Simulation analysis the effect of heat sink fins on the high-power LED

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Abstract: In this study, the heat dissipation of high-power LED with different heat sink fin thickness and space values is analyzed in detail, in order to tackle the problem of high-power LED overheating. It is shown that an increase in the heat sink fins’ thickness initially improves the high-power LED cooling effect, but this improvement is not obvious until the above thickness reaches 3 mm. At the same time, the heat sink fins’ space can also enhance the cooling effect, but when it attains 5 mm, the cooling ability is decreased instead. Through the comparative analysis of the thermal performance of high-power LED with different heat sink fins thickness and space values, it is proved that the junction temperature is minimum, when the heat sink fin thickness and space are 3 and 5 mm, respectively.

1. Introduction

Light-emitting diodes (LED), as the fourth-generation light sources, attract more and more attention and are increasingly applied in many fields, including displays, illumination lamps, and so on. Moreover, they have many advantages, including good monochromatic properties, long lifetime and high efficiency. Although LED has high luminous efficiency, 70% of the energy in the device is consumed in the form of heat [1-2]. We should reduce the LED chip junction temperature, in order to broaden the application fields, especially in the automotive headlamp industry. Now, the chip junction temperature is very high, if the power of the LED exceeds 1W, even up to 5W, or its power density reaches 100 W/cm² [3]. This may lead to dominant wavelength drift, decrease of photoelectric conversion efficiency and reduction of lifetime [4]. Moreover, if the heat is not released in time, some problems can occur, including the decline in stability, reduction of photoelectric conversion efficiency, damage to printed circuit boards, and declining life span. Urgent measures are required to minimize the heat generated in the LED chips. Among the effective solutions, the heat sink is a good candidate for reducing the temperature in the LED chip and improving the photoelectric conversion efficiency [5]. Several alternative LED chip temperature-reducing methods have been proposed by researchers [6-10]. In this paper, the comparative analysis of the affection of heat sink fin thickness and space on the heat radiation for high power LED.

2. Theoretical model

The equations of continuity, momentum and energy with buoyance are given below as equations (1), (2) and (3), respectively, to calculate the heat sink transfer capability of heat.

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho U) = 0
\]

(1)

\[
\frac{\partial (\rho U)}{\partial t} + \nabla \cdot (\rho U U^T) = -\nabla p + \nabla \tau + S_i
\]

(2)
\[
\frac{\partial (\rho h_{tot})}{\partial t} - \frac{\partial (\rho)}{\partial t} + \nabla \cdot (\rho \mathbf{U}_{tot}) = \nabla \cdot (\lambda \nabla T) + \nabla \cdot (\mathbf{U} \cdot \tau) + \mathbf{U} \cdot \mathbf{S}_v
\]  

Here \(S_v\) is the buoyance in the equation of momentum, as shown in equation (2), and the radiation in the equation of energy is also neglected in the model [11], as shown in equation (3). The essence of heat conduction is that the molecular thermal motions of a large number of materials collide with each other. The heat can be transferred from the part of high temperature to that of low temperature, or from the high temperature objects to the low temperature objects. The heat conduction equation is shown as equation (4).

\[
Q = \frac{kS(T_1 - T_2)}{L}
\]

where \(Q\) is the thermal flux, \(k\) is the heat conductivity coefficient, \(S\) is the heat conduction area, \(L\) is the heat conduction thickness, \(T_1\) and \(T_2\) are the contact surface temperature, respectively. It can be concluded that the heat conduction is directly proportional to the thermal conductivity, the heat conduction area and the temperature difference, and inversely proportional to thickness, as shown in equation (4).

The heat transfer inside the solid can only be carried out in a conductive manner. Whereas, the heat transfer process between the fluid and the substrate and radiator wall usually includes convection and conduction, there is thermal radiation for high temperature solids or fluids [12]. Thermal radiation is also a way of heat transfer; it is different with heat conduction and convection. It can transfer heat directly from one system to another by medium. If the object temperature is above 0K, it can radiate heat outside because of the personal temperature, it is called thermal radiation. The radiation capability of black body is highest in the same temperature, compared others, and the heat flux of radiation can be calculated by equation (5).

\[
E = \sigma T_b^4
\]

where \(T_b\) is the black body surface thermodynamic temperature, \(\sigma\) is the black body radiation constant.

