Light Emitting Diode

Thermal Design of the LEDs

Table of contents

1. Overview

When designing a product using LEDs, it is important to account for the heat generated by the LEDs. The ambient temperature that the LED can be used in is determined by the junction temperature (T_J). The LEDs may become dim, or not even illuminate if the T_J goes above the absolute maximum ratings specified in the specification sheet. It is important to have a good thermal design as keeping the T_J as low as possible will lengthen the life of the LED.
This application note will contain information on how to have a good thermal design.

2. Path of the heat

Figure 1 is an example of how the heat can pass through the LED. It is believed that the heat is transmitted to the air by going through the die bond, electrodes, solder, and the board.

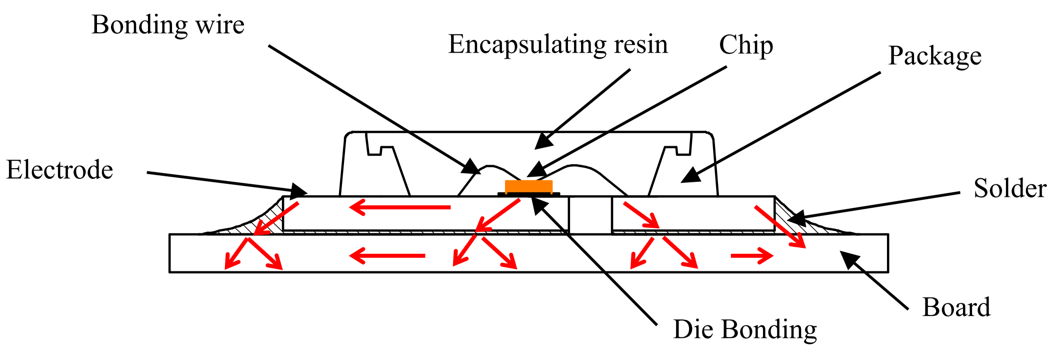


Figure 1. LED's structure and an example of the heat path (Example Part No. NS3W183)

Figure 2 indicates a flow chart of the heat from the chip.

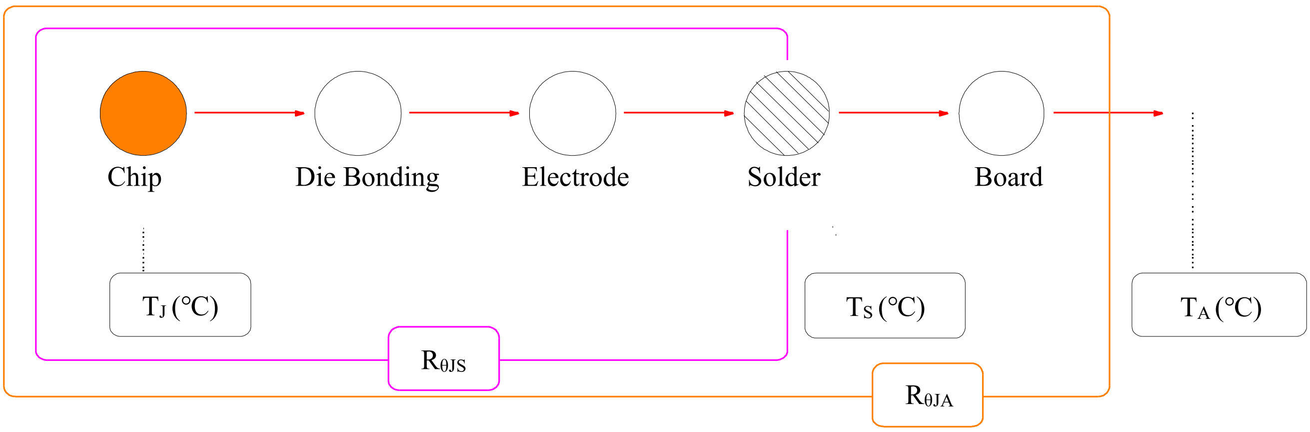


Figure 2. Flow chart of the heat from the chip

If the change in temperature from the chip is expressed as the thermal resistance (°C/W), two equations can be written with regards to T_J.

