Characteristics of high power LEDs at high and low temperature*

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Abstract: The high power light emitting diodes (LEDs) based on InGaN and AlGaInP individually are tested on line at temperatures from –30 to 100 ℃. The data are fitted to measure the relationship between temperature and the properties of forward voltage, relative light intensity, wavelength, and spectral bandwidth of two different kinds of LEDs. Why these properties changed and how these changes reflected on applications are also analyzed and compared with each other. The results show that temperature has a great influence on the performance and application of power LEDs. For applications at low temperature, the forward voltage rising and the peak wavelength blue-shifting must be considered; and at high temperature, the relative light intensity decreasing and the peak wavelength red-shifting must be considered.

Key words: power LEDs; low temperature; forward voltage; peak wavelength

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1. Introduction

Light emitting diodes (LEDs) based on AlGaInP and GaN semiconductor growth technology have enabled applications covering the entire visible spectrum. And these two kinds of LEDs can be packaged either individually or millions together for use in full color signs, automotive interiors and exterior signaling applications. LEDs have the following advantages: long life, low power consumption, compact size, ruggedness, cool operation and environmental friendliness. These lead to significant trends in LEDs, including increasing growth and adoption in the marketplace. High brightness LEDs have started to replace conventional incandescent light bulbs and halogen lamps in recent years. Solid-state lighting based on LEDs has created another revolution in the history of the lighting industry. With the development of brightness and efficiency and the extension of application areas, LED performance must meet different requirements, including working at different temperatures[1].

2. Experiment

Both InGaN blue and AlGaInP red 1 × 1 mm^2 die are packaged as standard 1 W high power LED lamps (shown in Fig. 1). Three lamps of each kind were chosen as the test sample. The red LEDs were numbered as R1–R3 and the blue LEDs as B1–B2. These LEDs were driven at 350 mA into an oven in a temperature range from –30 to 100 ℃, 10 ℃ as a step and the allowable error was ± 1 ℃. The spectrometer tested the LED optical properties when the light of the LEDs that went through optical fibers got into it.

During the experiment, all of the properties of the LEDs were tested after a 10 min delay at each temperature in order to keep the veracity of the results.

3. Test results and analysis

3.1. Relationship of relative light intensity with temperature

The relative light intensity of both kinds of LEDs increased at low temperature. The relative light intensity at 20 ℃ was normalized as 1. It is shown in Fig. 2 that as the temperature decreased from 20 to –30 ℃, the relative light intensity of the AlGaInP-based red power LEDs increased by about 10%, and the InGaN-based blue LEDs increased by about 9% on average. As shown in Fig. 2, the light intensity decreased as the temperature increased. There were several reasons for the high light intensity at low temperature. The lifetime, concentration and distribution state of carriers change with temperature, and then the spontaneous emission rate is varied by these factors. As the temperature was increased, the non-radiative recombination increased. The optical absorption in the epi-layer of the LED chip increased with rising temperature, reducing the LED optical output, so the relative light intensity of both kinds of LEDs decreased. Generally, the trends of the LED optical output changing with temperature are reversible. The relative

Fig. 1. Encapsulation sketch map of LED samples.

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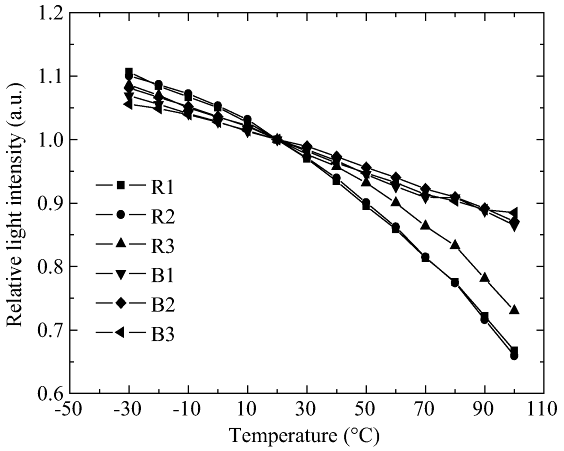

Fig. 2. Relationship of relative light intensity with temperature.

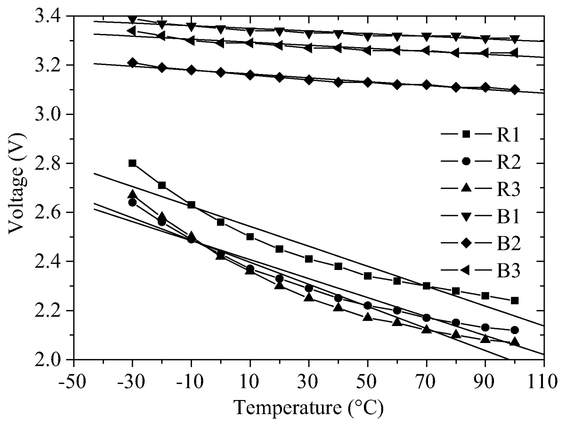

Fig. 3. Relationship of forward voltage with temperature.

light intensity drop of AlGaInP-based red high power LEDs was faster than that of GaN-based blue power LEDs when the temperature reached more than 20 ℃. The light relative intensity of the red LEDs at 100 ℃ dropped by about 31% at 20 ℃ on average; while the blue ones dropped by about 13% on average. The difference in light intensity between the different colors should be considered in the design of applications[2].

