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Review Article

Study on Optical and Thermal Uniformity of LED Filament Based on Flip Chip[1]

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Abstract:

The LED filament has become a research hotspot in industrial and academic fields. The filament was fabricated by the flip LED chip, and its optical and thermal uniformity was tested and analyzed in detail. The color temperature (CT), brightness and surface temperature (ST) of LED filament at different positions was measured by BM-7 aiming point luminance meter and Ti-32 infrared thermal imager respectively. The experimental results show that the brightness and ST of the filament conformed to the Lambert distribution. The filament was simulated by lightTools optical software and FLOEFD thermal software respectively, and the simulated illumination and temperature distribution were the same as the test results. Experimental results show that the CT and brightness of LED filament on both sides was 4.23% and 9.27% lower than that of the middle position, respectively. The ST difference of the whole device was 9.8^0C. The thermal parameters of LED filament were simulated by FLOEFD software. The simulated results indicated that the ST was distributed with high level in the middle and low level at both sides, the results of simulation and experiment are consistent. Therefore, it was reveled that the LED filament prepared based on the LED flip chip has good optical and thermal uniformity and be feasible as a new type of LED light source.

Keywords: LED Filament; Optical; Thermal; Flip Chip

Introduction

Light emitting diodes (LEDs) are the most promising cold light source in the previous century, which has been extensively used in street lamps, automotive hand lamps and even the liquid crystal display [1-3]. However, LED

filament now mainly faces two problems: one is heat dissipation; the other is the uniformity of stereoscopic luminescence [4-6]. LED filament bulb encapsulates the LED filament in the glass bubble, which can realize the full angle luminescence like incandescent bulb [7-8]. Hence, LED filament bulb is a new generation of LED lighting source with no blue light emission, energy efficiency and long operation life.

LED filament is the core of LED filament bulb, which are popular in academic and industrial fields [9]. A few blue chips were welded to aluminum alloy substrate, and then packaging into LED filament [10]. The flip LED chip adopts leaderless structure, and then the heat generated by the chip is directly transmitted to the package substrate through the solder bumps. Therefore, the LED filament has excellent reliability [11]. However, LED filament now mainly faces two problems: one is heat dissipation; the other is the uniformity of stereoscopic luminescence [12]. Evidently, the optical and thermal properties of these LED filament is closely related to the filament element. In heat dissipation, it is necessary to consider the shape of the phosphor and thermal conductivity of the substrate. The phosphor concentration and the chip size also play an important role on the optical properties [13-15]. However, few works have studied the optical and heat uniformity distribution of LED filaments due to its new lighting products, although they are widely applied in different fields.

In this paper, the spatial distribution of optical and thermal for LED filament based on flip chip and flat coating technology was studied in detail. The color temperature, brightness, and thermal distribution of the LED filament at different positions were measured to investigated their effects.

Experiments

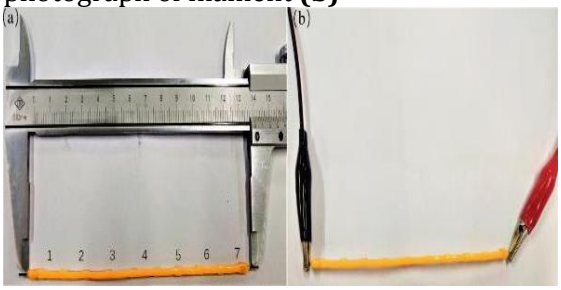
Sample preparations

Frist, forty-five blue chips were average distributed by using insulating adhesive and solder paste on the alloy aluminum substrate with a length of 14 cm [4]. The forward voltage of a single chip was 3.1~3.2 V, and the rated output power was 0.062 W at a current of 20 mA. The flip LED chip was cured by reflow soldering with a temperature of 180 0C for 40 s. An amount of yellow and red phosphors was uniformly mixed with the silicone resin in certain proportion, and the epoxy resin was coated on the substrate by flat coating technology. The epoxy resin was cured in the oven at 150 0C for 3h. The LED filament can be obtained while the preparations complete, as shown in (Figure 1).

Thermal and optical performance measurements

In order to obtain relevant data of LED filament, including the color temperature (CT), brightness and surface temperature (ST), the following experiments were completed. The seven points on the LED filament at equal intervals are selected. Take the position of the negative pole of LED filament as point one, and that of the positive pole as point seven, as shown in (Figure 1 (a)). The CT, brightness, and ST of each point on the LED filament was measured by BM-7 luminance meter and TI-32 infrared thermal imager when the driving current was 20mA, respectively. The numerical model of LED filament was established by the FLOEFD software for analyzing the temperature distribution.

Figure (1): The schematic of the selected test points on the LED filament **(a)** and photograph of filament **(b)**



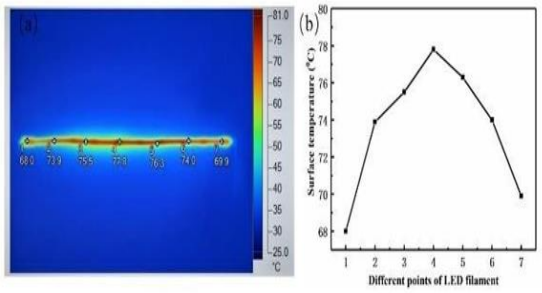
Results and discussions

Thermal performances of LED filament

(Figure 2) shows the steady state heat distribution of LED filament at seven points after 30 minutes with the driving current of 20 mA. It can be seen from the (Figure 2 (a)) that the highest temperature of LED filament mainly located at the point 3, 4 and

5. From the selected points, it can be concluded that the maximum temperature of LED filament was 77.8 0C. The maximum temperature difference of the LED filament was 9.8 0C. In (Figure 2(b)), the surface temperature of LED filament increases first and then decrease, reaching the maximum value at point 4. The high temperature in the middle of the LED filament is due to the concentration of the chip in the middle position, the slow convection with the air, and the edge can better release heat into the air, so the intermediate temperature is higher than the edge. The temperature of LED filament surface obtained by simulation is higher than the measured result due to the measured filament surface is coated with phosphor colloid.