(1) If using the value of the thermal resistance ($R_{\theta JA}$) from the chip to Ambient temperature:

$$\mathbf{T_J = T_A + R_{\theta JA} \times W} \quad \cdots\cdots ①$$

- T_A: Ambient temperature(°C)
- $R_{\theta JA}$: Thermal Resistance from Chip to ambient (°C/W)
- W: Input power consumption(=$I_F \times V_F$)(W)
  (I_F: Forward current, V_F: Forward voltage)

(2) If using the value of the thermal resistance ($R_{\theta JS}$) from the chip to Soldering temperature:

$$\mathbf{T_J = T_S + R_{\theta JS} \times W} \quad \cdots\cdots ②$$

- T_S: Soldering temperature (Cathode side) (°C)
- $R_{\theta JS}$: Thermal Resistance from the chip to T_S measuring point (°C/W)
- W: Input power consumption(=$I_F \times V_F$) (W)
  (I_F: Forward current, V_F: Forward voltage)

3. Calculating T_J

There are two methods to calculate T_J

- Calculating T_J by the T_S measurement
- Calculating T_J by the V_F measurement method

Details are shown below:

3.1 Calculating T_J by measuring T_S

(1) Attach a thermocouple to the T_S measurement point (cathode side) of the mounted LED. Turn on the LED and measure the temperature Ts, I_F and V_F when the LED has reached the thermal equilibrium state.

※The T_S measurement point and $R_{\theta JS}$ may vary according to the products. Please confirm it in our specifications.

※Please use the thinnest thermocouple possible to minimize the measurement interference. The connection of the thermocouple should be done by soldering.

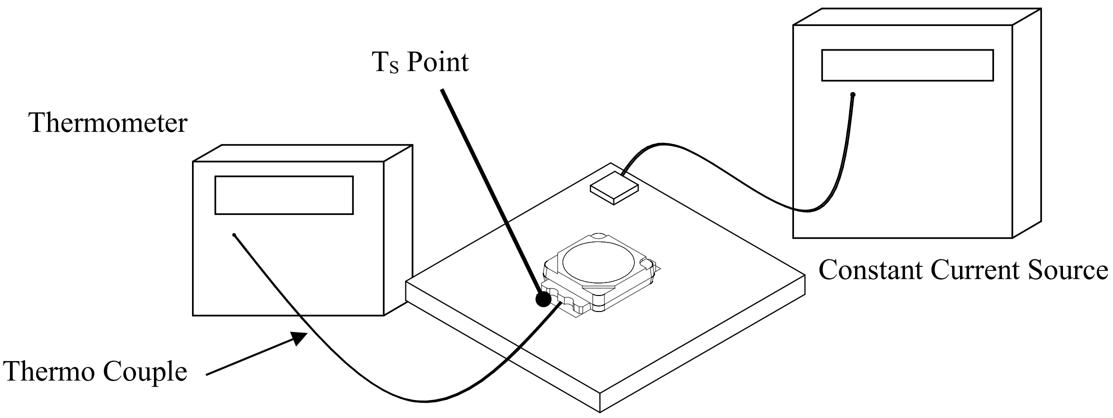


Figure 3. Thermal Measuring Set Up

(2) The T_J can be calculated using equation ② with the measured values of T_S, I_F and V_F.

3.2 Calculating T_J by measuring V_F

(1) The LED's forward voltage (V_F) is measured at a specific increment of ambient temperature (T_A) using a thermostatic chamber.
※The measurement is taken in a windless environment.
※Pulse current is used when measuring the LEDs to keep the V_F stable from being affected by its own heat generation. (Recommendation: Pulse width <10ms, Duty ratio < 1/10)

