Optimal Thermal Design with Through Holes

1. Objective for Optimal Thermal Design

To design LED products, it is essential to take thermal expansion into account.

The operating temperature of the LEDs is determined by the junction temperature (Tj). When the junction temperature exceeds the maximum value specified for each model, the luminous flux is significantly decreased, resulting in catastrophic failures such as no light emission due to wire breakage. Therefore, it is necessary to use LED products so that the junction temperature (Tj) does not exceed the maximum value.

The optimal Tj will enable LED products to have a long life.

It is required, therefore, to achieve the optimal thermal design for LED products.

In this application note, Nichia will recommend the design of Through Holes as a method of heat dissipation by verifying prototypes.

2. Thermal Path in an LED

Figure 1 shows the thermal path in an LED. The heat generated from the chip is transferred through the die bonding resin, electrode, solder, board, and finally to the external environment.

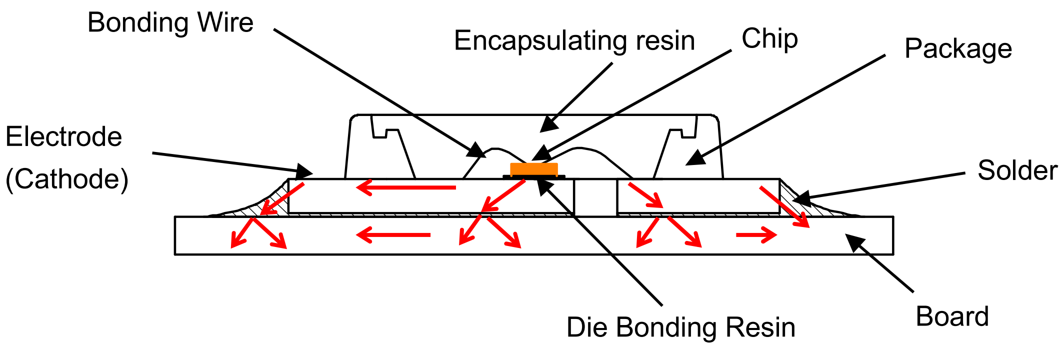
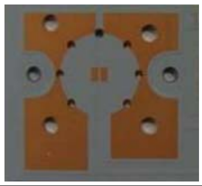
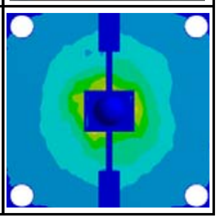


Figure 1
Cross Section of LED and Thermal Path

3. Heat Transfer to Board

Table 1 shows the simulation of heat dissipation from the chip to the board. The heat generated from the chip is transferred to the board in a concentric circle pattern.

Table 1 Simulation of Heat Dissipation

Board	
Simulation of Heat Dissipation	

4. Design of Through Holes

For the optimal design of Through Holes, we experimented with prototypes by changing the verifying items below:

Verification Item

1) Diameter of a Through Hole
2) The number of Through Holes
3) The diameter of a set of Through Holes

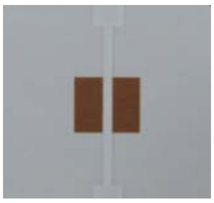
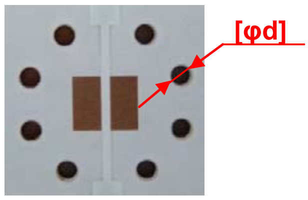
Note

We used a two-layer FR4 (Layer thickness: 1.6 mm, Copper plating thickness: 35 μm) for the prototypes. On the basis of the simulation of heat dissipation described in Section 3, we located the Through Holes in a circle around the LED prototype.

4-1. Setting of Diameter of a Through Hole

We evaluated the heat dissipation by changing the diameter of a Through Hole. (We used the same conditions in the number of Through Holes and the diameter of a set of Through Holes.)

Table 2 Verification Item: Diameter of a Through Hole

Reference Board	Diameter of a Through Hole
	

The heat dissipation in each condition is evaluated by the ratio of Tj, regarding the Tj of the reference board without any Through Hole as 1. Please refer to Figure 2 for the evaluation results of the heat dissipation depending on the diameter of a Through Hole.