Figure (2): The filament temperature was measured by infrared thermal imager **(a)** and temperature distribution curve of LED filament **(b)**



Simulation results of LED filament

In order to study the overall heat distribution of LED filament further, the LED filament model was established and analyzed by the FLOEFD software based on finite element analysis. LED filament is mainly composed of epoxy resin, chip, solder paste, and substrate. The maximum temperature difference of the LED filament by the experiment was 9.8 0C, indicating that the filament has a good heat dissipation effect in (Table 1). Through simplifying the model, some assumptions of numerical model are completed as shown below:

1. The temperature of the environment is set at 25 0C.
2. The optical power of LED filament could be obtained by spectrometer, thermal power was equal to electrical power minus optical power.
3. The thermophysical properties of material are independent of temperature.
4. The contact area is small, so the radiative heat transfer can be ignored.
5. The laminar and turbulent flow was three dimensional and steady.

According to isotropic homogenous materials and the law of energy conservation, the steady state govern equation are:

$$\nabla^2 T = \frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2} + \frac{\partial^2 T}{\partial Z^2} = -\frac{1}{K} Q(X, Y, Z)$$

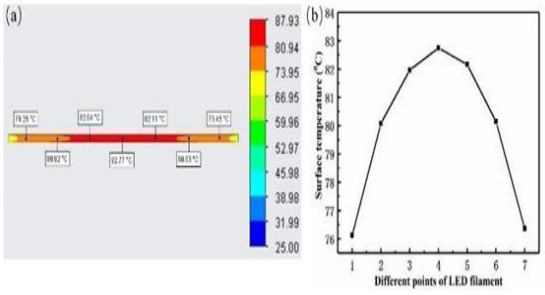
Where Q is generated heat by chips that serves as volume heat source, K is thermal conductivity, T is temperature, X, Y, Z is temperature field coordinates [16].

The simulation results of LED filament are listed in Fig. generally, the simulation and experiment results are roughly the same, and then the highest temperature of LED filament located in the middle. As can be seen from the simulation diagram, the maximum temperature of LED filament is 82.77 ^{0}C and the minimum temperature is 76.45 ^{0}C. The temperature of LED filament surface obtained by simulation is higher than the measured result due to the measured filament surface is coated with phosphor colloid.

Table (1): Material thermal conductivity used for LED filament simulation

Component	Material	Thermal conductivity	References
Chip	GaN	147	6,7
Substrate	Al+Cu	205	7,9,16
Solder paste	SnAgCu	58	6,15
Epoxy resin	Silica glue	0.3	7,15

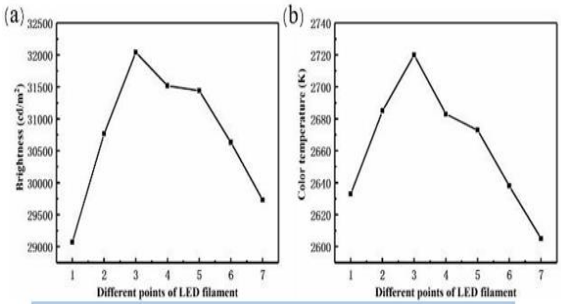
Figure (3): The filament temperature was measured by FLOEFD software **(a)** and simulation of temperature distribution curve of LED filament **(b)**



Luminous performances of LED filament

(Figure 4) shows that the brightness and CT of LED filament with the driving current of 20 mA at ten points. It can be easily seen from the Fig.4 that the brightness and CT increased gradually from point 1 to 3, reaching the maximum value of 32044 cd/m2 and 2720 K respectively at point 3. The color temperature difference of LED filament was 115 K, and its uniformity was 95.8 %. The brightness on both sides of the filament was about 90.7 % of the brightness in the middle. For the phosphor coating, the phosphor concentration is uniform. Due to the concentration of the chips in the middle of the LED filament, more blue light is emitting than on both sides of the filament, so the color temperature and lightness in the middle of the filament are higher than on both sides.

Figure (4): Luminous properties of filament at different points (a) Brightness (b) Color temperature



Conclusions

In this paper, the key influencing factors of LED filament based on flip LED chip are analyzed in detail: color temperature (CT), brightness and surface temperature (ST). It can be found from the test that the LED filament is lighting for 30 minutes with the driving current of 20 mA and the brightness on both sides of the filament was lower than that of filament in the middle. The average color temperature of LED filament is 2662K, indicating that coating phosphor resin can make the filament glow evenly. The maximum temperature difference of the LED filament by the experiment was 9.8 0C, indicating that the filament has a good heat dissipation effect. Through thermal simulation software, the maximum temperature difference of the filament is 6.52 0C, which is basically consistent with the experiment result. In conclusion, LED filament prepared based on flip LED chip has good optical uniformity and heat dissipation performance, which is feasible as a new LED light source.

Acknowledgements

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