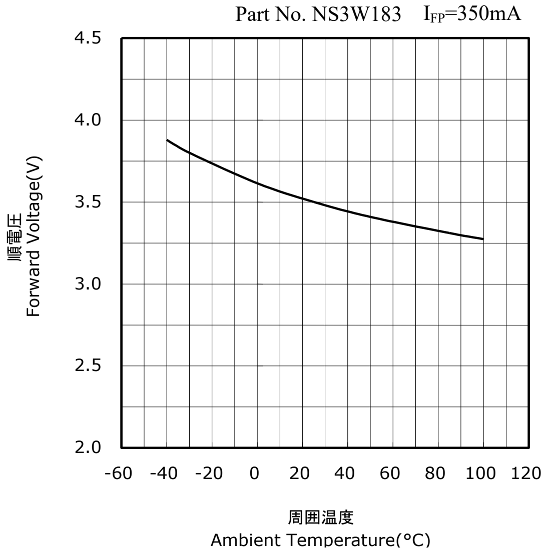


Figure 4. Ambient Temperature vs. Forward Voltage

(2) Making a graph of Ambient Temperature vs Forward Voltage from the measurement result (1).
(※We can consider $T_A \fallingdotseq T_J$ in a thermal equilibrium state.)
※Example: Figure 4 indicates the ambient temperature vs forward voltage properties for Part No. NS3W183.

(3) In a windless environment, turn on the LED with DC and measure the V_F once it is in a thermal equilibrium state.

(4) The T_J can be calculated by the V_F measured, using the ambient temperature vs. forward voltage graph.
[Example]:
At V_F=3.41(V), the T_J is 50°C as show in Figure 5.

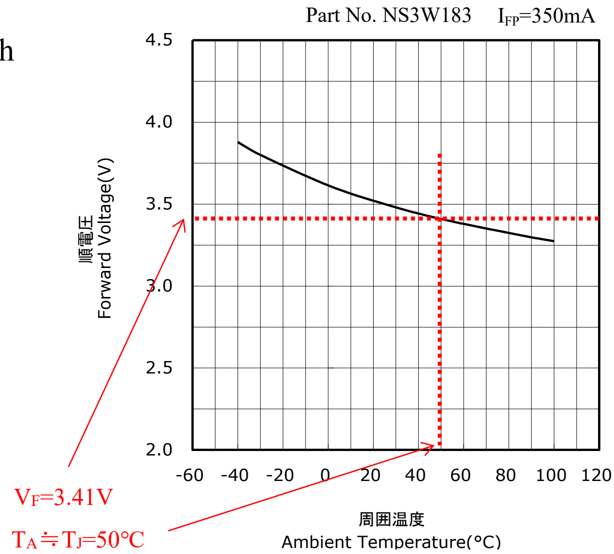


Figure 5. Calculation of T_J

4. Thermal Design

When designing a product, the T_J can be lowered by implementing methods to lower the thermal resistance of the product as a whole.

Example:
- Choice of board materials
- Optimization of the copper foil area of the board
- Optimization of the LED placement (LED pitch)
- Implementing heat sinks

Details of each are explained below.

4.1 Choice of board materials

Printed circuit boards can be classified as resin, metal-based, or ceramic as shown in Figure 6.

