Light Emitting Diode

Thermal Design Considerations for PCBs for the Nichia 170 or 131 Series LEDs

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The Nichia part numbers NCSW170C and NCSW131C within this document are merely Nichia's part numbers for those Nichia products and are not related nor bear resemblance to any other company's product that might bear a trademark.

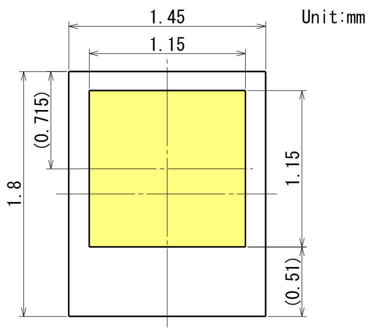
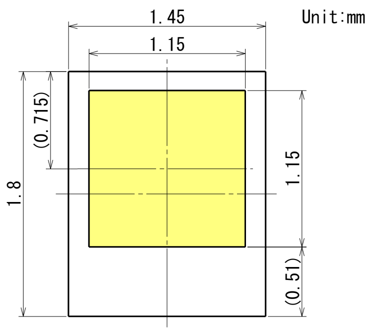
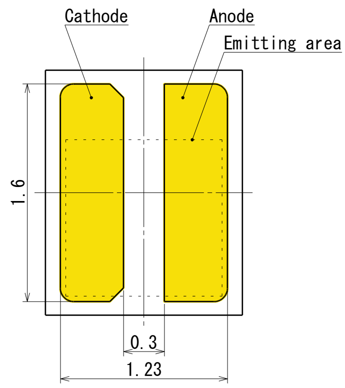
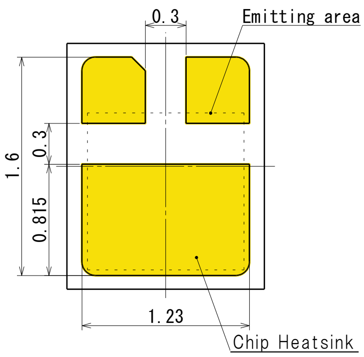
1. Overview

The thermal management for the LEDs is managed by Junction Temperature (T_J). If T_J value is out of spec. as overheated, it brings negative influence on reliability and might occur No-light mode at the worst case. Therefore, the thermal design is important such as not exceeding maximum T_J defined in the specification.
The LEDs have such structures typically as radiating heat mainly from the package backside, and the PCB is related and important factor to consider thermal management. This document introduces thermal designs with some evaluated results including simulations.

2. Applicable LED Series

This application note provides thermal design considerations for the Nichia 170 and 131 Series LEDs.
In the evaluations provided herein, the NCSW170C and NCSW131C LEDs were used; refer to the evaluation results for the other part numbers included in the Nichia 170 and 131 Series LEDs.

Table 1. Evaluated Part Numbers

Part Number	NCSW170C	NCSW131C
LED Outline Dimensions		
Electrode Pattern of Back Side		

3. Thermal design for metal-based PCB

The following items are introduced as the focused points for thermal design with metal-based PCB.

A) Area size and thickness of Cu layer
B) Thermal conductivity of insulating layer
C) Material of metal base
D) LED mounting pitch (clearance)

Generally, FR-4 is often used for LED mounting boards, but metal board PCB has the advantage of lower T_J controlled with its thermal management potential. The thermal designs with metal-based PCB are introduced in the following sections.
Also, this document uses images (drawings) omitting the resist mask pattern in order to make easier to understand the Cu layer pattern when explaining thermal design. Actually, the resist mask is needed in consideration of LED mountability, and the recommended land pattern for the resist mask are shown in the specification sheets of each LED.

3.1 Area size and thickness of Cu layer

Area size and thickness of Cu layer are important factors when designing heat radiation of mounting boards. The followings show the simulation results by changing area size and thickness of Cu layer.

LED Part No.:	NCSW170C (Forward current I_F=1(A), Mounting LED 1 piece)
Mounting board:	Al-based PCB (Size 40×40×1.5t(mm), Thickness of insulating layer 120(μm))
Heatsink:	A6063 (Size 40×40×25t(mm))
Simulation soft:	Flotherm

