Light Emitting Diode

How to Calculate the Junction Temperature for the Nichia 123G Series LEDs

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The Nichia part numbers NFSW123G, NFSA123G, NJSW123G, and NJSA123G 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.

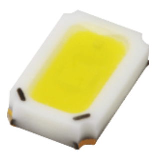
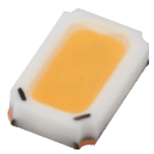
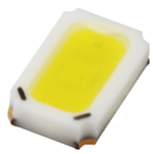
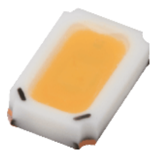
1. Overview

When designing applications using LEDs, it is necessary to consider the heat generated from the LEDs during operation. The junction temperature (T_J) of the LED is an important aspect to be considered in selecting the operating conditions of the application. If the absolute maximum rating T_J is exceeded even for a short period of time, it may cause an adverse effect on the performance of the LED; in the worst case, it could cause the LED not to illuminate. Note that the LED must be operated to ensure that the absolute maximum rating T_J is not exceeded. To prevent the T_J from exceeding the absolute maximum rating T_J, it is necessary to know how high the T_J will be when the LED is operated in the conditions/environments in which the LED will actually be used.
This application note provides how to estimate the T_J by measuring the temperature at the measurement point Nichia specifies with a thermocouple.

2. Applicable Part Numbers

This application note applies to the LEDs listed in Table 1.

Table 1. Applicable Part Numbers

Series Name	Nichia 123G Series			
Wattage	0.5W		1W	
Part Number	NFSW123G	NFSA123G	NJSW123G	NJSA123G
Emitted Color	White	Amber	White	Amber
Appearance				
Outline Dimensions (mm)	2.0×3.0×0.7	2.0×3.0×0.7	2.0×3.0×0.7	2.0×3.0×0.7

3. Terms and Descriptions

Figure 1 shows a cross-sectional view of the LED mounted to a PCB and a simple model of the thermal resistance.

Table 2 shows the terms and descriptions that are used herein regarding temperatures and thermal resistances of different points/areas.

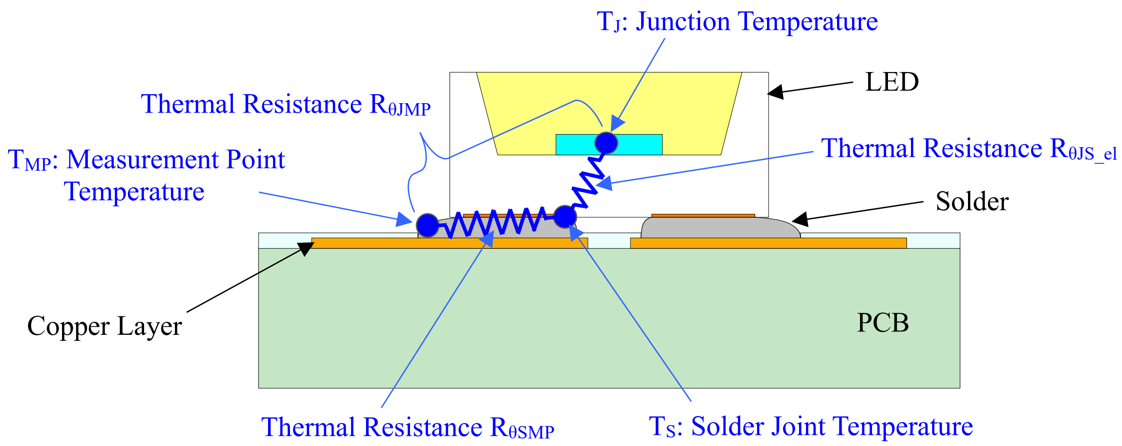


Figure 1. Cross-sectional View of the LED Mounted on a PCB and a Simple Thermal Resistance Model