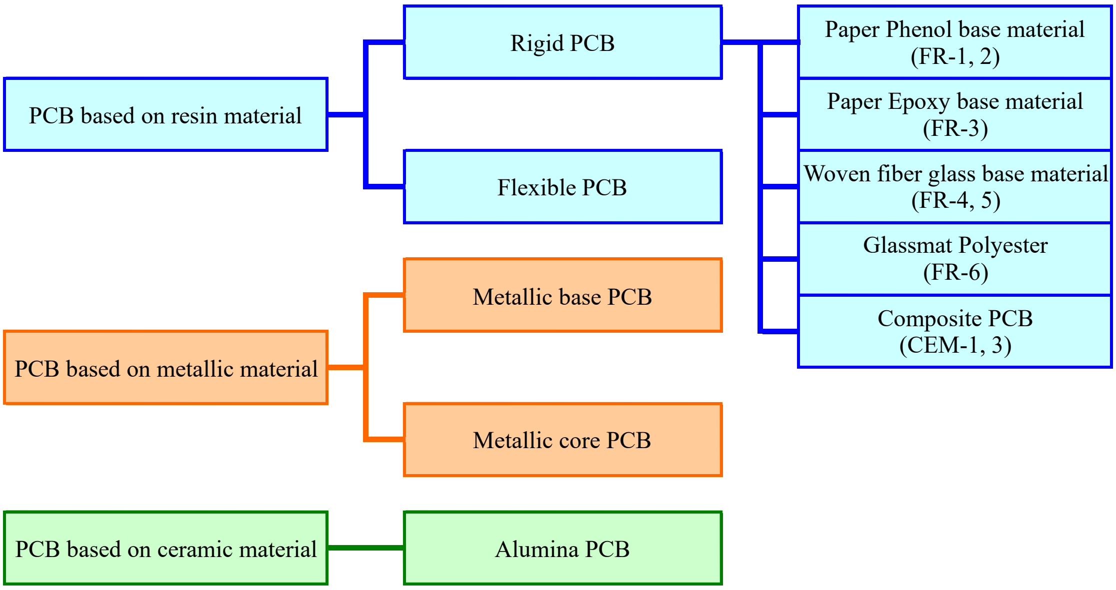
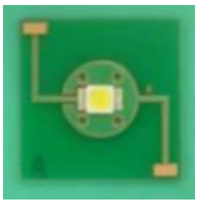
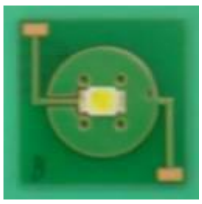
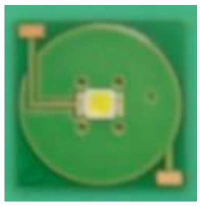
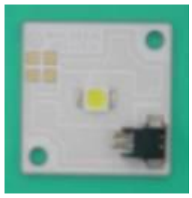


Figure 6. Classification of Printed Circuit Boards

Woven fiber based material (FR-4) boards are commonly used due to their cost and their dimension consistency. However, by using a metal-based board a higher thermal conductivity can be achieved and will lower the T_J of the LED. As a reference, Table 1 and Figure 7 show the thermal measurement results with a FR-4 and with an aluminum board.

Table 1. Thermal Measurement Results for Part No. NS6W183

	Type A	Type B	Type C	Type D
Appearance				
Board Material	FR-4			Aluminum
$R_{\theta JA}$ (°C/W)	63	50	44	34
PWB Size	30mm×30mm, t=1.6mm			30mm×30mm, t=1.7mm
Copper Area Face	154mm^2, t=0.07mm	302mm^2, t=0.07mm	616mm^2, t=0.07mm	500mm^2, t=0.07mm
Copper Area Back	154mm^2, t=0.07mm	302mm^2, t=0.07mm	616mm^2, t=0.07mm	-
I_F (mA)	700			
V_F(V)	3.18	3.24	3.29	3.3
T_S(°C)	143	118	95	80
T_J(°C)	165	141	118	103

※Measurement condition: $R_{\theta JS}$=10°C/W, T_A =25°C, Thermo Couple: Φ0.076mm