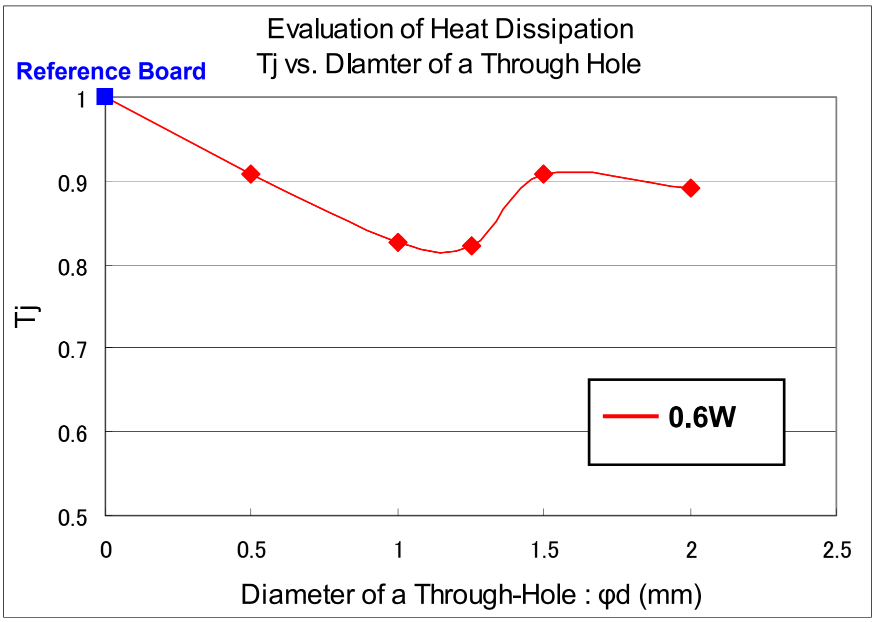


Figure 2 Evaluation Result of Heat Dissipation Depending on Diameter of a Through Hole

The measurement results in Figure 2 show that larger diameters of a Through Hole don't necessarily result in better heat dissipation; the optimal diameter can be read from the graph. This is probably due to the surface area of the copper plating.

In theory, the largest surface area of copper plating ensures the best heat dissipation, when the maximum value is given by the formula below:

(The sum of the inner surface areas of Through Holes) − (The sum of the lost top and bottom surface areas of Through Holes)

The value obtained from the formula is the net increase of the surface area of copper plating.

The net increase of the surface area of copper plating is defined by the following formula:

$$y = (x\pi \cdot A \cdot t) - \{(x/2)^2 \cdot A \cdot 2\}$$

$$= -1/2A\pi\{(x - t)^2 - t^2\}$$

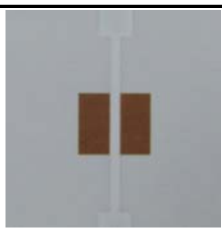
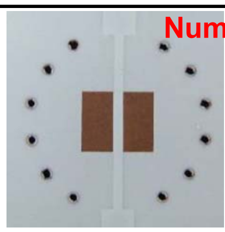
Here, x: Diameter of a Through Hole (ϕd mm)
A: The number of Through Holes
T: Layer thickness of the board (mm)
y: Net increase of surface area of the copper plating (mm^2)

When the diameter of a Through Hole is equal to the layer thickness, x=t, the net increase of surface area of the copper plating, y, becomes the largest.

4-2. Setting of the Number of Through Holes

We evaluated the heat dissipation by changing the number of Through Holes. (We used the same conditions in the diameter of a Through Hole and the diameter of a set of Through Holes.)

Table 3 Verification Item: Number of Through Holes

Reference Board	Number of Through Holes
	 Number of hole [N]

Please refer to Figure 3 for the evaluation results of the heat dissipation depending on the number of Through Holes.