Table 2. Terms and Definitions

Term	Symbol	Description
Junction Temperature	T_J	Temperature of the chip. The absolute maximum rating T_J of the Nichia 123G Series LEDs is 150°C; this temperature must not be exceeded.
Solder Joint Temperature	T_S	Temperature of the solder bonded to the cathode electrode (i.e. solder joint). The T_S cannot be measured. The T_S may be used in a thermal simulation.
Measurement Point Temperature	T_{MP}	Temperature measured at the measurement point Nichia specifies. The measurement point is on the solder that is applied on the soldering pad pattern on the cathode electrode side. The T_{MP} is measured with the LED mounted on a PCB. See Figure 2 in section 4. The T_{MP} is used to estimate the T_J. See the following sections for detailed information.
Thermal Resistance	$R_{\theta JS\_el}$	Thermal resistance from the chip to the solder joint. The $R_{\theta JS\_el}$ is obtained according to the measurement/calculation methods detailed in JESD 51. The $R_{\theta JS\_el}$ may be different depending on the part number; refer to the applicable specification for the typical and maximum $R_{\theta JS\_el}$ values of the LED. The $R_{\theta JS\_el}$ is not used in the T_J estimation method discussed herein.
	$R_{\theta JS\_real}$	Thermal resistance from the chip to the solder joint. The $R_{\theta JS\_real}$ is determined with taking the power conversion efficiency (η_e)[1] of the LED into consideration. The $R_{\theta JS\_real}$ is not provided in Figure 1. The $R_{\theta JS\_real}$ is obtained with the following equation: $R_{\theta JS\_real}=R_{\theta JS\_el}/(1-\eta_e/100)$ The $R_{\theta JS\_real}$ value may be different depending on the part number; refer to the applicable specification for the typical and maximum $R_{\theta JS\_real}$ values. The $R_{\theta JS\_real}$ may be used in a thermal simulation. The $R_{\theta JS\_real}$ is not used in the T_J estimation method discussed herein.
	$R_{\theta SMP}$	Thermal resistance from the solder joint to the T_{MP} measurement point. The $R_{\theta CMP}$ can vary depending on the heat dissipation performance (i.e. thermal conductivity) of the PCB used, the heatsink used, the operating temperature, etc.
	$R_{\theta JMP}$	Thermal resistance from the chip to the T_{MP} measurement point. As shown in Figure 1, the $R_{\theta JMP}$ is the sum of the $R_{\theta JS\_el}$ and the $R_{\theta SMP}$. For the $R_{\theta JMP}$ value of each LED part number, refer to the annex: Thermal Resistance Values of the Nichia 123G Series LEDs. The $R_{\theta JMP}$ is used to calculate the T_J using the T_{MP} value. See the following sections for detailed information.

[1] The power conversion efficiency is the ratio of the electrical energy output as light to the input electrical energy.
It can be determined with the following equation:
Power Conversion Efficiency (%) = Radiant Flux (W)/Input Power (W) × 100
For LEDs, all the electrical energy that has not been converted into light becomes heat.

4. T_{MP} Measurement

The T_J estimation can be calculated by measuring the T_{MP} of the LED once it has been soldered to a PCB. The measuring current should be the maximum operating current (I_F) that will be applied to the LED under the conditions in which the LED will actually be used. See Figure 2 for the T_{MP} measurement point.

To measure the T_{MP}, solder the temperature sensing part on the tip of the thermocouple to the soldering pad pattern (i.e. copper layer) of the PCB on the cathode electrode side; ensure that the temperature sensing part is attached at a point closest to the soldering pad pattern.