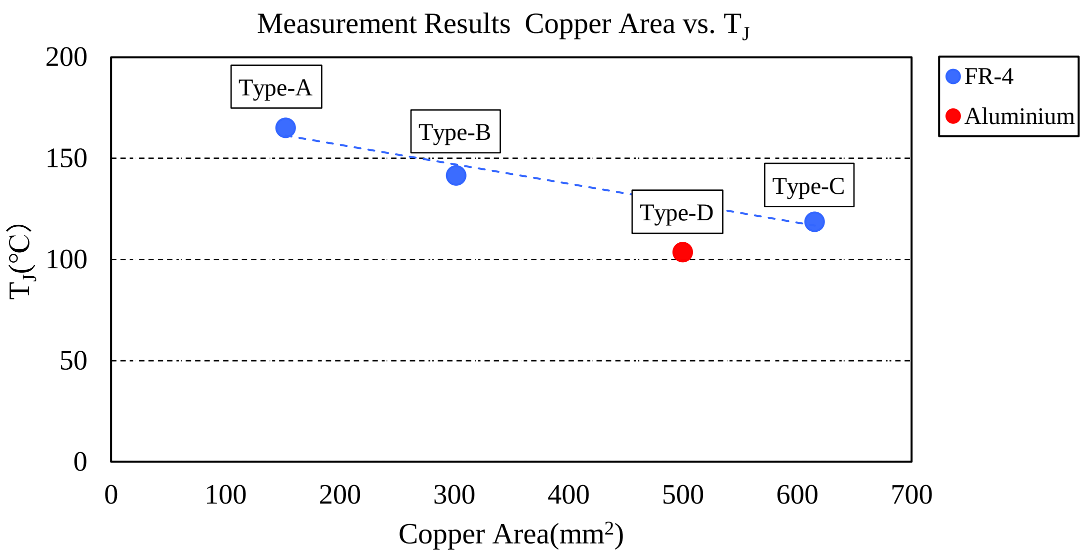


Figure 7. Thermal Measurement Results for Part No. NS6W183 (Copper area vs T_J)

Assuming that the board sizes are the same, it is clear from the measurements above that the T_J is lower on the aluminum board compared to the FR-4 board.

4.2 Optimization of the copper foil area of the board

To transfer the heat generated by the chip to the board as much as possible, it is recommended to increase the thermal conductive area by increasing the area of the copper foil as shown in Figure 8. Table 1 and Figure 7: The value of the T_J falls as the copper foil area increases.

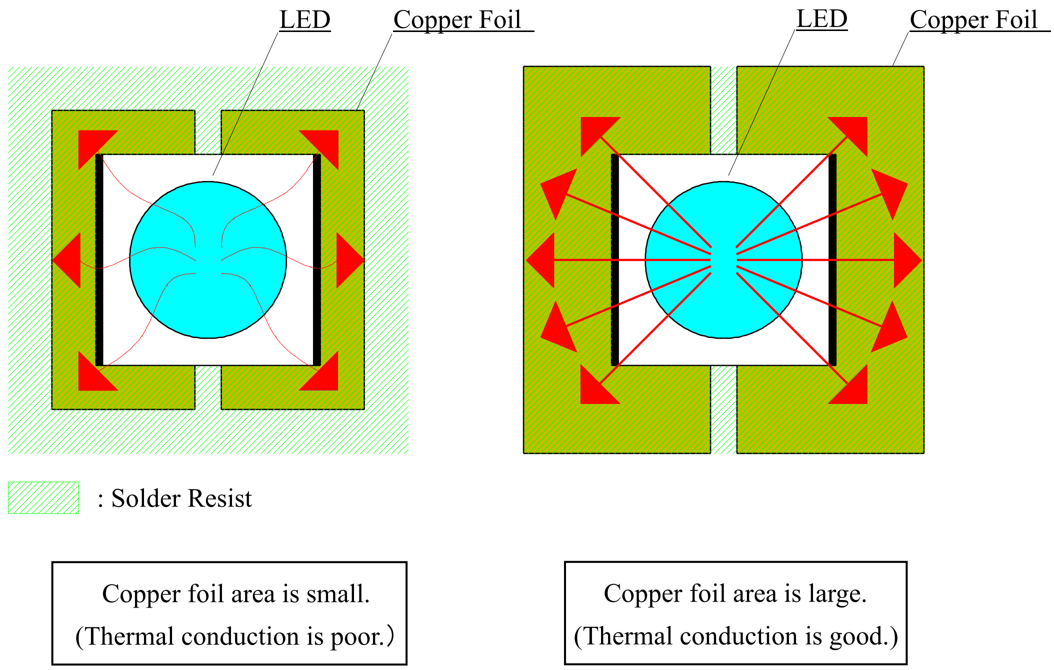


Figure 8. Copper foil pattern shape of the printed circuit board

4.3 Optimization of the LED placement (LED pitch)

If the LED pitch becomes too narrow as shown in Figure 9, it becomes harder to radiate the heat generated in a concentrated area.
Figure 10 shows the heat distribution simulation with various LED pitches.
It can be seen that the heat is trapped when the LED pitch is narrow. By increasing the LED pitch as much as possible, the T_J could be lowered.

