Light Emitting Diode

Thermal Design Considerations for Nichia NVSW719AC LEDs

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The Nichia part number NVSW719AC within this document is merely Nichia's part number for the Nichia product and is not related nor bear resemblance to any other company's product that might bear a trademark.

1. Overview

When an LED is exposed to high temperatures for a long period of time, the components and/or materials used in the LED will deteriorate, leading to degradation of the performance, reliability, and lifetime of the LED. Therefore, proper thermal design is important to achieve the performance that is specified in the applicable specification of the LED.
Since the Nichia NVSW719AC LEDs require a large input power, the thermal design may be challenging. However, if the increase of the LED temperature can be minimized by appropriate heat dissipation, it is possible to design more compact luminaires with a higher luminance than conventional LEDs. This application note provides the thermal evaluation method for the NVSW719AC LEDs.

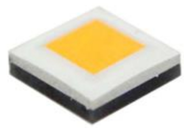


Figure 1. Appearance of the NVSW719AC LED

2. NVSW719AC LEDs

2.1 Outline Dimensions and Input Power

Figure 2 provides the outline dimensions of the NVSW719AC LEDs. Figure 3 shows a comparison of the input power for Nichia LEDs with the same package area. The amount of heat generated from the LED increases in proportion to the increase of the input power. Therefore, the thermal design is very important for the NVSW719AC LEDs to minimize the increase in the LED temperature.

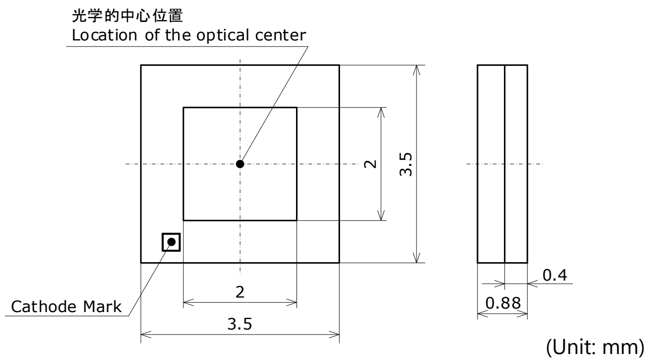


Figure 2. Outline Dimensions of the NVSW719AC LED

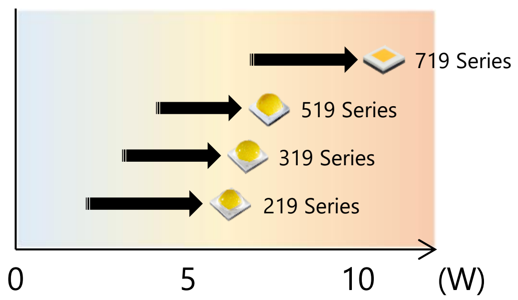


Figure 3. Comparison of the Input Power[1]

2.2 Structure and Thermal Paths of the NVSW719AC LEDs

Figure 4 shows a reference image of the structure and thermal paths of the NVSW719AC LED. The main heat sources are the LED chip and the phosphors. The heat generated from the LED chip and the phosphors mainly dissipates to the PCB and heatsink through the substrate and the electrodes of the LED. Since the NVSW719AC LEDs are designed to have a high luminance, the light density of the small emitting surface is high. This may cause the

[1] The ranges between the rated power consumption and the maximum rated power consumption are compared. The series numbers shown in this figure are Nichia LED series used for comparison with the NVSW719AC LEDs (i.e. 719 Series).

amount of heat generated in the phosphor layer of the LED to increase, resulting a higher temperature of the emitting surface than that of the LED chip. In the NVSW719AC LEDs, temperature control is important not only for the LED chip (junction temperature) but also for the emitting surface.

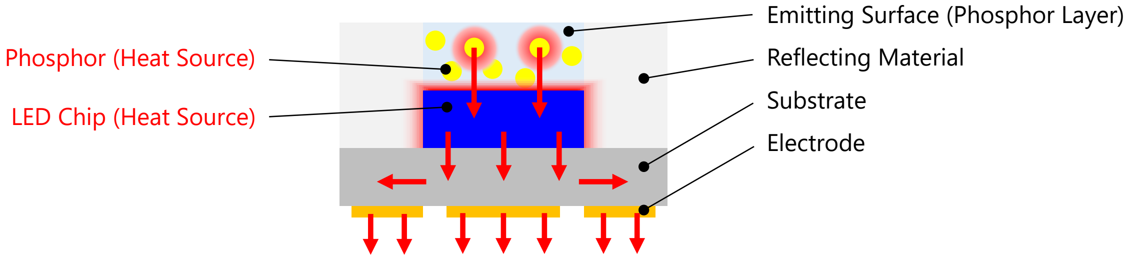


Figure 4. Reference Image of the Structure and Thermal Paths

3. Thermal Design Considerations

3.1 Thermal Resistance Model and Descriptions of the Terms

Figure 5 shows a thermal resistance model for the NVSW719AC LED. Table 1 shows the terms and descriptions that are used herein.

