The heat dissipation performance of LED applied a MHP

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ABSTRACT

This study will discuss the heat dissipation effect of light emitting diode (LED) device applied a commercial miniature heat pipe (MHP). For lowering the thermal resistance of LED, the MHP can reduce the working temperature and raise the allowable input power of LED chip obviously. By comparing with a copper rod, the LED temperature was decreased about 19\% at 1.59\textsuperscript{W} input power and the LED power was increased about 43\% under 118\textdegree C chip temperature. On the other hand, the thermal resistance of LED also can be reduced by using a thinner slug. Moreover, the results showed that the thermal spreading effect was significant. The MHP could be used to avoid the hot spot of LED packaging due to its excellent heat spreading property. Simultaneously, a LED thermal simulation was carried out to verify the optimum value of slug thickness.

Keywords: Miniature heat pipe (MHP), heat dissipation, LED

1. INTRODUCTION

In the past decade, LED has shown the powerful potential in solid-state lighting filed. Therefore, the developing of key technology and the rising for lighting efficiency are the important subjects\[1,2\]. For increasing the luminous flux of LED, the input power for chip of LED needs to be greater than before, and the thermal density inside LED will increase violently. However, the luminous efficiency and the life of chip will decrease at the high temperature condition, even the chip may be out of order or damaged\[3-5\]. A good packaging technology is the way to solve the heat dissipation problem, but it is a challenge to develop this technology in the limited space of LED\[6\].

The purpose of heat dissipating technology for LED is to decrease the working temperature of LED’s chip. It is necessary to reduce the thermal resistance of LED package\[7\]. For example, we could use a material with high thermal conductivity and design a package with low thermal resistance. The dimension of chip is tiny, so the high heat dissipating technology of LED has to be developed in micro scale.

The heat pipe can transfer heat flux in high efficiency, and it is a passive component that can be used conveniently. It owns not only high latent heat capacity by means of phase change mechanism, but also the excellent thermal spreading
ability [8-10]. Based on these advantages of heat pipe, the present study will use the commercial heat pipe in heat dissipation for LED. Then we use a copper rod with the same dimension to compare with the heat pipe and to discuss the decreasing effect in thermal resistance of LED. At last we changed the thickness of LED slug to survey the effect in thermal resistance of LED package, and carried out the simulations respectively in the same cases for heat pipe to verify our experiments.

2. EXPERIMENTAL PROCEDURES AND SIMULATIONS

The experimental samples were Emitter and Star types of Luxeon LEDs [11]. The heat dissipation mechanisms included a copper rod (380W/mK) and a commercial MHP. The dimensions of copper rod are 6.1mm in diameter and 200mm in length. The outer diameter and length of MHP are 6.1mm and 200mm, respectively, and its working fluid is methyl alcohol. The measuring apparatus of MHP was shown on Fig. 1, and the effective conductivity coefficients were listed at Table 1 under 10-degrees tilting angle. Fig. 2 showed that the thickness of Emitter LED without lens was polished from 2.5mm (condition C) to 2mm (condition D) and 1.5mm (condition E) gradually. The LED was fixed at evaporator of MHP by thermal grease (0.8W/mK) and a clamp. The LED measuring surrounding was inside a thermostatic chamber due to neglect the influences of convection and radiation heat transfer. When the steady state was reached, the temperature of the outer surface of MHP was measured by means of six T-type (Omega TT-T-40) thermocouples. The thermocouples were attached on the chip surface and other related positions by adhesive tapes.

Moreover, a 3-D thermal simulation of LED heat dissipation model by finite element methods was analyzed under steady state. Due to the LED working temperature was relatively low, the thermal radiation effects were ignored. Two dominant heat transfer mechanisms of the LED device were conduction and convection. We assumed 90% of total input electrical power of chip was heat generation and the surrounding temperature was 300K.

