Modeling Study of Red LED Spectral Characteristics

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Abstract. LED is widely used in various fields as a new style of light sources. Among the various characteristics of the LED, photoelectric characteristics are often the most intuitive and practical. This paper will discuss the photoelectric characteristics of red LED. A study on the relationship between the forward current and luminescence spectrum, peak wavelength, main wavelength, color purity, luminous flux, luminous efficiency is presented. The experimental results show that the spectrum, peak wavelength and main wavelength of the red LED will shift red with the increase of the forward current, and the color purity will remain at a high level during the period. In addition, the luminous flux and light intensity increase with the increase of forward current, the luminous flux from 0.5 lm to 3.5 lm, but the luminous efficiency decreases with the increase of forward current. from 40 lm/w to 32 lm/w.

Keywords: Driving current; LED; spectral characteristic; luminous efficiency.

1. Introduction

LED has many incomparable advantages, compared with other light sources. Firstly, the LED luminous efficiency is higher than that of other lighting tools, the maximum light efficiency LED in the laboratory has reached more than 200 lm/w, and the maximum light efficiency in the market has reached 160 lm/w, which is the most efficient lighting tool at present[1-5]. Secondly, because of the solid-state light source, the LED does not need to use fragile glass in packaging and only resin, which greatly enhances its impact resistance and makes it easier to preserve, while the very small volume also makes LED transport easier. The operating voltage LED again is low, with a single voltage of only 1.9 V~4 V, which is safer to use than high-voltage lighting tools such as HID lamps. In addition, the bandwidth of LED luminescence is narrower, so the luminous color is pure, no heterochromatic light, and visible light of any color can be formed by red, green and blue LED[6-10].

There are many parameters for LED. It includes luminous flux, optical efficiency, main wavelength, peak wavelength, chromaticity parameters, color coordinate, color purity, color temperature, and so on. In this paper, the influence of driving current on emission spectra of red LED has been investigated.

2. Experiment Theory

The LED luminescence spectrum refers to the distribution curve of the relative intensity of LED emitted light with wavelength. At the same time, the luminous spectrum also affects the luminous efficiency of the LED. Whereas, it is independent of the external conditions, such as the geometry of the device and the packaging mode. It is determined by the type, properties and structure of the luminescent center of the LED material.

The relationship between the photon wavelength \( \lambda \) and the energy difference \( \Delta E \) before and after the transition is shown as follows.
Where, \( h \) and \( c \) represent the Planck constant and the speed of light in a vacuum respectively. For LED, the energy difference before and after the transition is approximately equal to the band gap width \( (E_g) \) of the material, so the band gap width of the material determines the peak wavelength of the LED. However, for most semiconductor materials, due to the large refractive index, the emitted light usually reflects several times in the sample before emitting the semiconductor. In the meantime, short wave light is more easily absorbed than long wave light. So the energy of photon corresponding to peak wavelength is smaller than that of photon corresponding to forbidden band width.

In this paper, the conventional \( \Phi5 \) mm bullet-type red light LED is encapsulated by transparent epoxy resin. The LED emission spectrum and color quality were recorded by using comprehensive photoelectric parameter equipment (SSP6612). The system has a constant 3000mA current source with full control high precision, automatic light intensity distribution test system and 2040 pixel CCD spectrum analysis system. The test conditions are in accordance with the CIE specifications. When the forward current output is guaranteed, the forward voltage is automatically adjusted, and all tests are carried out at room temperature.

The photon energy \( (h\nu) \) of the optical transition can be represented by the following formula, according to the donor-acceptor (D-A) pair recombination theory.

\[
h\nu = E_g - E_D - E_A + \frac{e}{4\pi\varepsilon_0\varepsilon R}
\]

Where the \( E_g \) is the band gap width, the \( E_D \) is the binding energy of the donor, the \( E_A \) is the binding energy of the acceptor, the \( \varepsilon_0 \) is the dielectric constant, the \( e/\varepsilon R \) is the coulomb energy, and the \( R \) is the distance between the D-A pairs. Under the action of high current density, the LED power rises, which leads to the inevitable rise of PN junction temperature. Meanwhile, the increase of temperature will decrease the band gap of semiconductor. According to the formula, when the \( E_g \) decreases, the photon energy \( (h\nu) \) will decrease, so the frequency of photon will decrease, that is to say, the wavelength of photon will increase, it will lead to spectral red shift. Moreover, the increase of current enhances the ability of donor-acceptor energy level to capture electron-hole pairs, thus the D-A pair energy level widens and the \( R \) increases. According to the formula, when the \( R \) increases, the photon energy \( (h\nu) \) will also decrease. Therefore, the wavelength will also increase.

