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Collimate LED Light to Uniform Illumination with Refractive-Reflective Optical System

Chen Chen[1,a], Xiao-hui Zhang[1,b]

[1]Ordnance Engineering Department, Naval University of Engineering, Wuhan, Hubei 430033, China

[a]chenchen2004025@gmail.com,[b]zhangxiaohui505@vip.sina.com

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Abstract: An optical system which collimate the light of LED uniformly is proposed in this paper. This optical system consist of two part of optical surface. First a TIR lens collimate all of the light of the LED parallel to the z axis. Then the first reflector redirect the collimating light to a uniform distribution and the second reflector collimate the uniform light pattern. The simulation result of the designed system shows that the uniformity of the output wave-front is 0.78 and the total efficiency of the system is 89.32%.

Introduction

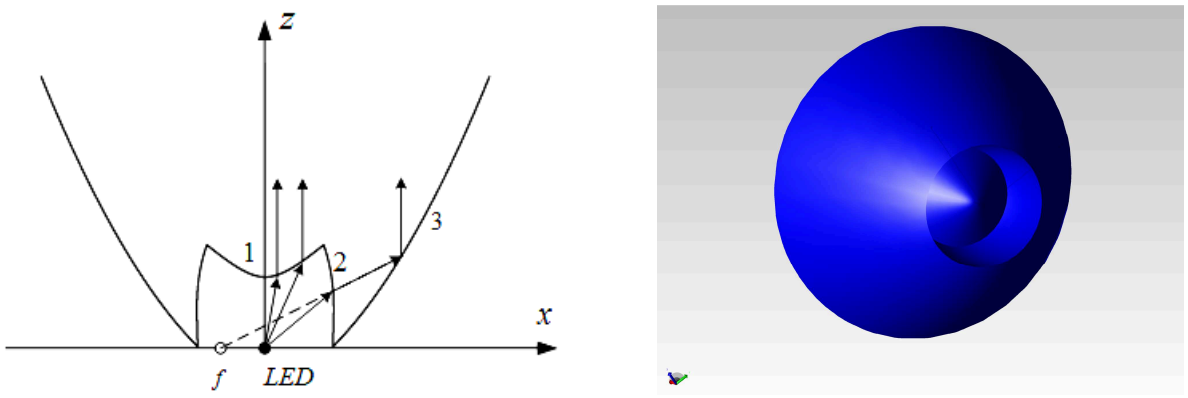
As the increase of efficiency and power of single light-emitting diode (LED) chip, LED is widely applied in the illumination region. The main purpose of LED illumination optical system is to redirect the light ray of LED in order to get the desired (mostly uniform) light distribution at the target surface. To achieve this purpose many free-form surface design method have been developed [1-5]. Most of the method [3-5] are based on the source-target energy map which can reduce the problem to ordinary differential equations and solve the optical surface numeri-cally.

To collimate the light of LED is also an illumination problem. The most concerned criterion of this kind of lens is the view angle of the output beam [6-8]. But the distribution of the collimated light has not been fully researched. The optical system can have more application when it achieve the uniform of the collimated light.

In this paper we propose a refractive-reflective optical system which can collimate the LED light to a uniform light pattern. This optical system consist of two parts. The first part is a TIR lens which collimate the light of LED to parallel light beam. The second part is a double free-form reflector system which redistribute the output light of the TIR lens to the uniform distribution then collimate the light again.

Optical System Design

Fig. 1 (a) shows the profile of the TIR lens. This TIR lens consists of three kind of free-form surfaces. Spherical wave-front emitted by a point source (LED) at origin point is either refracted by surface 2 and then totally reflected by surface 3, or refracted by surface 1. The output light of the surface 1 and surface 3 are parallel with the z axis. The TIR lens can be obtained by revolving the profile to the z axis. Thereby, spherical wave-front emitted by the LED is shaped to a plane wave-front which is perpendicular with z axis. Fig. 1 (b) shows the perspective view of the TIR lens.



(a) (b)

Fig. 1. (a) The profile of the TIR lens. (b) The perspective view of the lens.