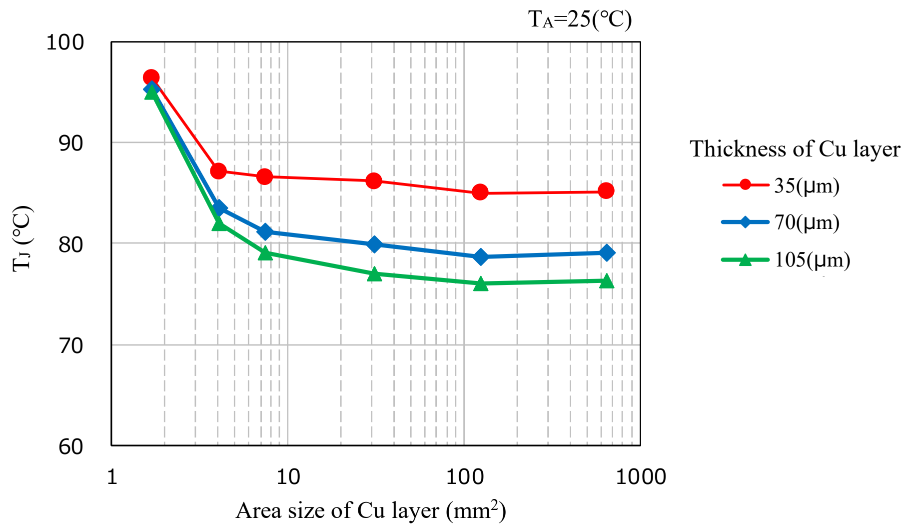
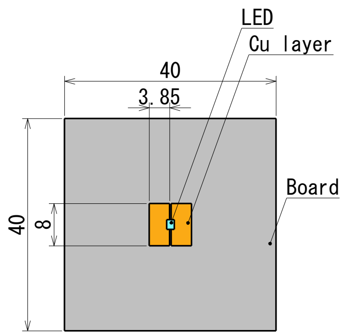
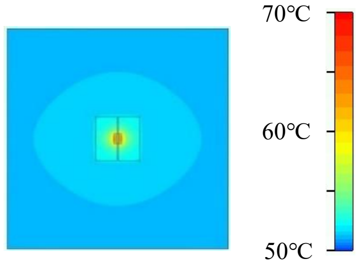
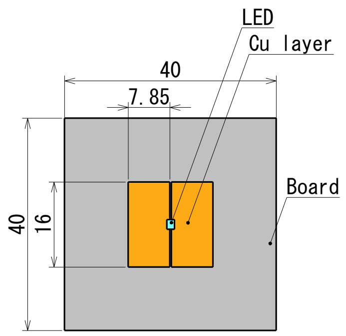
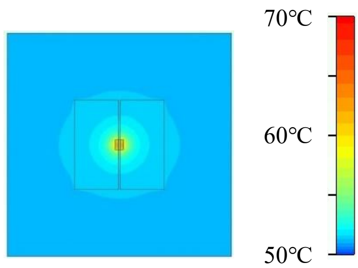
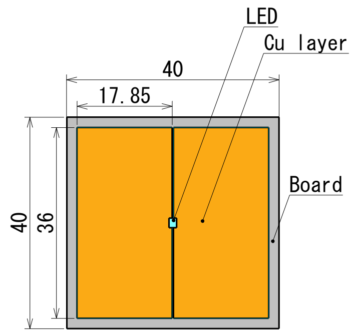
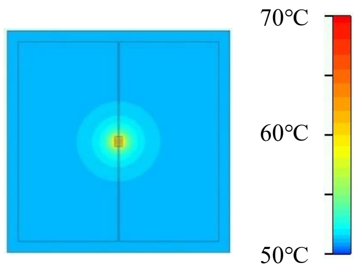


Figure 1. T_J vs. Area size and thickness of Cu layer (Simulation result)

Table 2. Temperature distribution on Cu layer vs. Area size of Cu layer (Thickness of Cu layer 35(μm))

Area Size of Cu Layer	Dimension of Cu Layer	Thermal Distribution on Cu Layer
31(mm²)		
125(mm²)		
650(mm²)		

As Figure 1 shows, T_J can be lowered when the area size and thickness of Cu layer are bigger. Also, as Table 2 shows, the heat dissipates radially which occurred from heat source, therefore the bigger area size and thickness of Cu layer is effective design on heat radiation.

3.2 Thermal conductivity of insulating layer

The thermal conductivity of insulating layer is one of the important parameters on heat radiation of metal-based PCB. Even if a metal-based PCB is used, when the lower thermal conductivity of insulating layer, it might be same performance level as FR-4 at the heat radiation effect. There are various metal-based PCBs with 0.8(W/mK) for inexpensive one, and 10(W/mK) or more for expensive one. Each manufacture of metal-based PCB uses a different insulating layer, and there are several grades in a manufacturer so that it needs to note when considering thermal designing.

LED Part No.:	NCSW170C (Forward current I_F=1(A), LED mounting pitch 1.75(mm)) Mounted to center when 1 piece. T_J measured center LED when mounted 5 pieces.
Mounting board:	Al-based PCB (Size 40×40×1.5t(mm), Thickness of Cu layer 35(μm), Thickness of insulating layer 120(μm))
Heatsink:	A6063 (Size 80×80×25t(mm))
Simulation soft:	Flotherm

