Heat Dissipation Analysis of High Power LED Package

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Abstract

With the increasing output power of LED chip, heat dissipation analysis and design of high-power LED has become one of the key technologies of LED packaging. In this paper, the three-dimensional packaging model of high-power LED is established. The finite element method is used to simulate the temperature field distribution of LED. The influence of bonding material and substrate thickness on the heat dissipation of LED package is analyzed by changing the relevant parameters of LED package, and this method has a certain guiding significance on optimizing the LED package.

1. Introduction

With the advantages of non-polluting, high efficiency, long life, small size [1-4], LED has become the most promising lighting source. At present, the luminous efficiency of LED can only reach 10% to 20%, and the remaining 80% to 90% of the heat are converted into heat energy [5,6]. The heat concentrated in the small size of the chip cannot effectively spread out, which may lead to the increased chip temperature, the reduction of luminous efficiency, the decreased color rendering index, the acceleration of the aging of its fluorescent device and a series of consequences, thereby reducing the normal LED Working life [7-9], In addition, with the electronic assembly density and power of the devices continue to increase, heat per unit volume is getting higher and higher。Data show that the failure of the device is often closely related to its operating temperature. If the device operating temperature increases by 10 ℃, the failure rate will increase by 1 times [10]. Therefore, it is of great theoretical and practical significance to study the heat dissipation of high power LED. The cost will be extremely large if we merely rely on experience to develop high reliability LED package, so it is significant to optimize the high power LED package by finite element numerical simulation. In this paper, a finite element numerical model is established for a typical high power LED, and its steady-state temperature field distribution is calculated. On this basis, the bonding material, substrate and other factors on the LED heat dissipation effect are further analyzed.

2. Thermal Model of High Power LED

According to the theory of steady heat conduction, the thermal differential equation related to the thermal analysis of LED package is established, that is, Poisson equation:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{q_v}{k}=0 \tag{1}$$

where q_v represents the heat flux density, which means the heat flow rate per unit area in unit time, and its unit is W/m^2. Poisson equation is the temperature field control equation of constant property, steady and three-dimensional with the heat source.

The heat convection problem discussed in heat transfer is mainly convective heat transfer process. Convective heat transfer is the exchange of heat between the surface of the solid and the fluid that is in contact with it, due to the presence of temperature difference. The convective heat transfer of the outer surface of the LED device with the ambient air is described by the Newton's equation of cooling, as follows：

$$q=h(T_S-T_B) \tag{2}$$

Where h is the convective heat transfer coefficient or the surface heat transfer coefficient, which is a physical quantity reflecting the strength of the convective heat transfer process, and its unit is W/(m^2·K), of which the physical meaning is heat flow through the unit area with the unit temperature difference. The surface heat transfer coefficient is related to many factors in the heat transfer process. It depends not only on the physical properties of the object, the shape, size, relative position of the heat transfer surface, but also the velocity of the fluid. TS is the temperature of the solid surface, and TB is the temperature of the surrounding fluid.

3. Finite Element Analysis

3.1 Geometric model

The finite element model of high power LED is established, as shown in Fig. 1 and Fig. 2. The model is mainly composed of (1) GaN chip, (2) bonding material, (3) internal heat sink, (4) pin, (5) filled silica gel, (6) lens, (7) plastic shell, (8) aluminum plate.

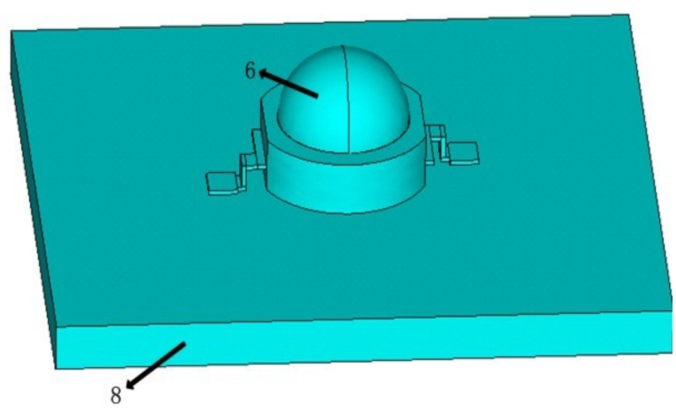

Fig.1: Working model of high power LED.

