Research Journal of Applied Sciences, Engineering and Technology 6(1): 89-94, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: October 22, 2012 Accepted: December 14, 2012 Published: June 05, 2013

Study and Design of LED Lighting Systems

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Abstract: In this study, the optical characteristics, thermal characteristics, electrical characteristics of the LED device are studied. After analysis of the significance of the optical model, we establish the model of the LED light source using optical simulation software to analyze the impact of modeling four factors and law, based on ray tracing model intensity distribution with the manufacturers. On this basis, we expand the LED secondary optical design, namely, increasing of LDE method to the light level. After comparing different forms of non-imaging optical components, combined with the actual situation, the final choice is the system composed of rotating parabolic reflector with LDE. Besides, the reflected changing the relative position of the body and LDE space lead to the normal light intensity of the entire system appearing two peaks, but their causes are different. In addition, the method of combining theoretical analysis and computer simulations to study the distribution of LDE array illumination is utilized. Formula on the illumination distribution in the LDB array to a plane parallel thereto is deduced, which is verified by computer simulation and agrees well with it. A quantitative study of the factors affecting the road surface illuminance distribution is made on the basis of previous study, combined with the actual road lighting works. These factors are: LDE array form, the number of LED, spacing between LDE, LDE interval between the street lamps. The derived entire road illumination distribution formula and the corresponding curve gives a basic method for the analysis of such practical problems related outcomes for the LDE illumination optical system design and research basis.

Keywords: Computer simulations, LDE array, optical simulation software, theoretical analysis

INTRODUCTION

The semiconductor is a focal point of the 21st century and the most eye-catching new technology related to the field of multi-technology materials, device structures, optical design, packaging technology, power circuit, lamps, lighting effects and visual matching (Tsunemasa *et al*., 2004a; Murakmai *et al*., 2000; Uehida *et al*., 2000; Edward *et al*., 1997). White LED light source developed by the success of its application development in the field of general lighting to create the conditions, the LED light source with conventional light sources such as incandescent and fluorescent lamps (David and Mark, 1997; Kaminski *et al*., 2002; Harald *et al*., 2002; Tsunemasa *et al*., 2004b; James, 2002), the most to attract the world's attention is energy-saving and environmentally friendly features. Compared with incandescent lamps, white LED lighting energy savings of 80% to 90%, 50% energy saving compared with fluorescent lamps; life of up to 100,000 hours, which is 20~30 times of incandescent, fluorescent lamps 10 times, especially with the solar electromagnetic induction batteries used in combination, it is an extremely competitive green light (Tsou *et al*., 2005; James *et al*., 2004; David and Kavita, 2004; Frank *et al*., 2004). High brightness LED in recent years have been new breakthroughs in technology, its applications continue to expand, has entered the field of special lighting, related to a large group of companies in the major developed countries in the world have invested in human and material resources to research and development of high brightness LED and formulating the development plan to overcome technical difficulties as soon as possible, to enter the field of lighting (Craford, 2002; Mueller-Mach and Mueller, 2000; Aurélien *et al*., 2007). China's ultra-high brightness LED industry is also subject to all levels of government attaches great importance to and vigorously support, a lot of well-known universities, research institutions and companies also invested heavily in the power of research, the development of ultra-high brightness LED, want to catch up with the world advanced level.

LED used in lighting research at home and abroad also have been committed to the optical structure design: Austria lighting design company had 14,000 white and mixed color LED lamps developed and lighting effects and visual matching innovation and research lighting the entire room, light levels reach 600 a 700 lux, enough of an ordinary office lighting; LED for traffic lights, many cities in Sweden to reduce the need to heat large traditional traffic lights; GE Company, USA, Germany the SIEMENS, OSRAM Company NICHIA, SONY Corporation, Japan also are

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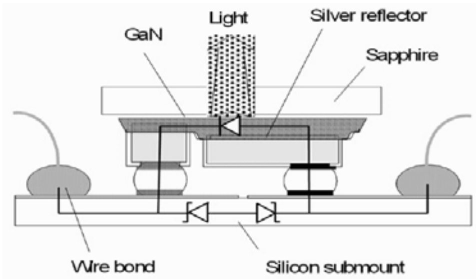

Fig. 1: Light emitting characteristics, in these PN junction of the semiconductor material

committed to the development of LED lighting products and lighting systems. China has also officially launched the "National Semiconductor Lighting Project" and has formed a four LED lighting R & D area of the Pearl River Delta, Yangtze River Delta, Jiangxi and Fujian, Beijing and Dalian and other northern areas. For the realization of the LED from light color lighting and special lighting to the extension of the general lighting, the state has invested a lot of money and manpower.