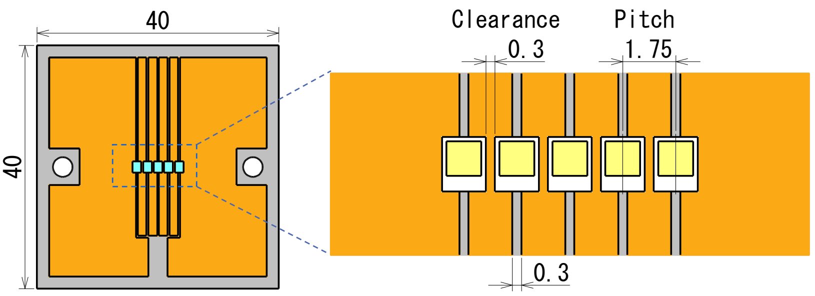


Figure 2. Evaluation PCB

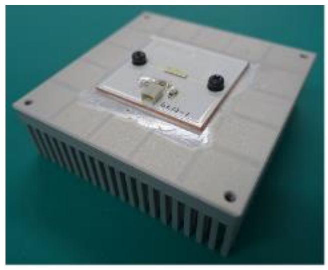


Figure 3. Heatsink

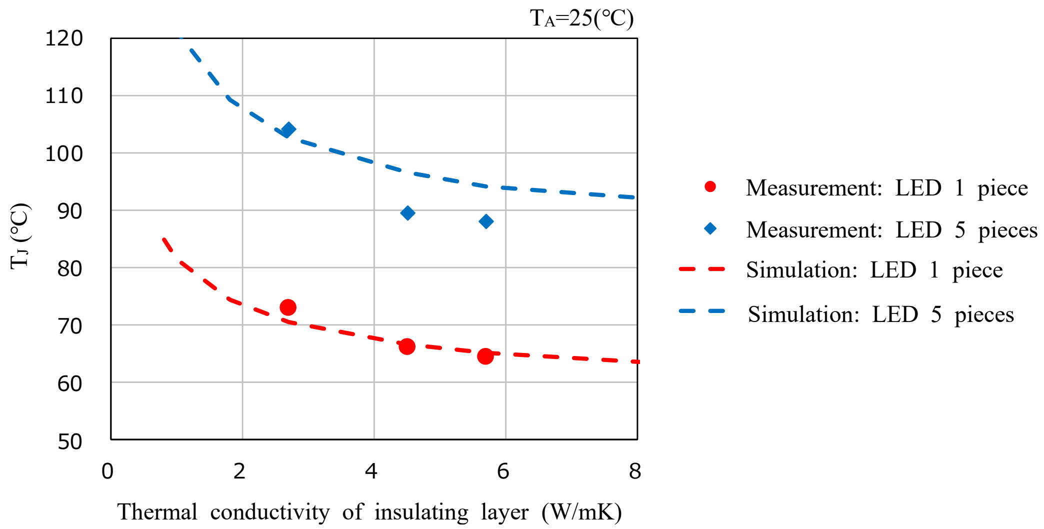


Figure 4. T_J vs. Thermal conductivity of insulating layer

3.3 Comparison base material of PCB

LED Part No.: NCSW170C (Forward current I_F=1(A), LED mounting pitch 1.75(mm))
Mounting board: Al-based PCB, Cu-based PCB (Size 40×40×1.5t(mm), Thickness of Cu layer 35(μm), Thickness of insulating layer 120(μm))
Heatsink: A6063 (Size 80×80×25t(mm))
Simulation soft: Flotherm

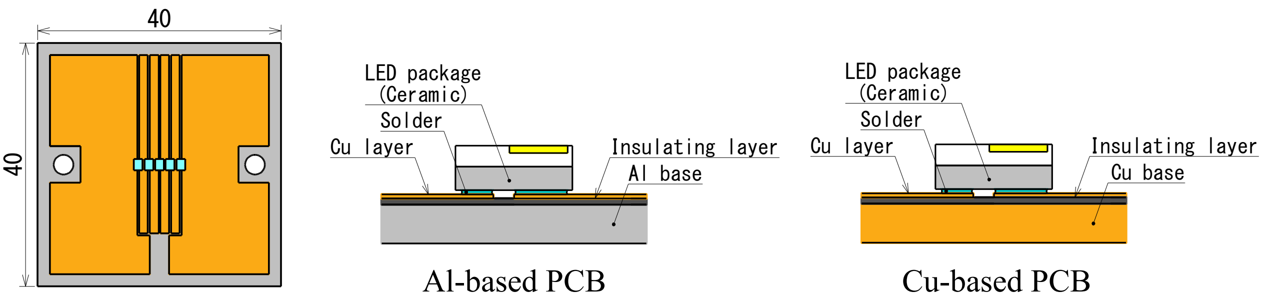


Figure 5. PCB and Cross section images

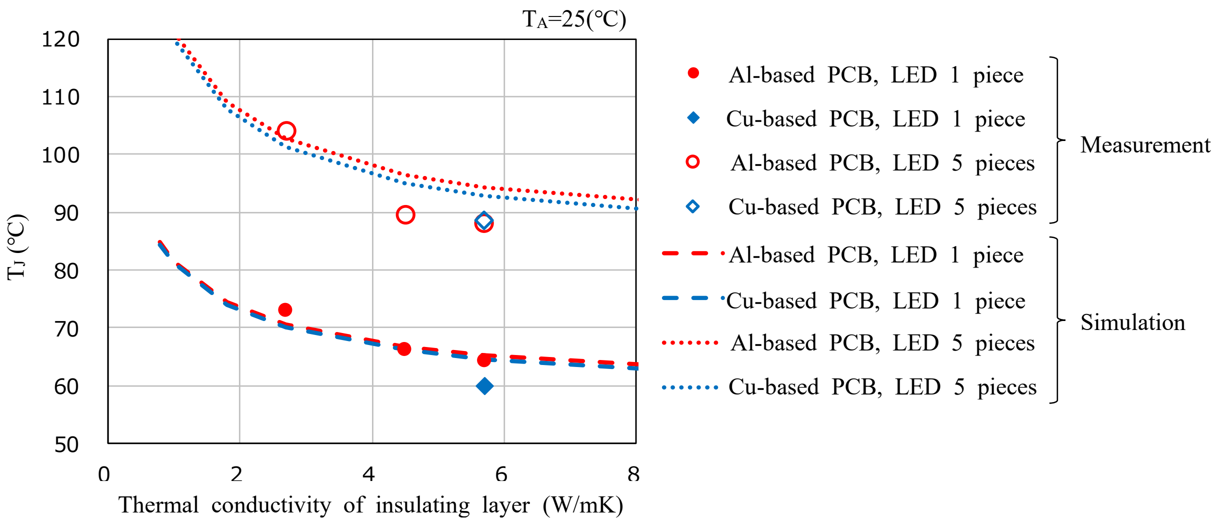


Figure 6. Result of comparison base material of PCB

There is no difference on T_J values between Al-based and Cu-based PCB at the above condition (PCB and heatsink), and the thermal conductivity of insulating layer is the dominated parameter to T_J value. There is other design approach that a higher thermal conductivity of base material is effectively to lower T_J value as mentioned in the section "3.5 Thermal bypass PCB". Please refer it as well.