The chip size is 1 mm×1 mm×0.25 mm. The power of chip is 1 W and the ambient temperature is 25 ℃. In the analysis, the heat load of the size of 3.20×10^9 W/(m^2·K) was added to the chip, ignoring the thermal radiation effect. The thermal performance parameters for each material in the LED model are shown in Table 1.

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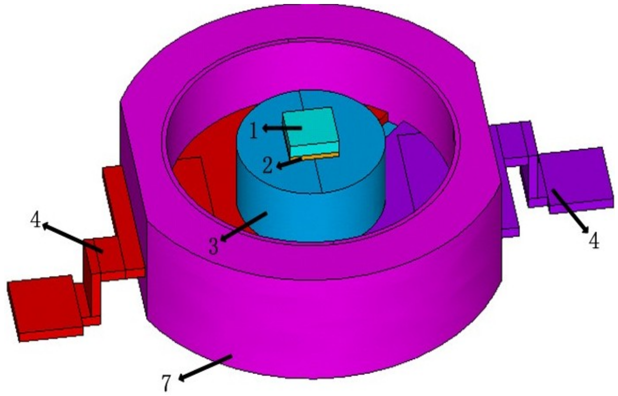

Fig.2: Internal structure of high power LED.

Material	Thermal conductivity /W/(m^2·K)	Material	Thermal conductivity /W/(m^2·K)
Chip	170	Filled Silica Gel	6
Bonding Material	2.80	Lens	0.20
Internal Heat Sink	401	Aluminum Plate	237
Pin	237	Plastic Shell	0.0768

Table.1: Thermal conductivity of each material in the LED model.

3.2 Results and analysis of simulation

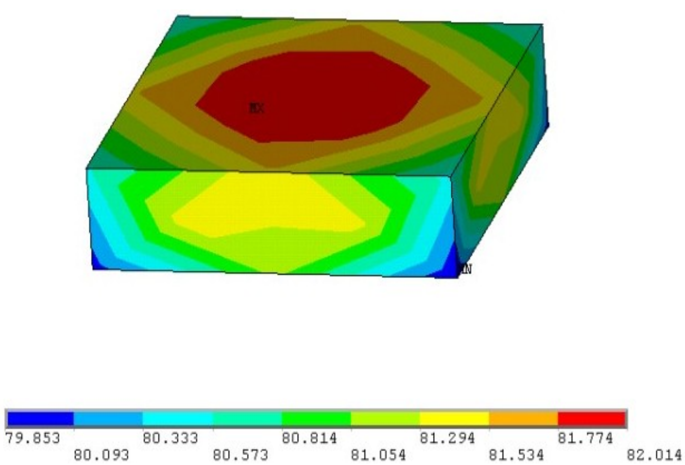

Fig.3: Temperature distribution of the chip at steady state.

The temperature distribution of the chip can be obtained by steady state analysis of the finite element model, as shown in Fig.3. It can be seen from the figure, after reaching steady state, the chip's maximum temperature is 82.01 ℃ and the minimum temperature is 79.85 ℃. The temperature distribution of the whole model is shown in Fig.4, of which the maximum temperature of the outer surface is 73 ℃ and appears at the position of lens. The temperature of plastic shell is the lowest, and the temperature difference between the chip is also the largest, which is due to the very low thermal conductivity of plastic and the great thermal resistance that both result in the difficulty of the dissipation of heat. The internal copper heat sink and the substrate both have high thermal conductivity, which makes heat can be easily distributed out and makes the substrate temperature and chip temperature are relatively close, thus the temperature difference is small. The vast majority of heat generated by the chip is distributed into the air through them.

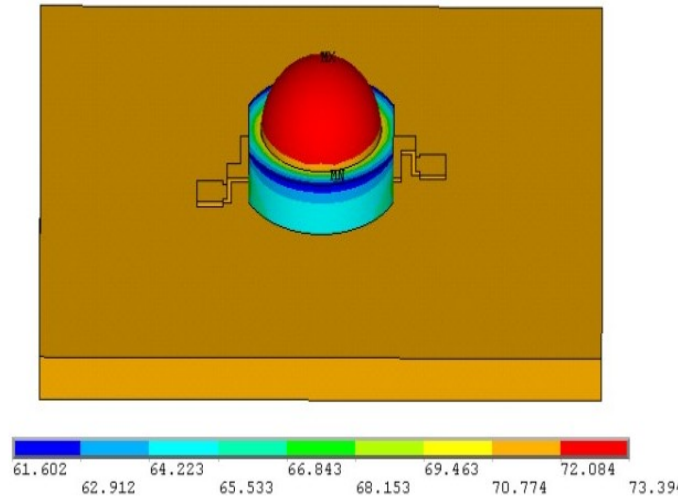

Fig.4: Temperature distribution of the whole model at steady state.