LED LIGHT-EMITTING PRINCIPLE AND CHARACTERISTICS

Emitting principle: LED III-V compound semiconductor such as GaAs, GaP, GaAsP, its core is a PN junction. The so-called PN junction means of a transition layer between the P-type semiconductor and N type semiconductor. Therefore, it has general PN junction voltage characteristics, namely: the forward conduction and reverse blocking and breakdown characteristics. In addition, under certain conditions, also having a light emitting characteristics, in these PN junction of the semiconductor material, as shown in Fig. 1, the electrons from the N-type material diffused into the P zone, while the diffusion of holes from the P-type material to the N-region, Examples of such diffusion results in the PN junction formed with a height of e ΔV a potential barrier to prevent electrons and holes further spread to reach the equilibrium state. When the PN junction when a forward bias voltage is applied, i.e., the P-type material connected to the positive electrode, the N-type material is then negative, PN junction barrier will reduce, the N area of electrons injected into the P zone and P zone of the hole injected into the N area and thus give rise to a non-equilibrium state. These injected electrons and holes in the PN junction meet composite; the excess energy is released in the form of light, i.e., the electrical energy into light energy (Narendran, 2005).

LED characteristics:

Spectral characteristic: PN junction of the wavelength of the radiation light is determined by the material bandgap E_g, namely:

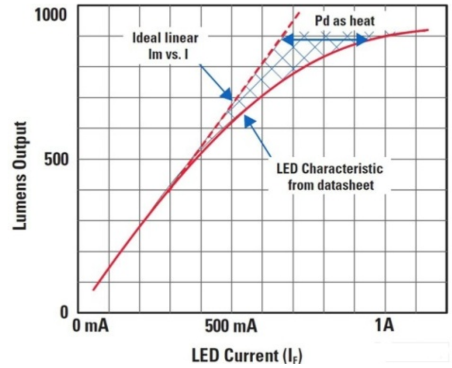

Fig. 2: Voltage characteristics of the light-emitting diode and PN junction voltage characteristics

$$\Lambda = 1.24\mu m * ev/Eg \quad (1)$$

Assume light of different wavelengths due to the different materials of different band gap, so the light emitting diode can be made of different materials. The light emitted by the light emitting diode is not a pure monochromatic light, however, in addition to the laser, its spectral width than the other light emitted by the spectrum of the light is narrow. For example, the spectral width of the GaAs light-emitting diode is only 25nm. Therefore, it can be considered monochromatic.

- **Strength characteristics of the current/voltage characteristic and current/light emitting:** For conventional LEDs, the single light-emitting diode is generally formed in a thickness of approximately 0.2-0.3 mm chip of the PN junction, the area of about 0.4 * 0.4 mm^2, respectively and in the P-surface and the N-surface to make an electrode and then an epoxyresin package, a package after the light-emitting diode to many properties of the same basic PN junction. Voltage characteristics of the light-emitting diode and PN junction voltage characteristics, as shown in Fig. 2, including the forward dead zone, forward workspace, reverse dead zone breakdown area.

When the applied forward voltage is less than the turn-on voltage, overcoming not barrier farms, the PN junction rendered larger resistor, the forward current is very small. The turn-on voltage of the light emitting diode vary with different materials and different. When the applied voltage exceeds the turn-on voltage, to overcome the barrier electric field, the forward current increases rapidly, a large number of holes and electrons injected compound and shine, the relationship between the current and the voltage at this time can be expressed as follows (Uehida *et al*., 2000):