The TIR lens only direct the light of LED to parallel with z axis but not change the light distribution of output wave-front. In order to achieve the uniform illumination of the collimated light there must be another part of optical surface to reshape the pattern of the plane wave-front. We design a double free-form reflector system to redistribute the light pattern of the plane wave-front. Fig. 2(a) shows the sketch map of the reflector system. The reflector 1 redistribute the input wave-front uniformly to the reflector 2. The reflector 2 direct the uniform light from the reflector 2 parallel to the z axis. After these step above the light of the LED is became the parallel light beam and have a uniform illumination.

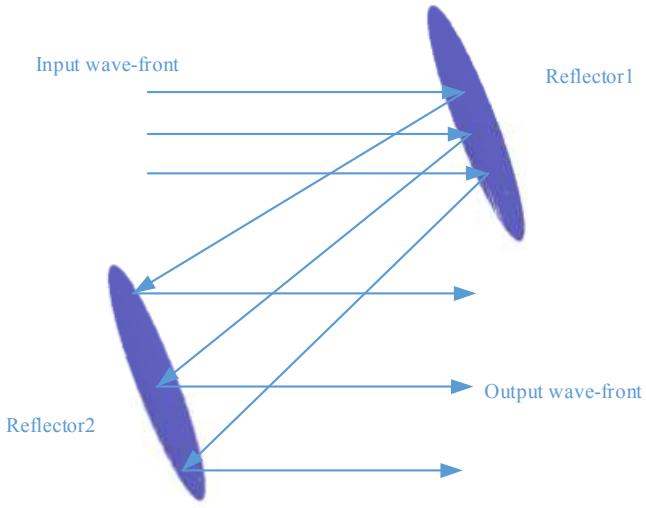


Fig. 2. (a) The sketch map of the reflector system.

Fig. 3 shows the energy map between the input and output wave-front. The illuminance distribution of the input wave-front can be calculate by the LED's light intensity distribution. The illuminance distribution of the output wave-front is set to be uniform. Both wave-front's surface are divided into same number of net grid. Each grid has the same amount light flux. The grid's light flux is calculated by the illuminance distribution of the wave-front. Then we can establish a one-to-one map between the two wave-front's net grid. After setting the initial point of the two reflector we can interpolate the reflector's shape data by the map of energy net grid.