3.4 T_J comparison of the number of LED terminals

LED Part No.: NCSW170C, NCSW131C
(Forward current I_F=1(A), LED mounting pitch 1.75(mm))
Mounting board: Al-based PCB (Size 40×40×1.5t(mm), Thickness of Cu layer 35(μm), Thickness of insulating layer 120(μm))
Heatsink: A6063 (Size 80×80×25t(mm))
Simulation soft: Flotherm

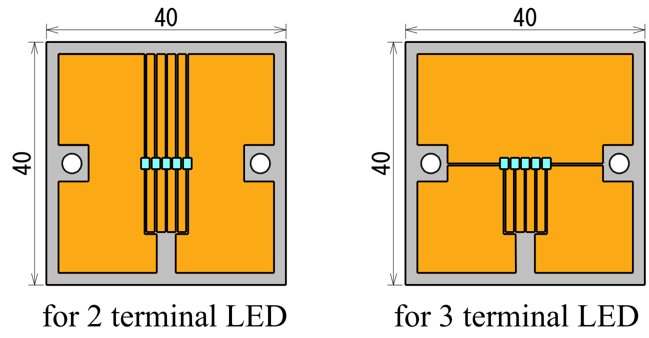


Figure 7. Evaluation PCB

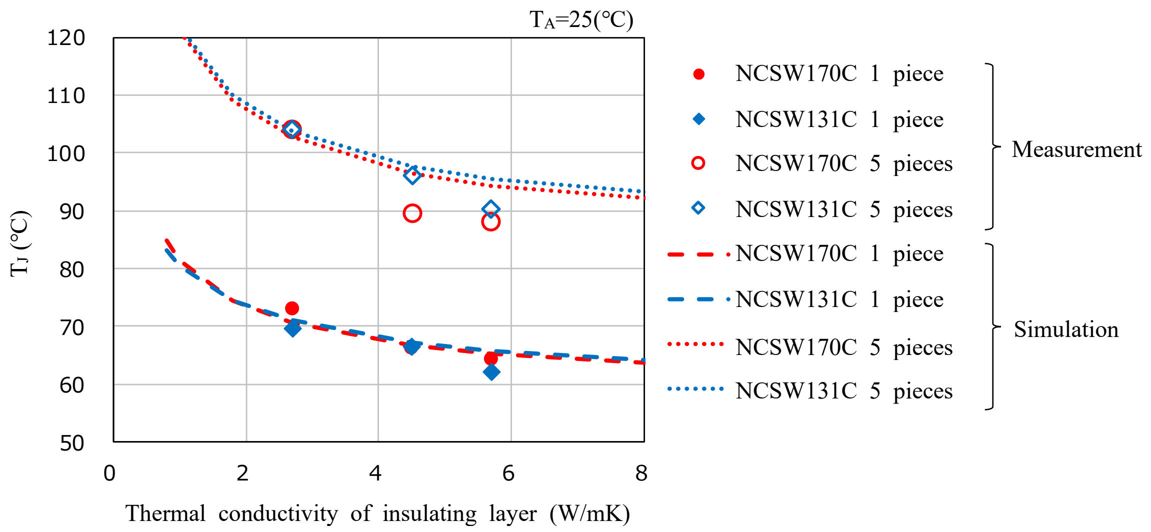


Figure 8. T_J vs. the number of LED terminals
(NCSW170C: 2 terminals, NCSW131C: 3 terminals)

As the above evaluation results show, there are no significant differences on T_J values between 2 terminal LED and 3 terminal LED in both results of measurement and simulation.

3.5 Thermal bypass PCB

As shown in section 3.4, T_J value might exceed 90°C at the condition of T_A=25°C when mounting multiple LEDs on PCB. This means that T_J value is possibly to exceed 150°C as the absolute maximum rating at hot ambient such as T_A=85°C. In such case, it is necessary to review the thermal design. This section introduces the following PCB as a method for more improving thermal management.

LED Part No.:	NCSW131C (Forward current I_F=1(A), LED mounting pitch 1.75(mm))
Mounting board:	Cu-based thermal bypass PCB (Size 40×40×1.5t(mm), Thickness of Cu layer 35(μm), Thickness of insulating layer 120(μm))
Heatsink:	A6063 (Size 80×80×25t(mm))
Simulation soft:	Flotherm