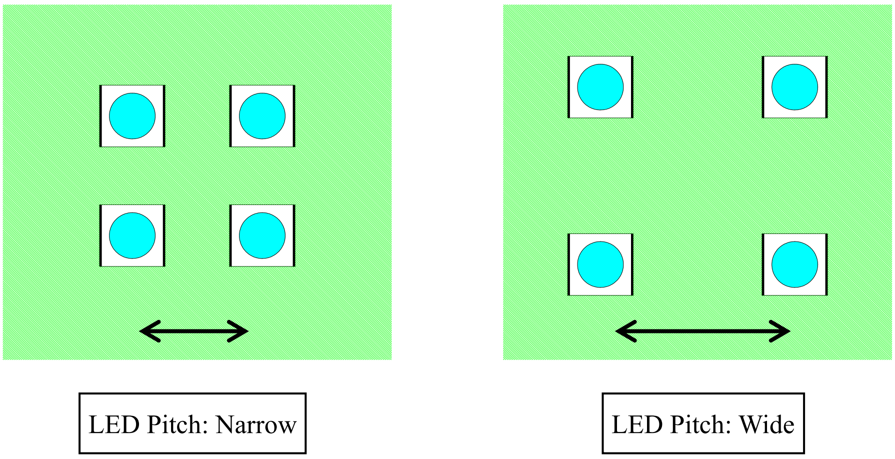


Figure 9. LED Placement

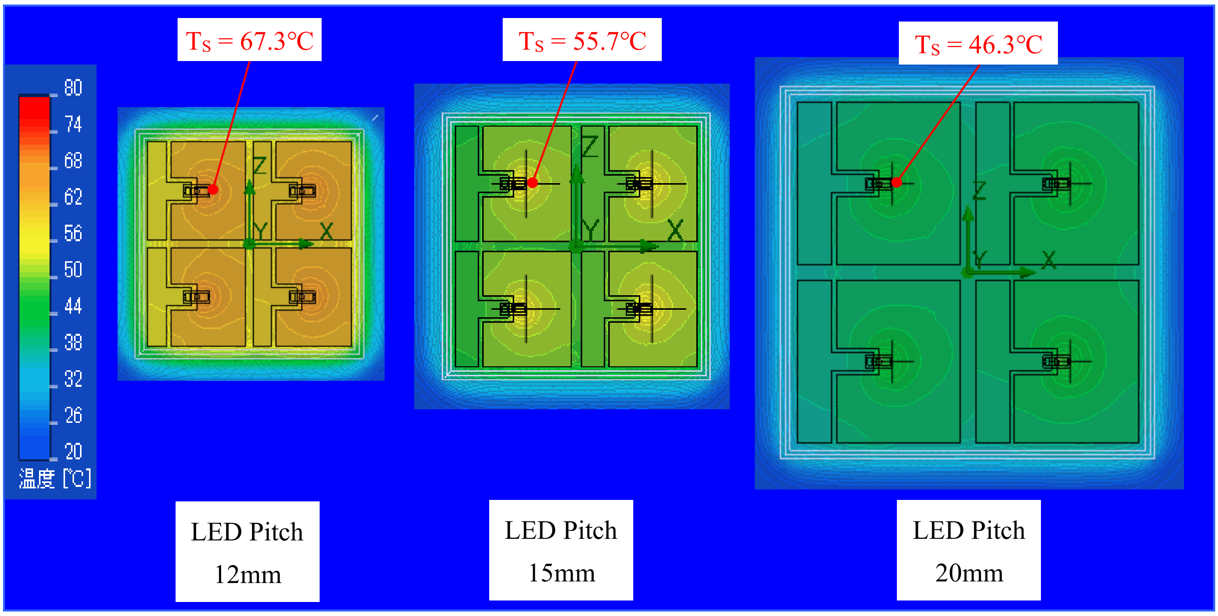


Figure 10. Thermal distribution simulation results (Example: Part No. NSSW157)

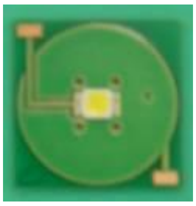
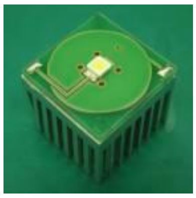
※Since the simulation is set to have the copper foil area as large as possible to in order to have the widest LED pitch, the copper foil area will be different for each simulation.