Heat produced by chip ration, convection by liquid and air are loaded in the simulation. In generally, the photoelectric transformation efficiency of chip is 20%. The changed heat between wall and liquid is shown as equation (6).

\[
Q = h \times A \times \Delta T
\]

where \(h\), \(A\), and \(\Delta T\) are surface-delivered heat coefficient, delivered heat area and temperature difference between wall and liquid, respectively. The convection coefficient is 10w/m\(^2\)C, the room temperature is 25\(^\circ\)C.

| Parameter                  | Red LED chip | Green LED chip | Blue LED chip |
|----------------------------|--------------|----------------|--------------|
| Peak wavelength(nm)        | 620          | 525            | 470          |
| Full width half maximum (nm)| 18           | 40             | 24           |
| Forward current(mA)        | 350          | 350            | 350          |
| Forward voltage(V)         | 2.7          | 3.6            | 3.6          |
| Luminous efficiency(lm/W)  | 38           | 40             | 11           |
The heat radiation is simulated by the finite element method using the ANSYS commercial software. The array of chip on the base is 12×12, the power of all chips is 166W. The chips key parameter is shown as table 1. Because the part of model is symmetric, the 1/4 model is studied in the paper. The three dimensional eight panel point unit of SOLID70 is selected in the course of heat analysis. The R, G, B based chip is reduced to a unit in the simplified figure of chip model, as shown in figure 1. The size of chip is 1.5×2×0.01.

![Figure 1. Schematics of chip array on the base in 1/4 model](image)

### 3. Results and Discussion

The effect of heat sink fins thickness on the LED junction temperature is studied. The LED temperature distribution based on different heat sink fins thickness is shown in figure 2. When the heat sink fins thickness is low, the surface area of radiation is increased with the heat sink fins’ thickness. It can improve the heat dissipation. However, the space between fins gets narrower with the increase in the heat sink fins’ thickness. The heat dissipation becomes slower, when the heat sink fins thickness is above 3 mm.

The LED temperature distribution based on different heat sink fins space is shown in figure 3. When the heat sink fins space is narrow, the interspace between the fins is small; the heat dissipation ability can be improved with the increase in the heat sink fins’ space. However, the heat sink fins are far from chip center with the heat sink fins’ space increase. So the heat dissipation becomes worse instead, when the heat sink fins space is above 5 mm.
Figure 2. The LED temperature distribution with different heat sink fins

Figure 3. The LED temperature distribution with different heat sink fins
Based on figures 2 and 3, the relationship between the heat sink fins thickness, space and the LED junction temperature are gained, respectively, as is shown in figure 4.

![Figure 4. The LED junction temperature curve with different heat sink fins thickness and space](image)

It is shown that the heat dissipation is more significant with the added of heat sink fins thickness, but when the thickness is more 3mm, the space between fins is narrower and narrower, the flow air gets worse, the heat dissipation becomes slower and slower, the decline of LED junction temperature is not obvious, as shown in figure 2 and 4. The LED junction temperature decreases with the added of heat sink fins space, but when the space is beyond 5mm, the heat sink fins is far from chip center when the size of heat sink is the same, the temperature rises instead, as shown in figures 3 and 4.

4. Conclusions
The heat dissipation of high-power LED at different heat sink fins’ thickness and space values was analyzed in detail. It is shown that an increase in heat sink fins’ thickness improves the heat dissipation, which effect is most pronounced when the thickness exceeds 3 mm. The airflow can be affected, when the space between the heat sink fins is too small, then the heat cannot be effectively dispersed. On the other hand, if the space is too large, the chip center is far from the heat sink fins and the heat in chip center cannot be dispersed. The high-power LED junction temperature is minimum, when the heat sink fin thickness and space are 3 and 5 mm, respectively.

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