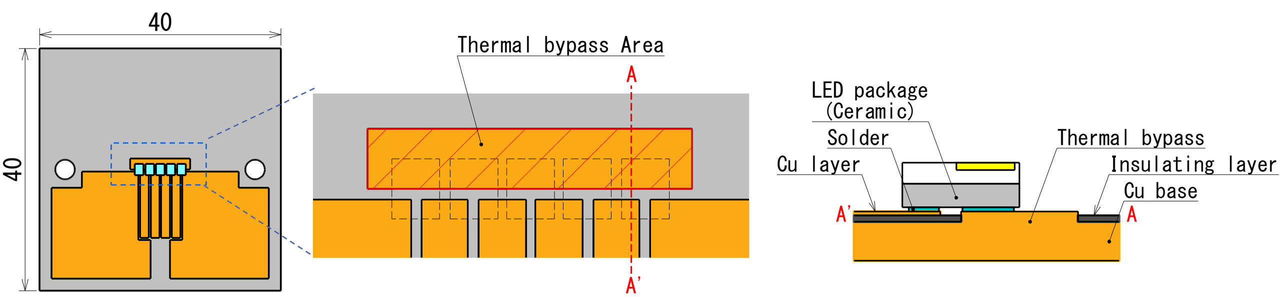


Figure 9. Thermal bypass PCB images

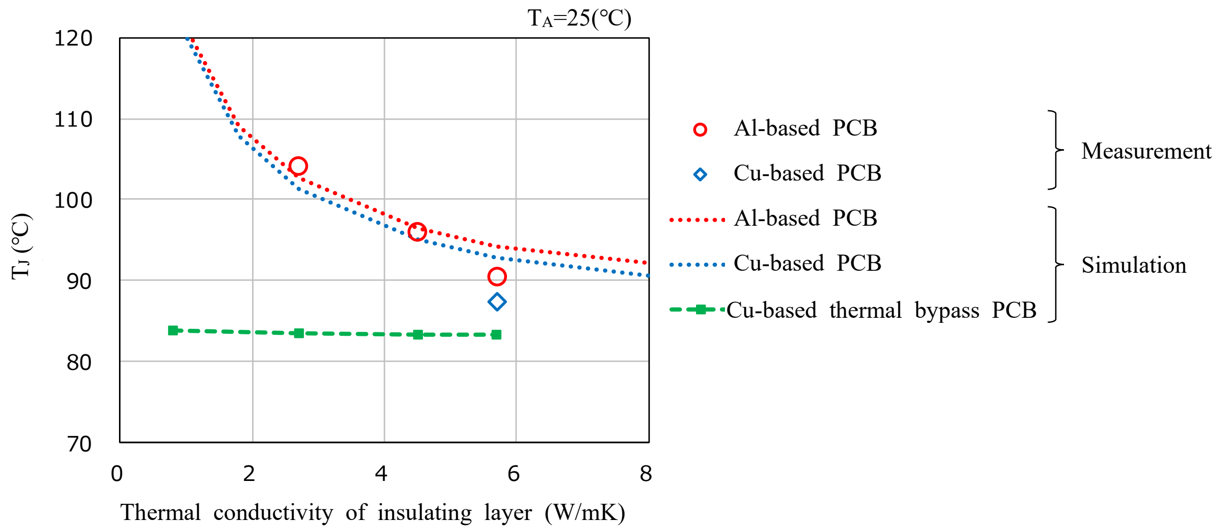


Figure 10. Evaluation result of Thermal bypass PCB

Thermal bypass PCB is expensive design due to complex structure, however it is effective to control for lower T_J. If there is not enough margin on T_J value, for example, much heat generating situations as mounting multiple LEDs, this design becomes the effective method for enhancing heat radiation. Thermal bypass structure is recommended for the 3 terminals LED type that includes non-electrical pad such as Chip heatsink and electrical conductive 2 terminals, avoiding the failure of electrical circuit.

3.6 Clearance of mounting LEDs

The clearance of mounting LED is effect to T_J value when mounting multiple LEDs. The narrow clearance is advantageous on considering of optical design, but it needs notice that T_J value become higher as the possible followed phenomenon.

LED model No.:	NCSW131C (Forward current I_F=1(A), Mounting LED 5 pieces)
Mounting board:	Al-based PCB, Cu-based PCB, Cu-based thermal bypass PCB (Size 40×40×1.5t(mm), Thickness of Cu layer 35(µm), Thickness of insulting layer 120(µm))
Heatsink:	A6063 (Size 80×80×25t(mm))
Simulation soft:	Flotherm

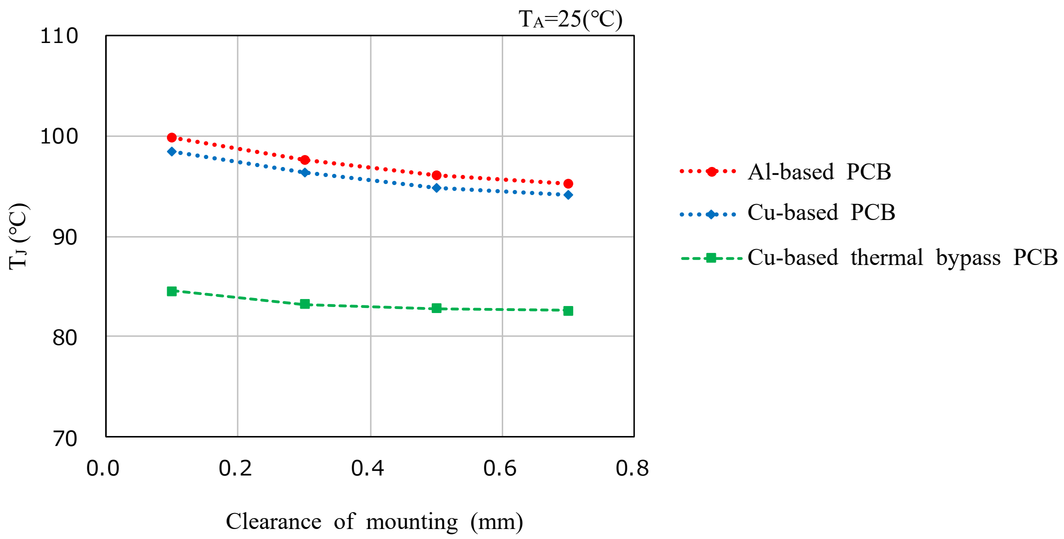
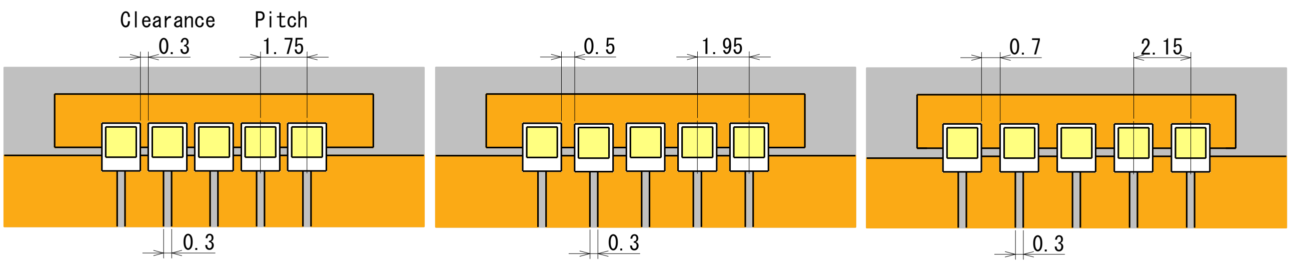