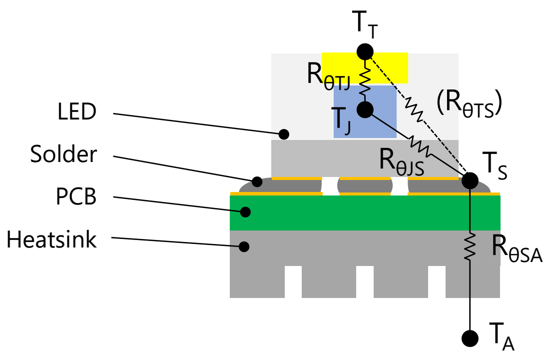
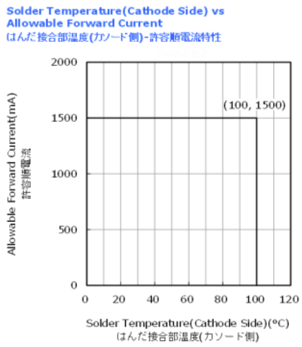


Figure 5. Thermal Resistance Model for the NVSW719AC LED

Table 1. Terms and Descriptions Related to Thermal Design

Term	Symbol	Description and Main Precautions
LED Surface Temperature	T_T	Temperature of the LED emitting surface. If the LED surface temperature is high, a decrease in the luminous flux, color shift, and degradation of the reliability may occur due to deterioration of the resin-based components used in the LED. Nichia recommends that the LED surface temperature does not exceed 180°C when using the LED.
LED Junction Temperature	T_J	Temperature of the LED chip. The thermal design must not exceed the absolute maximum junction temperature. The absolute maximum junction temperature of the NVSW719AC LEDs is 150°C. Note that the lifetime of the LED is determined by the derating characteristic of the LED junction temperature. Customers can contact a local Nichia sales representative for details.
Solder Joint Temperature	T_S	Temperature of the solder joint at the LED cathode electrode side. The solder joint temperature at the cathode electrode side is measured by using a thermocouple to conduct a thermal evaluation. When the LEDs are used under high temperatures, there are concerns such as solder deterioration and solder cracks; Nichia recommends operating the LED at the lowest solder joint temperature possible. The "Solder Temperature (Cathode Side) vs. Allowable Forward Current" is shown in the figure to the right (see the "DERATING CHRACTERISTICS" section of the specification for the NVSW719AC LEDs for the details). Ensure that the LED is operated at a solder joint temperature of 100°C or less. 
Ambient Temperature	T_A	Ambient temperature of the LED. If the heat dissipation of the chosen application (e.g. sealed fixtures) is not good around the LED module due to the design of the chosen application, note that the T_A and the T_J will be higher.
Thermal Resistance from the LED Emitting Surface to the LED Chip	$R_{\theta TJ}$	Thermal resistance from the LED emitting surface to the LED chip. The thermal resistance value varies depending on the color rank and the color rendering index rank as it is mainly related to the properties of the phosphors.
Thermal Resistance from the LED Chip to the Solder Joint	$R_{\theta JS}$	Thermal resistance from the LED chip to the solder joint. Using this thermal resistance value, the LED junction temperature can be calculated based on the temperature of the solder joint and the input power.
Thermal Resistance from the LED Emitting Surface to the Solder Joint	$R_{\theta TS}$	Thermal resistance from the LED emitting surface to the solder joint. Using this thermal resistance value, the LED surface temperature can be calculated based on the temperature of the solder joint.
Thermal Resistance from the PCB to the Ambient Air via the Thermal Interface Materials	$R_{\theta SA}$	Thermal resistance from the solder joint to the ambient air via the thermal interface materials. It is the combined resistance of the thermal interface materials including the PCB, thermal grease, and the heatsink.