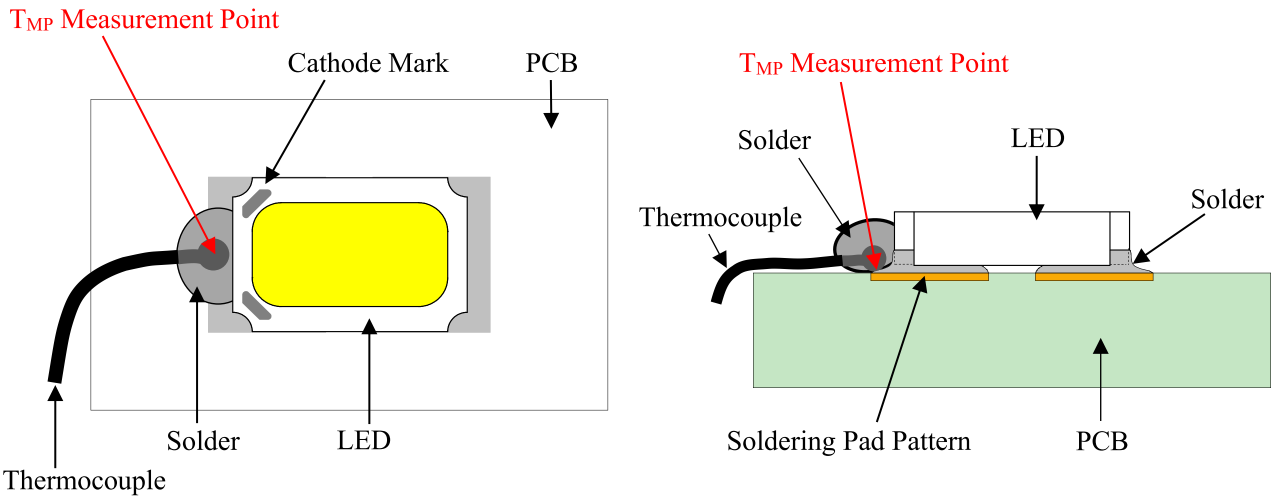


Figure 2. T_{MP} Measurement Point

5. How to Calculate the Junction Temperature (T_J)

When the product using the LED is operated, the T_J can be calculated with Equation 1 below.

Equation 1: $\mathbf{T_J = T_{MP} + R_{\theta JMP} \times W}$

T_J: Junction Temperature (˚C)
T_{MP}: Measurement Point Temperature (˚C)
$R_{\theta JMP}$: Thermal Resistance from the Chip to the T_{MP} Measurement Point (˚C/W)
W: Input Power ($I_F \times V_F$) (W)
I_F=Forward Current (A), V_F=Forward Voltage (V)

The $R_{\theta JMP}$ value may be different depending on the part number. For the $R_{\theta JMP}$ value of each part number, refer to the annex: Thermal Resistance Values of the Nichia 123G Series LEDs. For the LEDs whose $R_{\theta JMP}$ values are not listed in this annex, contact a local Nichia sales representative.

6. Calculation Example of the Junction Temperature (T_J)

This section provides an example of the T_J calculation using the measured T_{MP}.

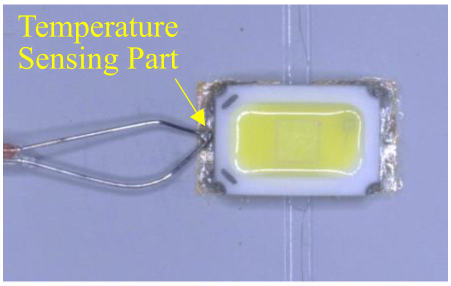
Example: The NFSW123G LED is operated at an input power of 0.5W.
The measured T_{MP} is 45˚C.

The $R_{\theta JMP}$ value of the NFSW123G LED is 31.6˚C/W (refer to the annex: Thermal Resistance Values of the Nichia 123G Series LEDs).
Using Equation 1 ($T_J = T_{MP} + R_{\theta JMP} \times W$), the following calculation is obtained:
T_J = 45(˚C) + 31.6(˚C/W) × 0.5(W) = <u>60.8</u>(˚C)

7. Considerations and Suggestions when Using a Thermocouple

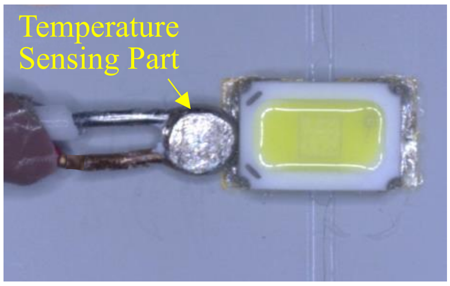
It is recommended to use a thermocouple with wires that are as thin as possible. If the wires are too thick, they may create thermal paths causing measurement errors.
If the temperature sensing part of the thermocouple is too large and/or is not located at the tip of the thermocouple, the temperature sensing part may not contact the T_{MP} measurement point; if the temperature sensing part is attached too far away from the T_{MP} measurement point and/or in contact with a place that is not the T_{MP} measurement point, it may affect the measurement accuracy.