Figure 11. T_J vs. Clearance of mounting LED (Simulation)



a) Clearance 0.3(mm) b) Clearance 0.5(mm) c) Clearance 0.7(mm)

Figure 12. Clearance of mounting LED images (Ex.: Cu-based thermal bypass PCB)

4. Thermal design for FR-4

A The thermal design for FR-4 is explained in following sections. These items are introduced as the points for thermal design.

A) Pattern (area size) and thickness of Cu layer
B) Through-Hole
C) Combination with heatsink

The effect of area size and thickness of Cu layer is the same as metal-based PCB, bigger area and thickness size are effective to heat radiation as for (A). In (B) section: the hole size, position (distance from LED), number of holes, and thickness of side Cu layer of Through-hole are the related factors for heat radiation.

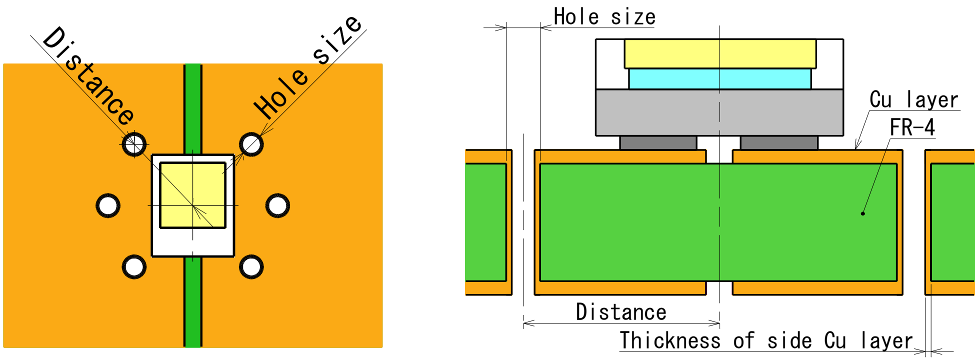


Figure 13. Through-hole of FR-4 image

4.1 Effects of Through-hole

LED Part No.:	NCSW170C (Forward current I_F=1(A), Mounting LED 1 piece)
Mounting board:	FR-4 (Size 30×70×1.6t(mm), Thickness of Cu layer 70(μm)) Through-hole (Thickness of side Cu layer 35(μm))
Heatsink:	—
Simulation soft:	Flotherm