3.2 Soldering Pad Pattern

Figures 6 and 7 show the electrode configuration of the NVSW719AC LED and a recommended soldering pad pattern for NVSW719AC LEDs. The die heatsink electrode has the largest effect on the heat dissipation. The die heatsink electrode is electrically insulated inside the LED, and this allows the cathode electrode and the die heatsink electrode shown in Figure 8 to be connected with the copper layer of the PCB. Having such a larger copper layer pattern immediately under the die heatsink electrode enables the generated heat to spread to the PCB efficiently.

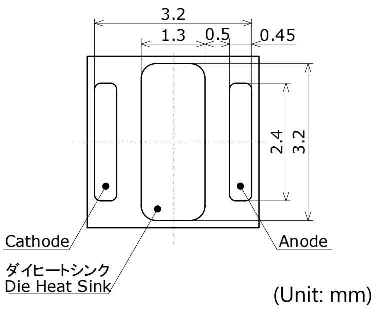


Figure 6. Electrodes on the LED Back Surface

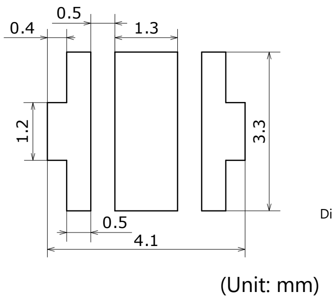


Figure 7. Recommended Soldering Pad Pattern

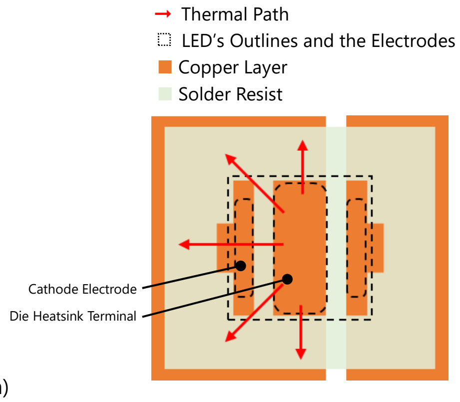


Figure 8. Example of Soldering Pad Pattern

3.3 Components Used with the LEDs

When components (e.g. secondary optical lens, cover, etc.) are used with the LED, ensure that heat and light emitted from the LED emitting surface do not affect these components (see Figure 9). Table 2 shows typical heat resistance temperatures for the materials of the optical components used with the LEDs for reference.
Note that if foreign materials (e.g. flux, dust, particles, etc.) have adhered to the LED emitting surface and/or the components used with the LEDs, the foreign materials may be heated by the intense light emitted from the LED, causing burns and/or the occurrence of smoke (see Figure 10).

Table 2. Typical Heat Resistance Temperatures of Materials (For Reference)[2]

Material	Typical Heat Resistance Temperature
Acrylic	70 to 90˚C
Polycarbonate	120 to 130˚C
Glass	>200˚C
Silicone	>200˚C

[2] These are typical temperatures and vary depending on the types of materials and their specifications.

Figure 9. Example of Deformation of a Secondary Optical Lens due to Heat

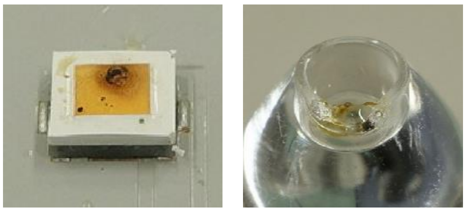


Figure 10. Examples of Burnt LED Emitting Surface and Secondary Optical Lens due to Flux Attached

4. How to Measure/Calculate the Temperatures

For proper thermal evaluation of the NVSW719AC LED, the temperature of the solder joint (T_S), the junction temperature (T_J), and the LED surface temperature (T_T) will need to be obtained. This section explains how each of the temperatures is measured or calculated.

4.1 How to Measure the Solder Joint Temperature (T_S)

As shown in Figure 11, attach a thermocouple to the solder joint area (the cathode side) to measure the solder joint temperature (T_S). Ensure that a thermocouple with a small and thin tip is used to avoid affecting the thermal dissipation. Also, ensure that the LED emitting surface is free from contamination (e.g. flux, adhesive) before attaching the thermocouple to the solder joint area.