$$\mathrm{I} = I_0(\exp\frac{eV_\alpha}{\beta kT} - 1) \quad (2)$$

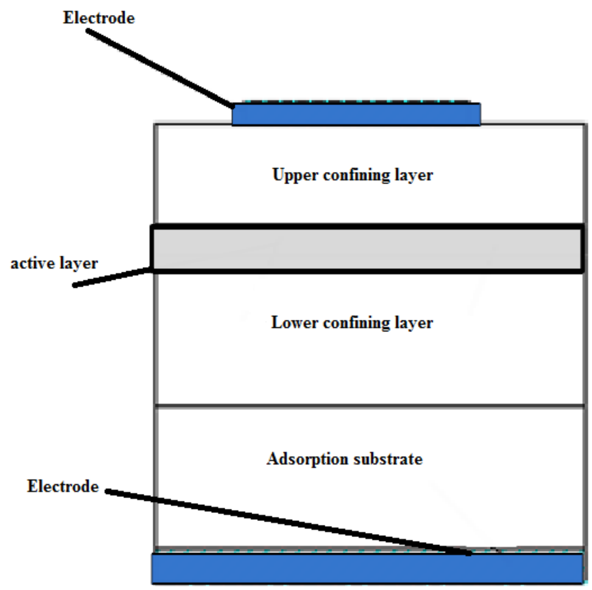

Fig. 3: Componentsinside the LED chip

where,

V_α = Applied on the PN junction forward voltage
β = A coefficient, the value 1 for the diffusion current, within the space charge layer of the composite current whose value is 2
k = Boltzmann's constant and its value.1.38 * 10^{-23} J/K
T = The absolute temperature
I_0 = The reverse saturation current and the carrier concentration, diffusion related to the situation, temperature and other factors, when PN junction is made, it is only with the temperature-related coefficient amperes.

The luminescence brightness light-emitting diode forward current is closely related. A general enhancement of the emission luminance of the light emission tube of the light emitting diode and the current increases linearly proportional difficult to saturation; Zn-O doped GaP red light emission luminance of the light emitting diode, is easy to achieve the increase of the current saturation. GaP red light emitting tube is emitting light, but the concentration of Zn, O doped not improve rely on the Zn-O, so that the light-emitting composite probability is low, the minority carrier reaches a certain value, the light emitting center saturation occurs; GaP the yellow and green light emitting diode, is based electronic substituted P, N, etc. can be very high doping concentration, therefore, to achieve a very high concentration is not saturated.

- **LED optical model:** Photons generated within the active layer of the LED chip in a random manner the exit and thus the trajectory of the photons emitted from the active layer after the running is also random, i.e., the photons in all directions in space are likely to exit. Usually several parts, including limitations layer, the active layer, substrate, electrodes, are inside the LED chip, shown in Fig. 3.

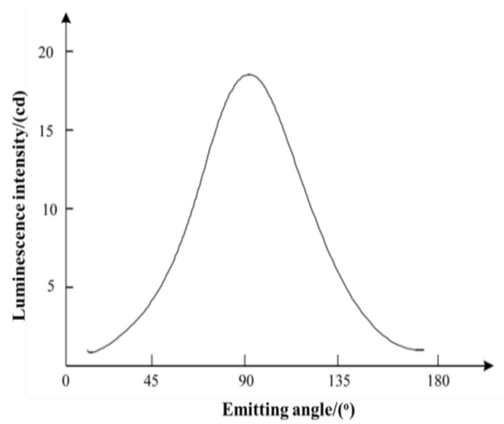

Fig. 4: The light intensity distribution of the LED light source chip

The light source is very small, compared to a much smaller distance to the light source and the illumination surface, its size can be ignored, can be the light source as a point light source. Proportional to the cosine of the luminance formula by the second chapter, it is possible to push the point light source that is irradiated to the vertical plane and the illumination on the plane and the light source is proportional to the light intensity. The angle between the normal to the plane and the incident light ray and the square of the distance inversely proportional to, the formula is expressed as:

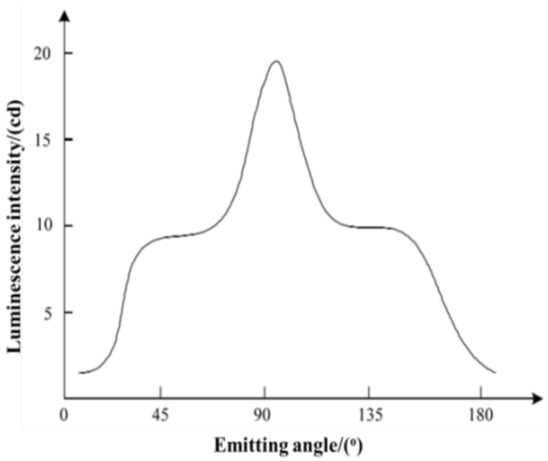

Fig. 5: Light intensity distribution of the general situation

$$E = I\cos\theta/r^2 \quad (3)$$

The light intensity distribution of the LED light source chip is not the ideal Lambertian distribution. Lambert cosine distribution, as shown in Fig. 4, the formula is expressed as:

$$I(\theta) = I_0 \cos\theta \quad (4)$$

Intensity distribution of the LED chip:

$$I(\theta) = I_0 \cos^m\theta \quad (5)$$

Light intensity distribution of the general situation, as shown in Fig. 5.
where I_0 is the light source in the direction normal to the light intensity and θ is the angle of the light and sandwiched. When $I = I_0/2$, the light and the normal to an angle of θ:

$$I_0/2 = I0 \cos^m\theta_{1/2} \quad (6)$$

Therefore:

$$M = - In2/In(\cos\theta_{1/2}) \quad (7)$$

LED vertical irradiation horizontal plane, according to the formula (8) can be obtained when the illumination of each point of the horizontal plane:

$$E(x, y, z) = E_0\cos^{m+1}\theta \quad (8)$$

where,
E_0 = Vertically irradiated to the point

If (x, y and z) is the illuminated point coordinates, (X, Y) coordinates, as the light source:

$$E(x, y, z) = z^{m+1} I_0/[(x-X)^2+(y-Y)^2+Z^{2]}(m+2)/2 \quad (9)$$

LED SECONDARY OPTICS DESIGN

The shape of the LED is mainly formed by a cylinder and a hemispherical surface, in the process of constructing the LED entity model, the measured parameters available less, only the epoxy resin cylinder and the hemispherical surface of the set parameters. Epoxy resin inside of the LED chip, the shape and position of the reflector bowl are not accurately measured and the light intensity distribution can only rely on the estimation obtained after the model space and then tracing rays and compared with the actual measurement of the distribution, so that by repeatedly modify the parameters of the simulated light intensity distribution gradually close to the measured light intensity distribution, is considered good when the analog light intensity distribution and the measured light intensity distribution within the acceptable range, then the LED optical design is completed, can be used as two times optical design of the optical model use.

According the optical software Tracepro simulation steps, the first model, seen from a theoretical model of the LED light of the previous section and exit point when the photons leave the surface of the LED chip is randomly distributed in the surface of the chip and in the six faces of the chip are different degree of exit, but it the chip peripheral reflector bowls will change from the LED chip the edge of the path of the outgoing photon, in addition to the chip electrode at the bottom will absorb part of the photon, so we can use a cube said LED chip, set the cube's six surface light source, the light-emitting point in the surface of random distribution, that is, the light emission characteristics of the chip six faces centrally defined on one surface, so that both can accelerate the ray trace efficiency can sufficiently accurate. Of tablets three aspects of the chip, the reflector bowl and the mold to set the parameters: the size of the height of the light source, the size of the chip, the angle of aperture of the reflector bowl, stent insertion depth and the lens, the model shown in Fig. 6.

The reflector bowl opening angle change: When the reflector angle is large, the light emitted from the chip directly unchanged, less refraction of light from reflective bowl fired cylinders more light, so that reduces the normal light intensity; When the reflector bowls the opening angle is very small, the light emitted directly from the chip and toward cylindrical light becomes smaller and the refracted light rays from reflective bowl becomes large, the light intensity is still smaller. The figure shows that by the light intensity distribution, caused by changes in the inclination of the great changes in light intensity, perspective but did not cause significant changes (Table 1).

Chip depth of change: With the increase in depth of the chip, the reflector bowl away from the spherical top

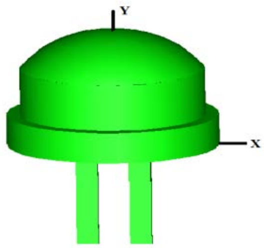

Fig. 6: A model of the LED tablets

Table 1: Light intensity and visual data of different reflector bowls angle

Opening angle of the reflector bowls	Light intensity	Visual angle
95°	0.0531cd	41.7°
105°	0.9615cd	43.5°
115°	0.8993cd	42.1°

Table 2: Light intensity and visual data of different clip insertion depth

Clip insertion depth	Light intensity	Visual angle
0.4 m	1.314cd	30.9 °
0.7 m	0.9023cd	43.1 °
1 m	0.4756cd	69.2 °

Table 3: Light intensity and visual data of different lens radius

Lens's radius	Light intensity	Visual angle
1.4 m	1.184cd	33.9 °
1.8 m	0.942cd	43.6 °
2.2 m	0.763cd	47.2°

farther, the smaller the proportion of the direct light, that is, a large part of the light emitted from outside the total reflection occurs in the other direction, but not from the ratio of light refracted by the reflector bowl change, the light refracted by the cylinders is increased, but such light proportion throughout the lighting ratio is little, so that the maximum light intensity becomes gradually smaller. Changes in perspective, indicating the depth of the chip, have a great impact on the viewing angle (Table 2).

Lens changes: As the lens radius increases, the proportion of direct-out chip increases, the refracted light through the lens the same proportion and the proportion of the light emitted by the cylindrical smaller, due to the increase of the radius, the effect by the reflective bowl incident spherical the incidence angle is small, to deviate from the law by the spherical refractive angle increases, the light divergence. The light intensity distribution more uniform and thus the light intensity becomes gradually smaller, the viewing angle becomes larger (Table 3).

