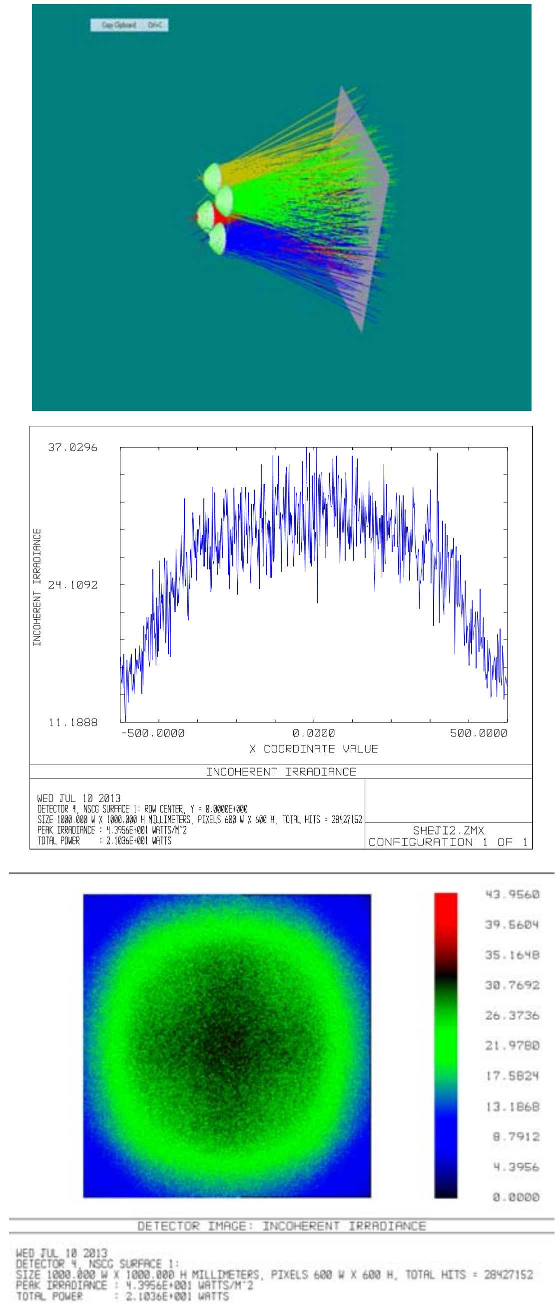


Fig.7 LED illuminance arrays and the luminance distribution

Fig.7 shows the 4×4 arrays, and the luminance distribution in the distance 2.5m from the system. we can get that luminance distribution is relatively homogeneous, and meet the daily illuminance.

5. Conclusion

This study has present an LED projection system composed of a reflector and sphere lens, it can used in indoor illuminance. By using a single high-brightness LED device of 7.6W, the testing result of the prototype accord with simulation, and can reach the illuminance distribution requirements in our daily life. The simulation result is consistent with the theoretical analysis. The illuminance array can distribute the light energy uniform at the percent of 64.86.Moreover, we have do the system optimization to reduce the energy and improve the illumination homogeneity.

Acknowledgments

This work is supported by the National Natural Science Foundation of China under Grant No. 61271167 and No. 61307093. It also supported by Research Foundation of the General Armament Department of China under Grant No. 9140A07040913DZ02106, Sichuan Provincial Foundation for Leaders of Disciplines in Science, China（Y02001010401012） and the Fundamental Research Funds for the Central Universities under Grant No. ZYGX2013J051.

References

[1] A. Ge,W. Wang, Z. Du, Appl. Opt. **52**(12), 2688 (2013).
[2] M.A. Moiseev, S.V. Kravchenko, L. L. Doskolovich, N. L. Kazanski, Proc. SPIE, **8550**, 85502N (2012).
[3] X. Lee, I. Moreno, C. Sun, Opt. Express. **21**(9), 10612 (2013)
[4] G. Wang, L. Wang, F. Li,G. Zhang, Appl. Opt. **51**(11), 1654 (2012).
[5] Y. Ding, X. liu, Z. Zheng, P. Gu, Opt. Express. **16**(17), 12958 (2008)

*Corresponding author: yanghj@uestc.edu.cn