3.3 Analysis of bonding material

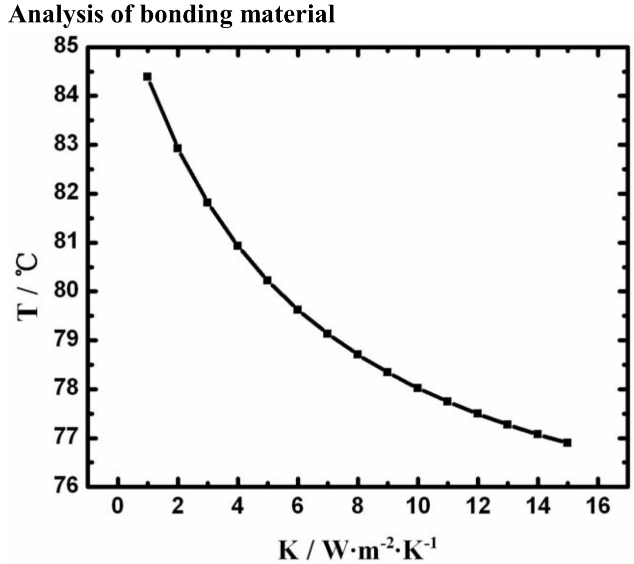

Fig.5: Curve of the junction temperature of the chip with varied thermal conductivity of bonding material

The existing research results show that the bonding material has a great influence on the heat dissipation performance of the high power LED package [11-12]. Small thermal conductivity and large thermal resistance of the bonding material impede the dissipation of heat. What's more, the bonding material is in the middle of the main cooling channel, which seriously hinders the dissipation of LED heat.

Figure.5 shows the variation curve of the junction temperature of the chip with thermal conductivity of bonding material. It can be seen from the Fig.5 that increasing the thermal conductivity of the bonding material can reduce the junction temperature of the chip to a certain extent. When the thermal conductivity is low, the chip junction temperature

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decreased significantly. However, with the gradually increased thermal conductivity, the rate of descent of the junction temperature tends to be gentle. We can conclude that under the existing technical conditions, the higher the thermal conductivity of the bonding material, the better the cooling effect of LED, but the effect is less and less obvious.

3.4 Analysis of substrate thickness

The heat generated by LED chip is distributed to the air mainly through the substrate that plays a vital role in the dissipation of the heat, thus it can be reasonable that increasing the thickness of the substrate may enhance the cooling effect. Fig.6 demonstrates the effect of substrate thickness on LED junction temperature. As shown in Fig.6, with increasing substrate thickness the LED junction temperature reduced approximately linearly, indicating that increasing the thickness of the substrate can achieve the purpose of enhancing heat dissipation. Substrate thickness of 2 mm-3 mm is proper, when we take the price factor into account.

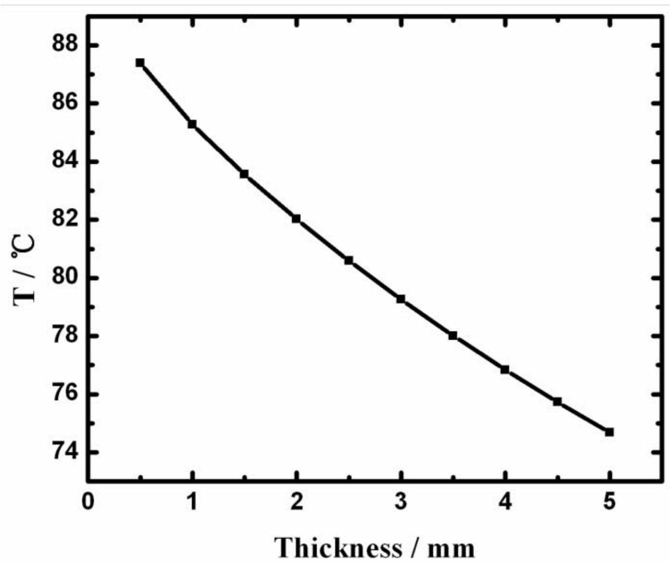

Fig.6: Curve of the LED junction temperature with the varied substrate thickness

3.5 Analysis of pins and internal heat sink

The internal heat sink of LED package generally use copper as a material while the pins use aluminum as a material, and some manufacturers use internal hot-dip silver and pin gold plating method in order to reduce the LED junction temperature.