The forward voltage of LEDs depends on the properties of the semiconductor material, the fabrication process of the devices and so on. When the LEDs were driven on operation current and got to heat balance at any temperature, the forward voltages of the LEDs decreases as the temperature increased. It was shown in Fig. 3 that the forward voltage of both kinds of LEDs dropped with the environment temperature rising, and the forward voltage values of GaN-based blue LEDs showed more approximately linear dependence with temperatures than of AlGaInP-based red LEDs.

For a LED lamp, under a constant input current and neglecting the value of LEDs series resistance changing with temperature, the relationship between the forward voltage of the LEDs and temperatures can be described as

$$V_{\rm fT} = V_{\rm fT0} + K(T - T_0), \tag{1}$$

where T is the temperature inside the oven and T_0 is the room temperature; $V_{\rm fT}$ represents the value of forward voltage at T and $V_{\rm fT0}$ represents the value of forward voltage at T_0; K is the temperature coefficient of forward voltage. The K coefficient was calculated by fitting the data of experiment results displayed in Table 1. The average value of the K coefficient of AlGaInP-based red power LEDs is -4.1×10^{-3} V/K, while the average value of the K coefficient of GaN-based blue power LEDs is -6.4×10^{-4}. This means that the temperature of LEDs chip increased by 1 K, the forward voltage of the red LEDs decreased by -4.1×10^{-3} V, while the blue LEDs decreased by -6.4×10^{-4} V[2, 3].

Table 1. K coefficient of power LEDs fitted with Microsoft Origin.

Sample	K coefficient (V/K)
R1	-4.7×10^{-3}
R2	-3.9×10^{-3}
R3	-4.5×10^{-3}
B1	-5.3×10^{-4}
B2	-7.8×10^{-4}
B3	-6.2×10^{-4}

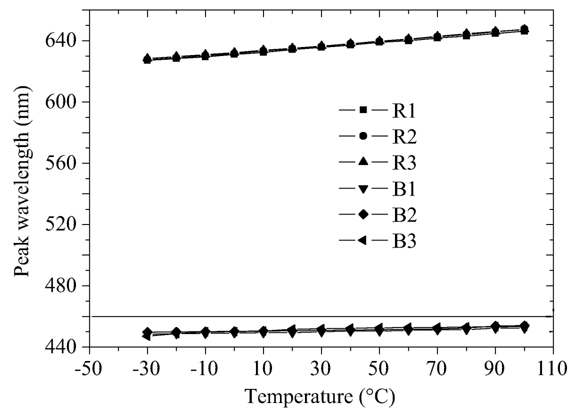

Fig. 4. Relationship of peak wavelength with temperatures.

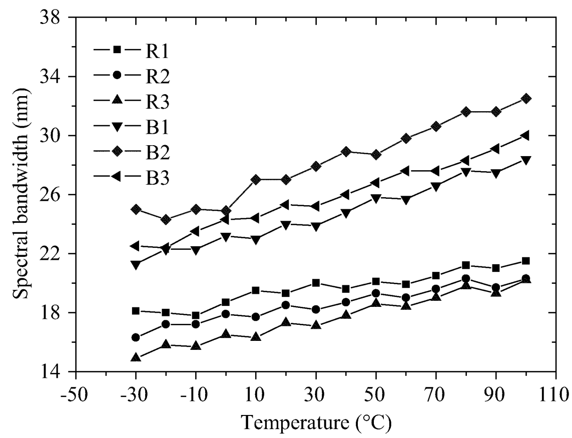

Fig. 5. Relationship of spectral bandwidth and temperature.

3.2. Relationship of peak wavelength and spectral bandwidth with temperature

The peak wavelength of LEDs was decided by the band gap of the LED active region. Figure 4 displays the relationship of the LED peak wavelength with temperature, and it can be seen that the peak wavelength of both kinds of LEDs was red shifted as the temperature rising, because the band gap width of the active region decreased with the temperature increasing. There are approximate linear correlation between the peak wavelength of both kinds of LEDs and the temperatures. And the peak wavelength of AlGaInP-based LEDs shifted more than that of GaN-based LEDs with rising temperature.

Figure 5 shows the relationship between spectral bandwidth and temperature. The value of both kinds of LED spectral bandwidth at low temperature was lower than that at room temperature, and the LED spectral bandwidth showed an increasing tendency with rising temperature. This broadening has many potential causes, including fluctuation of well width, compositional fluctuation, the low-energy tail of the band gap states, and variations among wells[4].

4. Conclusions

The temperature has great influence over the properties of both AlGaInP-based red and GaN-based blue high power LEDs. Under the condition that the environment temperature is low, the relative light intensity of both kinds of LED increases, and it seems to benefit the LED applications, but it should be taken into consideration that the increasing relative light intensity would involve people's visual acuity; the forward voltage increasing makes design of the driving circuit difficult, because there is a maximum voltage set inside the protection circuit for over voltage in all of the driving circuit to prevent all of the LEDs from breakdown, and the rising voltage might be over the maximum value of voltage set in the protection circuit, in this case the LEDs cannot work well even worse cannot be lighted up; the peak wavelength is blue shifted as well, and the blue-shifted peak wavelength will impact the applications of the chroma, especially in the full color display. In addition, junction temperatures of LEDs increase when driven at room temperature and the relative light intensity of LEDs decreases, the forward voltage drops and the peak wavelength is red shifted. Compared with the GaN-based LEDs, the properties of AlGaInP-based LEDs change more as the temperature increases, and this results in chromatic aberration when these two kinds of LEDs are applied as white lighting or full color display. These also should be considered in the applications of LEDs, except that the chromatic aberration, heavy input current or difference in temperature are the major problems of the applications of LEDs[5, 6].

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