Optical and thermal properties of flip-chip LED bulbs using chip-scale package

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Abstract: A kind of LED bulb which is made by the school and enterprise is introduced in this paper. Fluorescent film is used for chip-scale packaging on flip-chip LED. The film is made by spin coating method, bonded to the surface of the chip and cut off by laser and then finished by a simple process. The optical properties and thermal properties of the LED bulbs were measured by various methods. The experimental results showed that with the increasing of the voltage, color temperature and the color rendering index changing 0.522% and 0.200% respectively which can be seen as a relatively stable data. The highest surface temperature of the flip-chip LEDs using chip-scale package we estimated which can be kept between 133.8°C and 135°C can also be accepted. These results have a certain guiding significance for the industrialization of the LED bulbs.

1. Introduction
LED is considered to be the most important light source in solid-state lighting due to its advantages in energy efficiency, long life, vivid color, high reliability, environmental protection, safety and multiple applications [1-3]. The research on improving the performance of LEDs has been widely reported in literatures. For example, excellent LED packaging technology can improve the performance of LED in many ways, such as optical, thermal and mechanical properties, especially light extraction efficiency [4-7].

LED packaging technology is mainly focused on the optimization of LED packaging materials and structures [8]. LED packaging technology follows the application needs and it reflects the development of LED chip technology. From the through-hole type to the surface mounted devices (SMD), the LED package has witnessed the development of high power / brightness solid state lighting (SSL) products and market demand [9]. When the market demand for high brightness LED light source and heat sink becomes more and more important, the flip chip (FC) LED has been developed, in order to provide a new perspective for LED packaging and lighting modules [10].
Figure 1. (a) Illustration of typical chip-scale package (CSP) structure and (b) the dimension comparison of SMD type LED packaging and CSP.

By virtue of the excellent thermal conductivity of the FC, the chip scale package (CSP) is developed, as shown in figure 1 [11]. LED CSP maximizes the cost reduction of the batch process, and provides the ultimate size design freedom to get rid of the limitations of the leadframe. Therefore, LED CSP can be customized for the specified application scenarios [12].

2. Experiment
The fluorescent film used for packaging is made by spin coating method and the thickness is about 0.35mm. The chips are packaged in a 1.35*1.35 *0.5 mm dimension. Chips(1.35*1.35*0.5mm) manufactured by TECORE SYNCHEM, Inc. of Tianjin and CSP LED bulb manufactured by Zhejiang Emitting Optoelectronic Technology company, shown in figure 2, were used in this study.

Figure 2. Flip-chip LED bulb lamp with CSP.

The manufacturing process of CSP LEDs is shown in figure 3. Chips packaged with fluorescent film. Under a certain pressure, film heated to a certain temperature was pressed on the rearranged chips with a press machine. The thickness of the film on the top face can be controlled by the height of a kind of blocks setting on the operating platform. The pressed chips coated with film was baked in an oven for three hours at a temperature of 300°C. Then, cutting tools with different thickness is used to cut the semi-finished products accurately after baking, and than CSP LED can be obtained. Compared with traditional packaging method, this packaging method is simpler, quicker and lower cost.
3. Results and discussion

3.1. Optical characteristics of FC-LED bulbs with CSP

The luminous flux and light effect with the change of voltage of CSP LED bulbs are as showed in figure 5. We can see that with the increase of the voltage from 220V to 240V luminous flux decreased from 560.9lm to 545.8lm which means there is only 2.69% reduction. Meanwhile luminous efficacy
drops from 89.6lm/W to 85.9lm/W, a variety of 4.13%. Figure 4 shows the change of color temperature and color rendering index with voltage rising. With the increasing of the voltage, correlated color temperature increased gradually and the color rendering index decreased slightly, changing 0.522% and 0.200% respectively. It can be seen that CSP LED bulbs’ optical performance is very stable and efficient despite a substantial change of voltage.