✓ Correct



The wires are thin.
The temperature sensing part contacts the T_{MP} measurement point.

Incorrect



The wires are thick.
The temperature sensing part is too large.

Figure 3. Examples of Correct/Incorrect Thermocouples
(Before soldering to the soldering pad pattern)

The temperature sensing part of a thermocouple is at the base of the bonding/contacting area of the wires. Figure 4 (b) shows a thermocouple twisted near the base. With this type of thermocouple, perform the temperature measurement at the base of the twisted part, not at the tip of the thermocouple. With a thermocouple whose temperature sensing part is not at the tip, the T_{MP} measurement may be lower than the actual T_{MP} even when the tip is in contact with the T_{MP} measurement point; ensure that the temperature sensing part is attached to contact the T_{MP} measurement point.

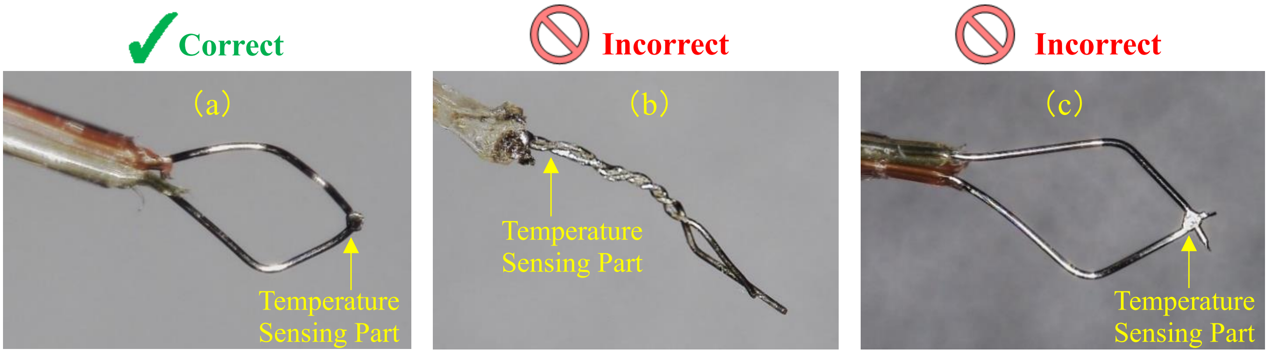


Figure 4. Temperature Sensing Part of Thermocouples

8. T_{MP} Measurement Considerations

Even under the same operating conditions, the T_J of the LED may vary depending on the heat dissipation conditions around the LED. The T_{MP} should be measured once the saturation temperature at the junction has been reached while ensuring that the LED is incorporated in the chosen application at the finished product level and in a manner that takes into consideration the conditions/environments in which the LED will actually be used, oriented the way it will actually be used, and the LED is operated at the maximum possible ambient temperature after aging. Note that the measurement may be affected by the material of the PCB, the thickness of the copper layer, the design of the soldering pad pattern, the location of the LED, the environment/components adjacent to the LED, the heatsink used, etc.

Taking into consideration the possibility of measurement variations it is recommended that the evaluation is performed with more than one LED. The more measurements that are used in the evaluation, the easier it will be to judge the accuracy of the T_{MP} measurement.

9. Summary

In this application note, Nichia has provided how to calculate the estimated value of the T_J for the LED mounted on a PCB using the thermal resistance $R_{\theta JMP}$ and the measured T_{MP}. To estimate the T_J more accurately, perform the evaluation as per the precautions/suggestions provided herein regarding how to attach the thermocouple to the soldering pad pattern and the T_{MP} measurement conditions/environments.

Additionally, ensure that the chosen design has a sufficient margin to not exceed the absolute maximum rating T_J by taking into consideration the heat dissipating conditions (i.e. the material, design, etc. of the components used with the LED, mounting conditions of the LED, etc.) and the variation of the heat dissipation performance of each individual component.

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