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Fig. 1. The measuring apparatus of MHP (Unit: mm)

Fig. 2. The cross-section view of LED (Unit: mm)
3. RESULTS AND DISCUSSION

From Fig. 3, we found the temperature of chip surface will be decreased obviously by using the heat pipe (condition C). At the case for the input power is 0.71W, the surface temperature was dropped from 116 ºC to 63 ºC by using a miniature heat pipe. And the performance in heat dissipation for using heat pipe is better than using a copper rod or using an aluminum star board (made by Lumileds) also shown in Fig. 3. When the input power was 0.71W, the LED temperature was decreased about 32%, 34%, and 46% for using the heat sink of the copper rod, the star board, and the MHP, respectively. Therefore, by using a heat pipe to replace the traditional board can increase the maximum input power of LEDs. In Fig. 3, we found when the surface temperature of chip reached about 118°C, the input power for the LED that was with MHP will be higher than the one with a copper rod about 43%. However, the MHP performance was not good enough at the condition of input power is only 0.05W due to the temperature of chip is not reached the working temperature of MHP. The reason of the performance for using an aluminum star board was a little better than the condition for using a copper rod, that was because a smaller thermal resistance which resulted from its wider cross-section area and shorter length.

![Graph showing the relationships between the surface temperature of chip and the input power under different heat dissipation mechanisms](image)

According to the definition of thermal resistance, while the slugs are given in the equal cross-section area, the thinner slug will own a lower thermal resistance than the thicker one. Then the temperature of chip surface will be decreased by reducing the thickness of slug, as shown in Fig. 4, the surface temperature in condition C are lower than the surface temperature in condition D at the same input power. However, in the cases for different cross-section area of slug, the temperature distribution will be affected obviously by the thermal spreading effect, so the surface temperature in condition E are higher than condition C and D, as shown in Fig. 4.
We calculated the effective conduction coefficient of the MHP that was used in our experiment by the experimental results, and listed them in Table 1. By means of these effective conduction coefficients, we simulated the physical model that is same as our LED sample. The simulated results were shown on Fig. 5, we found that the surface temperature of chip is lower than the experimental data under the same input power. The reason is that in our experimental procedure, we used the thermal grease to connect the LED slug and the MHP, it would cause higher thermal resistance.

Table 1. The effective conduction coefficients of MHP under different input power

<table>
<thead>
<tr>
<th>Input power (W)</th>
<th>0.05</th>
<th>0.29</th>
<th>0.71</th>
<th>1.09</th>
<th>1.59</th>
<th>2.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition C</td>
<td>372</td>
<td>458</td>
<td>560</td>
<td>735</td>
<td>880</td>
<td>1067</td>
</tr>
<tr>
<td>Condition D</td>
<td>375</td>
<td>483</td>
<td>583</td>
<td>747</td>
<td>898</td>
<td>1156</td>
</tr>
<tr>
<td>Condition E</td>
<td>379</td>
<td>512</td>
<td>607</td>
<td>759</td>
<td>941</td>
<td>1186</td>
</tr>
</tbody>
</table>

(Unit: W/m-K)
Then we simulated the case that was at the same input power, the value is 1.59W, but different slug thickness of LED, and the results were shown in Fig. 6. We found the surface temperature of chip was decreased when the slug thickness decreasing. However, when the slug thickness was closed to 1.55mm, the cross-section area will be changed from 20 mm$^2$ to 7 mm$^2$, so the thermal spreading effect will vanish. So we found the surface temperature of chip at the thickness range between 1.5 mm to 1.55 mm was increased when the slug thickness decreasing.

![Fig. 5. The simulated data of the surface temperature of chip and the input power for different thickness of LED slugs with MHP](image1)

![Fig. 6. The simulated data of the surface temperature of chip and the thickness of LED slugs in the fixed input power](image2)
For we want to study the steady state heat transfer of heat pipe without the fin, the condensing end of heat pipe was exposed to the ambient. But we found the condensing end temperature (T6) was increased when we added the input power. Therefore, we propose that for increasing the natural convection heat transfer in practice, the fins were necessary.

In Fig. 7, we plotted the experiment data for different thermal couples that were attached along the axial direction of heat pipe at 1.59W input power, respectively. We found the more uniform thermal spreading effect was in evidence; hence the temperature differences in the axial direction (between T2, T3, T4, T5 and T6) were very small.

![Fig. 7. The measured temperatures for thermocouples on different position](image)

**4. CONCLUSIONS**

By the excellent heat dissipating ability of MHP, the chip temperature of LED with the MHP was lower than the one with a copper rod. In order to reduce the thermal resistance, the thinner slug of LED will lead to decrease the chip temperature until the thickness of slug was reached a critical value. The reason is owing to the thermal spreading effect became weak. From our results of thermal simulation, the critical value for the thickness of slug could be obtained. Moreover, the MHP could be used to avoid the hot spot of LED packaging due to its excellent heat spreading ability and heat transfer efficiency.

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References