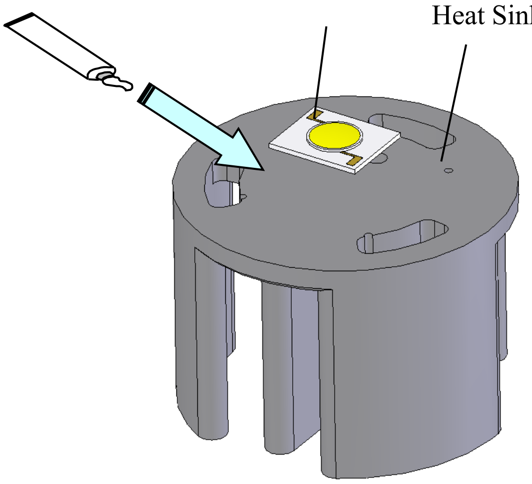
4.4 Implementing a heat sink

The heat radiation efficiency can be improved by attaching a heat sink to the back side of the board. Table 3 shows the measurement results with or without a heat sink. Both $R_{\theta JA}$ and T_J are lower when a heat sink is attached.

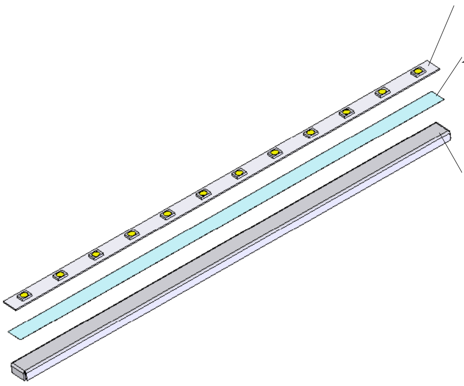
To further improve the heat radiation efficiency, it is recommended to attach the heat sink to the board using a thermally conductive tape, sheet, or grease.
Examples of connecting a heat sink to the board are shown in Figure 11.

Table 3. Thermal measurement results with the heat sink for Part No. NS6W183

	without Heat Sink	with Heat Sink
Appearance		
Board Material	FR-4	
$R_{\theta JA}$ [°C/W]	44	32
PWB Size	30mm×30mm, t=1.6mm	
Copper Area	616mm^2, t=0.07mm	
I_F (mA)	700	
V_F(V)	3.29	3.49
T_S(°C)	95	73
T_J(°C)	118	97



Connection with COB and the heat sink



Connection with an LED board and the heat sink

Figure 11. Connection with the board and the heat sink

5. Summary

By following the thermal designs mentioned in this application note, LEDs can be more efficiently used and thereby potentially improve the reliability of the end product.

Disclaimer

This application note is a controlled document of Nichia Corporation (Nichia) published to provide technical information/data for reference purposes only. By using this application note, the user agrees to the following:

- This application note has been prepared solely for reference on the subject matters incorporated within it and Nichia makes no guarantee that customers will see the same results for their chosen application.
- The information/data contained herein are only typical examples of performances and/or applications for the product. Nichia does not provide any guarantees or grant any license under or immunity from any intellectual property rights or other rights held by Nichia or third parties.
- Nichia makes no representation or warranty, express or implied, as to the accuracy, completeness or usefulness of any information contained herein. In addition, Nichia shall not be liable for any damages or losses arising out of exploiting, using, or downloading or otherwise this document, or any other acts associated with this document.
- The content of this application note may be changed without any prior or subsequent notice.
-

NICHIA CORPORATION
491 Oka, Kaminaka-Cho, Anan-Shi, TOKUSHIMA 774-8601, JAPAN
http://www.nichia.co.jp Phone: +81-884-22-2311 Fax: +81-884-21-0148