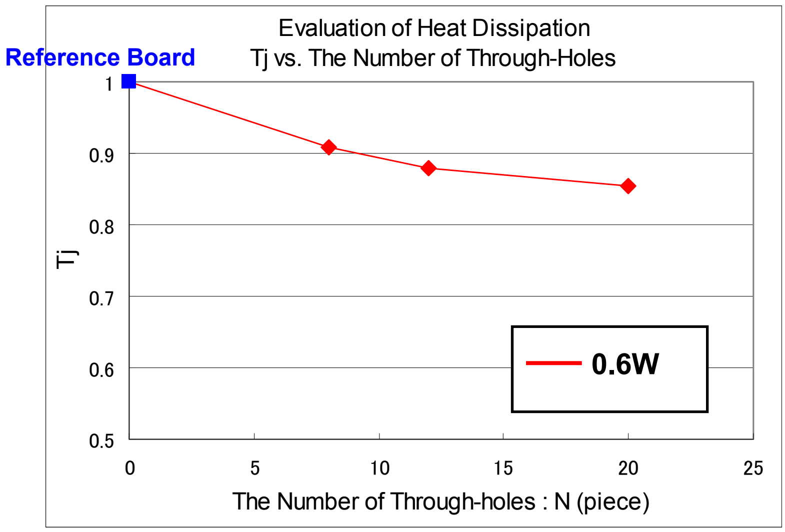


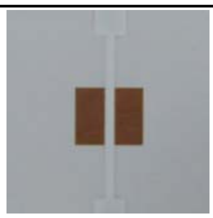
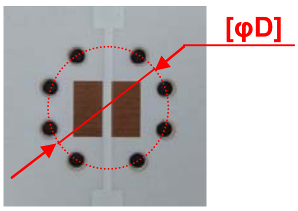
Figure 3 Evaluation Result of Heat Dissipation Depending on the Number of Through Holes

The measurement results in Figure 3 show that the higher the number of Through Holes, the better the heat dissipation. We confirmed, however, that too many holes don't necessarily contribute to good heat dissipation. Moreover, too many holes could affect the performance of the board and increase the processing cost.

4-3. Setting of the Diameter of a Set of Through Holes

We evaluated the heat dissipation by changing the diameter of a set of Through Holes. (We used the same conditions in the diameter of a Through Hole and the number of Through Holes.)

Table 4 Verification Item: Diameter of a Set of Through Holes

Reference Board	Diameter of a set of Through Holes
	

Please refer to Figure 4 for the evaluation results of the heat dissipation depending on the diameter of a set of Through Holes.

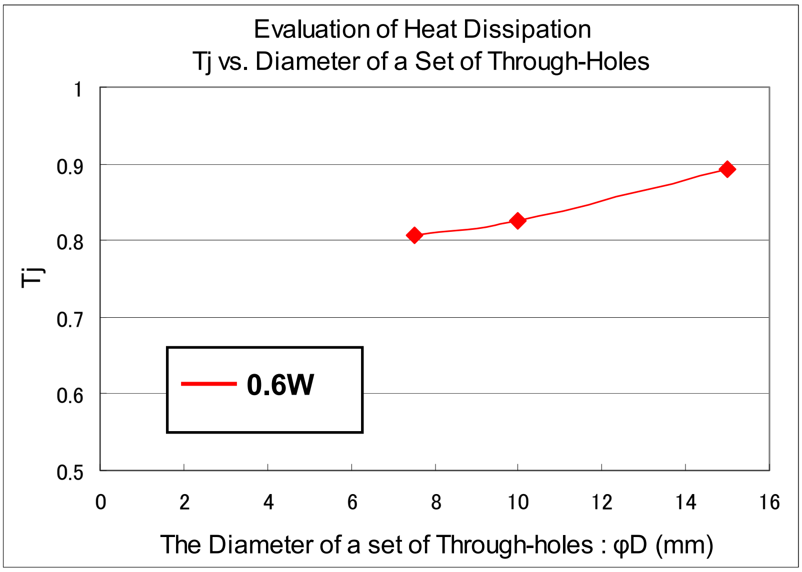


Figure 4 Evaluation Result of Heat Dissipation Depending on the Diameter of a Set of Through Holes

The measurement results in Figure 4 show that the heat can be dissipated more effectively as the Through Holes are located nearer to the LEDs, as heat sources. It is necessary to take the performance of the board and working efficiency into account to determine the optimal location of the Through Holes.

5. Summary

Nichia recommends that the board be designed by taking the above evaluation results into consideration.

The optimal thermal design can enable LED products to be used efficiently, leading to the quality improvement of the finished products.

Please note that the reverse side of the board can short circuit, when Through Holes are located on the copper plating with the potential energy.