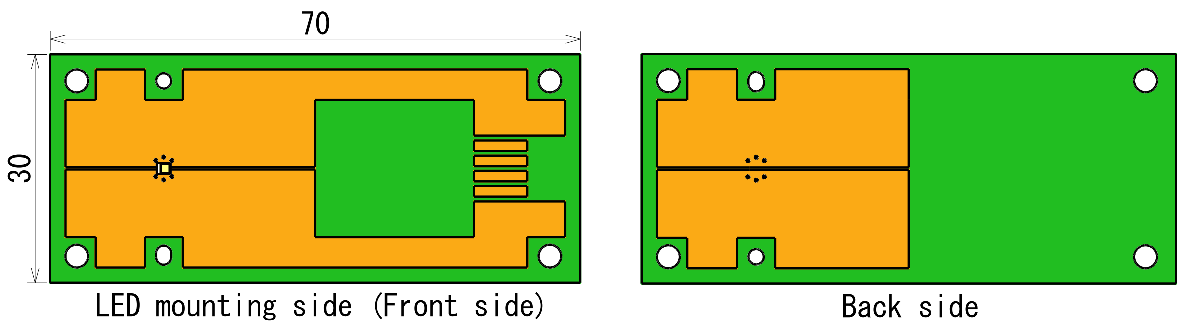


Figure 14. FR-4 image of Through-hole evaluation

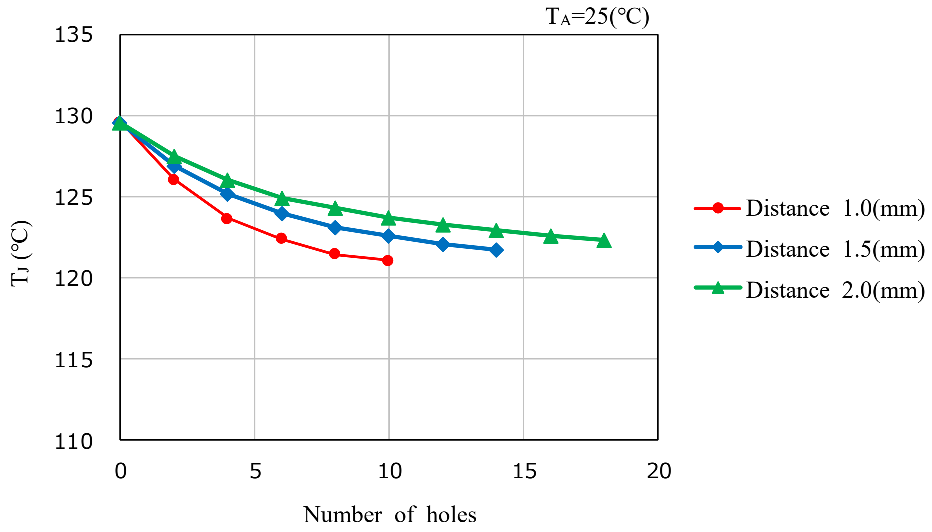


Figure 15. T_J vs. Through-hole 1 (Number of holes and distance)

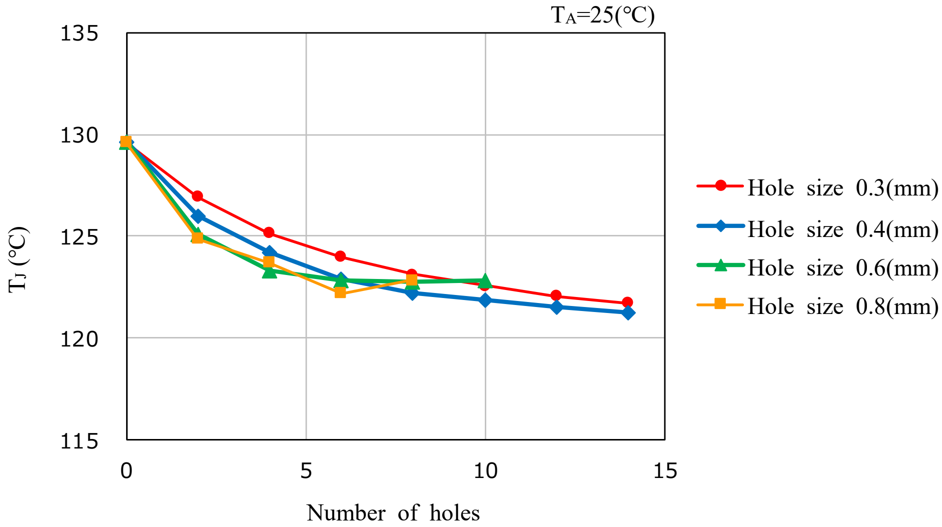


Figure 16. T_J vs. Through-hole 2 (Number of holes and hole size)

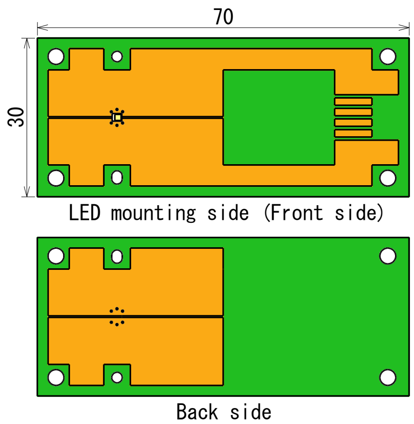
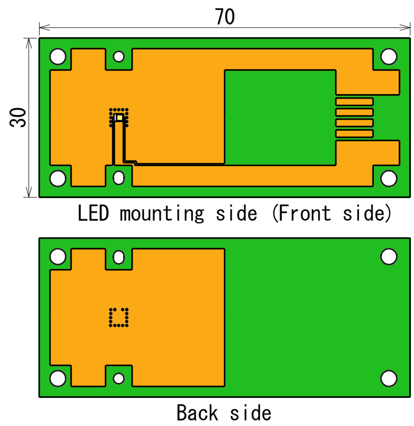
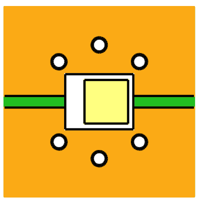
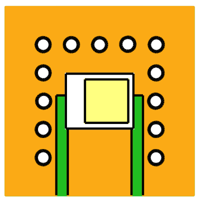
Increasing the number of holes and the bigger hole size make effective to heat radiation, but too large number of holes or too big hole size do not have effect. And the cost of hole processing is getting expensive when increasing the number of holes. It is important to find the balance between heat radiation effect and cost.

4.2 Pattern of Cu layer

The pattern of Cu layer with using lead-frame package LED is often designed an asymmetry pattern, as shown the right image in Table 3. But the Nichia 170 and 131 Series LEDs are ceramic packages, and that radiate heat uniformly from both electrode (anode and cathode), therefore the symmetry pattern is effective for heat radiation of the Nichia 170 and 131 Series LEDs, as shown the left in Table 3.
Also, when designing Through-hole both anode and cathode, it is necessary to countermeasure to avoid short-circuit such as setting space on back side of PCB because the structure related to the electrical potentials of anode and cathode.