Figure 4. (a) Luminous flux and luminous efficacy under varying voltage; (b) correlated color temperature (CCT) and Color Rendition Index (CRI) under varying voltage.

3.2. Thermal characteristics of FC-LED bulbs with CSP

Temperature has an important influence on the lifetime of LED bulbs, so we have adopted a variety of means to estimate the exact operating temperature of the flip-chip LED bulbs with CSP at steady state. The result of the thermal imager is shown in figure 6 from which we can see the rough temperature of substrate surface and chips. Because this method of testing temperature is influenced by environmental factors seriously, the data is not very stable. We chose an ideal date which shows the temperature of substrate surface and chips is around 65.9 °C and 91.5 °C, respectively. Then in order to get a more accurate data, thermocouples were chosen to measure the temperature of the chip surface and substrate surface directly. Figure 7 shows variation of the surface temperature of the chip and the substrate surface temperature measured by thermocouples. The results show that the temperature of the chip and substrate tends to be stable after 30 minutes. The heating process is shown in figure 7. It can be seen from the figure that the surface temperature of four chips is relatively close, however, the surface temperature of substrate, due to the different chosen points, is not quite similar. The measured results after lighting on 30 minutes is recorded in table 1 from which the average temperature of chips and substrate is 111.03 °C and 81.77 °C, respectively. Although this method of testing the temperature is relatively accurate but there is still some difference from the actual lighting bulb. Because the bulb shell can not be covered when the bulb is being measured, we can not figure out the error of the test temperature caused by the difference of air flow condition.

Table 1. Temperature of chips and substrate.

| Temperature of chips(°C) | 1   | 2   | 3   | 4   | Avg  |
|--------------------------|-----|-----|-----|-----|------|
| 112.9                    | 107.1| 110.3| 113.8|     | 111.03|
| Temperature of substrate(°C) | 5   | 6   | 7   | 8   | Avg  |
| 81.8                     | 72.3| 84.9| 88.1|     | 81.77|
Figure 6. Thermal imaging results of flip-chip LEDs bulb lamp with CSP.

Figure 7. Temperature of chips and substrate measured by thermocouple.

Figure 8. Model established by ProE.
Figure 9. Temperature of flip-chip LEDs using CSP bulb lamp for the simulation.

A three-dimensional model was built by a modeling software named Pro/Engineer to simulate the heat performance of flip-chip CSP LED bulbs. The model established with 64582 grids totally is showed in figure 8. After 160 iterations, the results obtained are shown in figure 9. In the simulation results, the temperature of the eight chips is between 133.8 °C to 135.0 °C and the temperature of the whole body is from 32.8 °C to 136.4 °C, and the average temperature of the lamp is about 80 °C. It can be seen from the figure that the results of simulation is about 22 °C higher than the results of thermocouples. It indicates that the bulb shell have a certain impact on the chip temperature. From the above several methods of testing temperature, we can estimate the actual operating temperature of the flip-chip LEDs with CSP should be about 120 °C.

4. Conclusions

According to the experiment results above, we can conclude that flip-chip LED bulbs using chip-sale package have a lot of outstanding performance. When the voltage change from 220v to 240v, the luminous flux and luminous efficacy declined just 2.69% and 4.13%, respectively, and the color temperature and color rendering index changed 0.522% and 0.200%, respectively. It means the chip-scale package making a really stable optical properties for flip-chip LED bulbs while the voltage changed violently. Thermal simulation of the flip-chip LED bulb with chip-sale package shows the highest temperature of the chip is 136.4 °C under a power of 7w. Temperature results measured from the thermocouples shows the highest temperature of the chip is 113.8 °C under a voltage of 220v. Based on the above two results, we estimate the temperature of the chip is about 120 °C. All the data indicate that the CSP packaging and flip-chip structure provide excellent performance for the whole bulb. The results of this experiment verify the excellent properties of flip-chip LED using CSP, which is of great significance to the industrialization.

References

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