LED ARRAY ILLUMINATION DISTRIBUTIONS

In recent years, the LEDs of the photoelectric conversion efficiency continued to improve, instead of other lighting products having great possibilities with LED. However, a single ultra-high brightness LED does not reach the level of illumination, it is necessary to combine multiple LED chips. The light emitting surface of such a light-emitting composition is neither a uniform surface light source, not a point light source alone, but rather a collection of a plurality of light emitting center, the light distribution curve, with traditional light sources, lighting of the composition of the illumination attachment device, whose function is to redistribute the light flux, in order to achieve the purpose of the rational utilization of the light source. Fan *et al*. (2011) LED for illumination, In addition to the environmental protection and energy saving in the exterior design of the illumination angle, brightness transform, transform according to demand and gave rise to a great free space. The optical design of the main tasks of the LED lighting system by the calculation of the light flux, to rational arrangement location of the LED, determining the number of LED's, to satisfy the lighting needs.

Two LED array: In this case, at a certain point of the target surface illuminance distribution, E is the illuminance of the LED in both superimposed, if two LED spacing is d, then we have the follow equation:

$$E(x,y,z) = \mathrm{z}^{\mathrm{m}} A_{LED} L_{LED} \{[(x-\frac{d}{2})^2 + y^2 + z^2]^{-(m+2)/2} + [(x+\frac{d}{2})^2 + y^2 + z^2]^{-(m+2)/2}\} \tag{10}$$

Adjusting the size of d, in contrast to the irradiation area of a single LED, the illuminance distribution can be uniform in a larger area. The starting point of the design of this arrangement is to eliminate both LED respective irradiation region between the peak luminance minimum value (Hinterberger and Winston, 2006).

Do second differential to Equation E and make $\frac{\partial^2 E}{\partial x^2} = 0$ x = 0, y = 0, we can obtain flat conditions of the maximum D:

$$d_0 = \sqrt{\frac{4}{m+3}}\, z \tag{11}$$

LED arrays arranged in the annular: In the application of machine vision systems, the most common LED light source is an annular LED array. Disposed ring of radius r, so that the target surface of the illuminance distribution E on the ring of the N LED illuminance value superimposed:

$$E(x,y,z) = \mathrm{z}^{\mathrm{m}} A_{LED} L_{LED} \sum_{n=1}^{N} \{[x - r\cos(\frac{2\pi n}{N})]^2 + [y - r\sin(\frac{2\pi n}{N})]^2 + z^2]^{-(m+2)/2} + z^2\}^{-(m+2)/2} \tag{12}$$

Illuminance distribution in a central area within the ring of radius r, can be adjusted so that the target surface approximately uniformly distributed, while in (cos (2πn/N), sin (2πn/N)) direction, especially evenly. Due to the symmetry of the arrangement in this model, we only need to study to illuminance distribution along the diameter of the shaft in a one-dimensional direction. Optimize of the ring of radius r and erase the illuminance of the center of the minimum value.

Do second differential to Equation E and make $\frac{\partial^2 E}{\partial x^2} = 0$ at x = 0, y = 0, we can obtain flat conditions of the maximum D:

$$r_0 = \sqrt{\frac{2}{m+2}}\, z \tag{13}$$

For only three LED ring model, flat condition can only get a small uniform irradiation region, by experiment, can be given a greater experience value of the flat region:

$$r_0 = \sqrt{\frac{1.851}{m+2.259}}\, z \tag{14}$$

Linearly arranged LED array: In the structured illumination, the most common LED light source is a linear LED array, in which case, the use of the N LED illuminance distribution E is:

$$E(x,y,z) = z^m A_{LED} L_{LED} \sum_{n=1}^{N} \{[x-(N+1-2n)\cos(\frac{2\pi n}{N})]^2 + [y - r\sin(\frac{2\pi n}{N})]^2 + z^2]^{-(m+2)/2} + z^2\}^{-(m+2)/2} \tag{15}$$

CONCLUSION

After repeated optical modeling, we complete ray tracing on the basis of the analysis of the system performance on the establishment of the basic method of the illumination optical system. The optical designed model can effectively improve the single the LDE law to the light intensity of the illumination optical system, which uses a rotational paraboloid as the reflecting body. The ray trace results show that: for the insertion depth of the reflector body according to different white LDE, there are two peak values of the light intensity and different causes. In addition, at this stage, LDE lighting use more LDE array forma and LDE array size of the spacing of the LEDs light uniformity and good agreement with theoretical calculations and computer simulations. Based on the above results, further research on lighting illuminance distribution of LDE street lamp road and factors that affect the road surface illuminance distribution would be analyzed.

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