LED Part No.:	NCSW170C (Forward current I_F=1(A), Mounting LED 1 piece)
Mounting board:	FR-4 (Size 30×70×1.6t(mm), Thickness of Cu layer 70(μm)) Through-hole (Hole size 0.4(mm), Thickness of side Cu layer 35(μm))
Heatsink:	—
Simulation soft:	Flotherm

Table 3. Comparing the effect of Cu layer pattern on FR-4 (Simulation)

	Symmetry pattern	Asymmetry pattern
Cu layer pattern		
Through-hole pattern		
LED T_J	121 (°C)	136 (°C)

T_J value is 120°C or more at the condition of T_A=25°C in the above result, it is not enough margin to the higher T_J, estimated high temperature ambient condition such as T_A=85°C. T_J can be lower by increasing the board size of FR-4 or by using a heatsink. But if it is not possible to control T_J lower sufficiently with the thermal designed PCB and heatsink, it needs to reduce the driving current of LED. The luminous flux become lower by reducing the driving current of LED, but it is important to design not to exceed the absolute maximum rating of T_J value.

4.3 Size of FR-4

T_J can be lower by the thermal design as increasing board size and area size of Cu layer of FR-4. The result of thermal simulation with larger board size is shown below.

LED Part No.:	NCSW170C (Forward current I_F=1(A), Mounting LED 1 piece)
Mounting board:	FR-4 (Thickness of board 1.6(mm), Thickness of Cu layer 70(μm)) Through-hole (Hole size 0.4(mm), Thickness of side Cu layer 35(μm))
Heatsink:	—
Simulation soft:	Flotherm

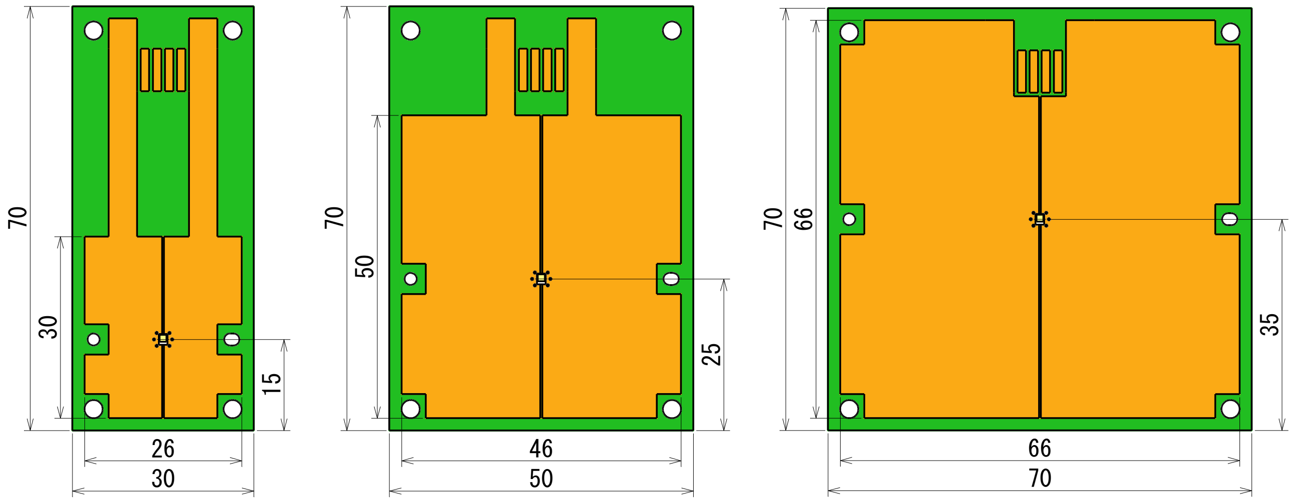


Figure 17. FR-4 images of comparison board size

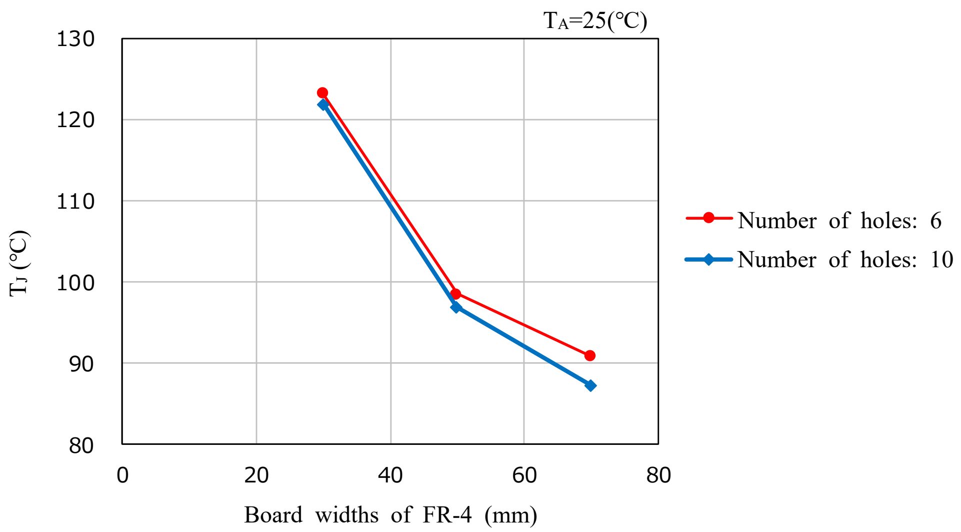


Figure 18. T_J vs. Board size of FR-4 (Simulation)

5. Summary

This document explained about the basic thermal design for LED mounting board in order to manage T_J of LED under appropriate zone. Please make sure that T_J does not exceed the absolute maximum rating.

In addition, the measurement and simulation results of the thermal design, described as examples in this document, it is not reproductions of the user's usage environment such as individual heatsink and housing structure. Please make sure T_J behaviors at user's actual thermal design.

Disclaimer

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