The temperature distribution of the chip with silver internal heat sink is shown in Fig.7. It can be seen that the maximum temperature of the chip is 81.978 ℃, and the temperature almost never decline compared to the previous 82.014 ℃, which indicates that the internal heat sink with a higher thermal conductivity of silver or silver plating surface have no significant effect on reducing the chip junction temperature. Similarly, Fig.8 shows that the pin gold plating cannot significantly reduce the LED junction temperature. The thermal conductivities of the two components are high enough to dissipate the heat, so it is not worth continuing to increase their thermal conductivity by using hot silver or silver plating pin, which cannot achieve the desired results but increases the cost.

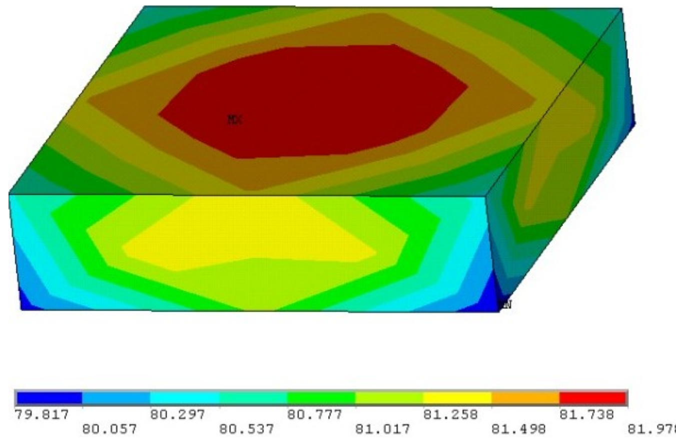

Fig.7: Temperature distribution of the chip with the silver heat sink

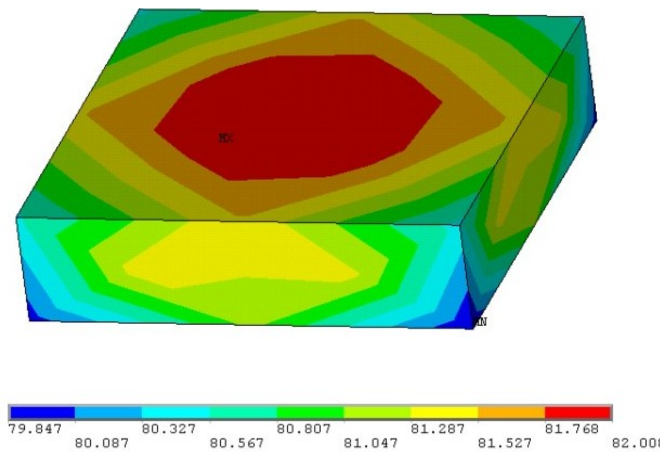

Fig.8: Temperature distribution of the chip when the pin material is gold

Conclusions

In this paper, a finite element numerical model is established for a typical high power LED, and its steady-state temperature field distribution is calculated. On this basis, the influence of bonding materials, substrate and other factors on the thermal performance of LED is further analyzed. The conclusion is as follows:

(1) Under the existing technical conditions, the higher the thermal conductivity of the bonding material, the better the LED cooling effect. But with the gradual increase in thermal conductivity, the effect is less and less obvious.

(2) The thermal performance of the LED can be greatly enhanced by increasing the thickness of the substrate. Taking the cost factor into account, the substrate thickness is generally selected as 2 mm-3 mm appropriately.

(3) The thermal conductivities of the internal copper heat sink and aluminum pin are high enough to dissipate the heat, so it is not worth continuing to increase their thermal conductivity by using hot silver or silver plating pin, which has little effect but increases the cost.

The finite element analysis results provide an important reference for the thermal optimization design of high power

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LED, which is instructive for the actual engineering development of LED.

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