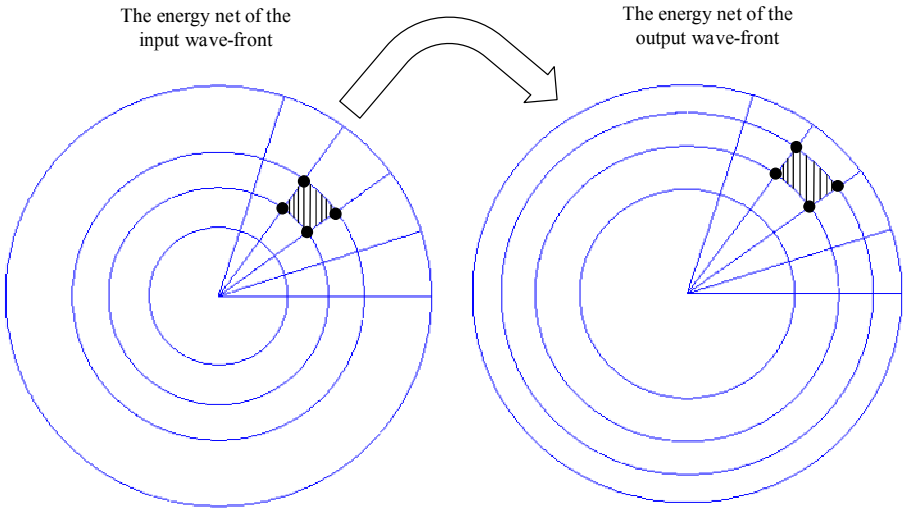
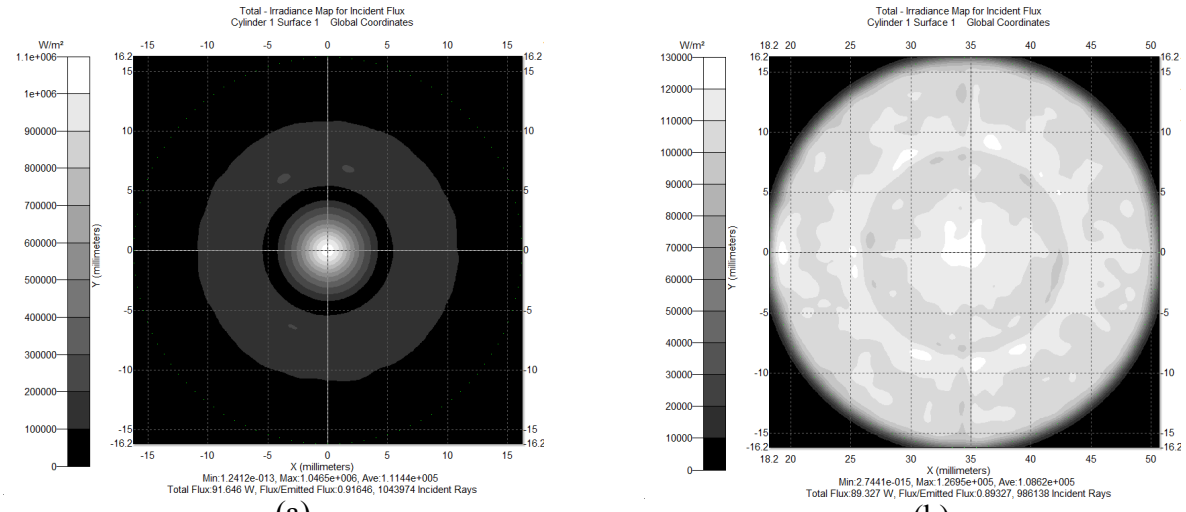


Fig. 3. The energy map between the input and output wave-front.

Simulation and Results

After the shape data of TIR lens and reflectors been calculated we construct the optical surfaces by the NURBS model software. The TIR lens only need the profile curve to get its shape. The reflectors are not revolve symmetry. In order to get the shape of the reflector the skeleton curve of the reflector must be calculated. The reflector can be got by loft this skeleton curve. The reflectors are symmetrical with the x axis so we only need to calculate half of reflector shape data. After the TIR lens and reflector are constructed we use the optical design software to validate the system's performance. Fig. 4 (a) shows the light distribution after been collimated by the TIR lens and the result show the dramatic un-uniformity. Fig. 4 (b) shows the simulation result of the whole system. The detective surface is set to have the same x axis projective radius of Reflector 2 in fig. 2. The uniformity of the light distribution is defined as $U_E = E_{\min} / E_{\max}$, $E_{\min}$ and $E_{\max}$ represents the minimum and maximum illuminance of the detective surface. From the illuminance distribution map of the detective surface we calculate $U_E = 0.78$. The total efficiency (TOE) is defined as the ratio between the light flux of the output wave-front and the light flux of the LED. The ray trace result tell us that the TOE is 89.32%. Using the light efficiency of the TIR lens we can calculate the light efficiency of the reflector system is 97.47%.



(a) (b)

Fig. 4. (a) The light distribution after been collimated by the TIR lens. (b) The light distribution after reshaped by the reflector system.

Conclusion

An LED collimating system which can generate uniform light pattern is designed. This system consist of a TIR lens and double reflector system. The TIR lens collimate the light of LED firstly and the light distribution of this light wave-front is highly un-uniformity. After the TIR lens the reflector 1 redirect the light to a uniform light distribution and then the reflector 2 collimate the uniform light parallel with z axis. The simulation results shows the uniformity of the output wave-front is 0.78 and the TOE of the system is 89.32%. This result shows that the designed system is effective. This system have many application such as light communication. However the light efficiency of the TIR lens should be improved. Besides the shape of the output could be considered of any geometric shape in the further study.

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