3. Results and Discussion

The red LED spectrum is shown as figure 1. From figure 1, we can see the shift of the peak of the luminescence spectrum with the increase driving current. With the increase of current, the peak of luminescence spectrum gradually shifts to the long wavelength. And the migration of the longer part is obviously larger than that of the shorter part.
The main cause of the luminescence spectrum drift is the thermal effect of the PN junction. Since there is no heat dissipation system for the low power red LED, when the current density increases, the heat production of the LED chip will increase greatly, and the heat generated will not diffuse out. As a result, the temperature of the LED chip increases which makes the LED luminescence spectrum drift.

![Red LED emitting spectrum](image1)

**Figure 1.** Red LED emitting spectrum.

In order to analyze the variation of luminescence wavelength with current more clearly, the change trend of peak wavelength with current increase can be shown in figure 2.

From figure 2, we can see that the peak wavelength will produce a jump at a certain current. In the case of small current, the increase of current will also produce localized state. Under the condition of small current, the peak wavelength increases slowly. When the domain state is filled, the peak wavelength increases rapidly, resulting in the jump, as shown in figure 2. However, the band gap will not decrease infinitely with the decrease of temperature, and the distance between D-A pairs will not increase infinitely with the increase of temperature, so the growth rate of peak wavelength will slow down again.

LED main wavelength rises with the increase of current. Compared with the change of peak wavelength, it is found that the change speed of main wavelength is different from that of peak wavelength. The narrower of the spectrum, the main wavelength is closer to the peak wavelength.

![Relationship between injection current and wavelength](image2)

**Figure 2.** The relationship between injection current and wavelength
(a) peak wavelength (b) main wavelength.
Because the spectrum of the sample is wide and the spectrum does not have good symmetry, the change speed of the main wavelength is obviously different from that of the peak wavelength.

![Graph showing the relationship between injection current and color purity](image)

**Figure 3.** The relationship between injection current and color pureness.

The degree is called color purity, which the color of the red LED is close to the main wavelength. It can be seen that the color purity will increase slightly with the increase of current and it always remains above 0.98, as shown in figure 3. Therefore, we can consider that the current size has little effect on the color purity of red light LED.

The luminous flux increases with the increase of current. When the current is small, the luminous flux increases linearly. When the current increases gradually, the luminous flux growth rate decreases gradually and finally tends to saturation, as shown in figure 4(a).

Because AlGaInP is a direct band gap semiconductor, the recombination of electron-hole pairs is mainly radiative recombination, which can emit photons. The number of photons produced by its recombination is proportional to the number of electron-hole pairs injected into it. When the current is small, some unfavorable factors, such as trap, radiation free center and junction temperature, have little effect on it, so the luminous flux increases linearly at small current. With the increase of current, the number of electron-hole pairs injected increases, the recombination efficiency increases, and the luminescence intensity increases, so the luminous flux increases. As the current increases, the luminous flux increases and the slope becomes smaller. When the current increases, the radiation-free composite component in the LED gradually rises and becomes the main contradiction. At the same time, the role of traps and harmful centers is becoming stronger and stronger, coupled with high junction temperature and high heat consumption, which slow down the growth rate of luminous flux. Furthermore, the high lattice mismatch rate between the AlGaInP and the substrate will produce some dislocation lines to form a radiation-free center. When the current increases, a large number of carriers will be trapped by the radiation-free center, which will slow down the increase of luminous flux. When the current reaches a certain degree, a large amount of energy will also be absorbed by the lattice and converted into heat energy, which will increase the junction temperature and lead to the quenching of the temperature caused by light radiation.
Figure 4. The relationship between injection current and (a) luminous flux (b) photoelectric efficiency

We can see that the light effect of the LED increases first and then decreases, as shown in figure 4(b). When the current is small, the adverse factors have little effect on the photon emission, the increase speed of luminous flux is larger than that of input power, so the luminous efficiency increases. Because more and more energy is absorbed by the lattice into heat energy when the current increases, the increase speed of input power is larger than that of luminous flux, so the light efficiency decreases.

4. Conclusions
In this paper, we investigated the relationship of red LED light luminescence spectrum, peak wavelength, main wavelength, color purity, luminous flux, luminous efficiency with forward current. The results show that the luminescence spectrum of the red LED is red-shifted with the increase of the forward current through the LED, and the longer the wavelength is, the greater the partial red-shifted degree is, and the luminous flux of the LED increases with the increase of the forward current, but the luminous efficiency decreases with the increase of the current. In the future, the actual work of LED can provide guidance and help, and more efficient.

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