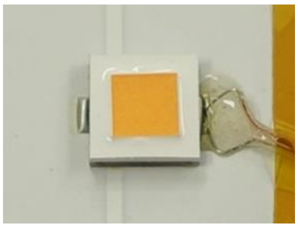


Figure 11. Example of How a Thermocouple is Attached with an Adhesive

4.2 How to Calculate the LED Junction Temperature (T_J)

There are the following two methods for calculating the LED junction temperature. These methods are briefly explained below.

- Calculating the LED junction temperature (T_J) in accordance with JESD51 standard
- Calculating the LED junction temperature (T_J) based on the solder joint temperature (T_S) and the input power

4.2.1 How to Calculate the LED Junction Temperature (T_J) in accordance with JESD51 Standard

Nichia obtains the LED junction temperature (T_J) in accordance with the method detailed in the JESD51 standard. Nichia usually obtains the LED junction temperature (T_J) by measuring the forward voltage (ΔV_F) that has a correlation with the T_J; however, for the NVSW719AC LEDs, the peak wavelength (λ_P) of the LED chip that has better linearity than the forward voltage (ΔV_F) is used to obtain the T_J. The calculation method is shown below.

4.2.1.1 Obtaining the Relationship between the Junction Temperature and the Peak Wavelength

First, the LED is operated with the pulse current (I_{FP}), which is the same as the operating current (I_F) and can minimize the heat generation, while the temperature of the LED is maintained at a certain temperature within a constant temperature chamber. Then, the emission spectrum (the peak wavelength of the LED chip [λ_P]) is measured (see Figure 12). This procedure is repeated at different temperatures for the constant temperature chamber. Since no LED self-heating affecting the measurement occurs, the LED junction temperature becomes the same temperature as that of the constant temperature chamber. Using these values, the relationship between the junction temperature and the peak wavelength is obtained as shown in Figure 13.

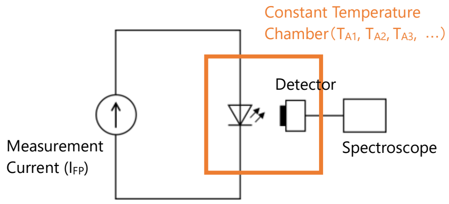


Figure 12. Measurement Circuit

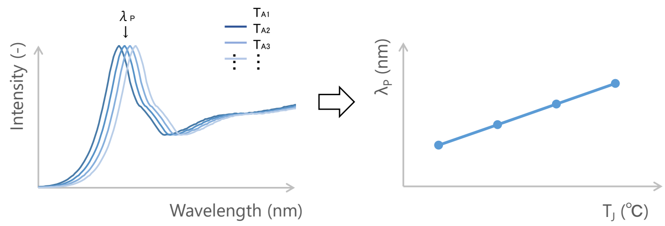


Figure 13. Relationship Between the Junction Temperature and the Peak Wavelength

4.2.1.2 Peak Wavelength Measurement and Obtaining the Junction Temperature

To measure the peak wavelength, the LED is operated with the operating current (I_F) until the LED thermally saturates (see Figure 14). Using the relationship between the junction temperature (T_J) and the peak wavelength shown in Figure 13, the T_J can be obtained based on the measured peak wavelength (see Figure 15).

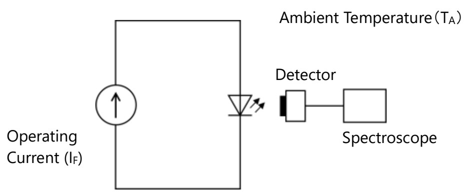


Figure 14. LED Chip's Peak Wavelength Measurement

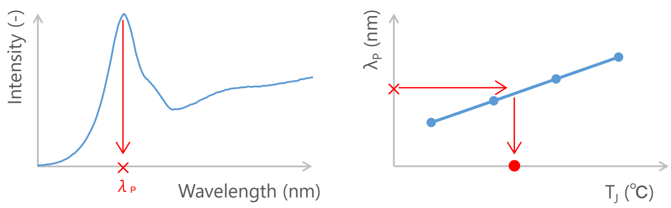


Figure 15. How to Obtain the LED Junction Temperature

For the NVSW719AC LEDs, the junction temperature and thermal resistance are obtained using the above procedures.[3] This measurement requires dedicated equipment and is not suitable for luminaries or modules. Nichia recommends the following calculation method based on the solder joint temperature (T_S) and the input power.

4.2.2 Calculating the Junction Temperature (T_J) based on the Solder Joint Temperature (T_S) and the Input Power (W)

The junction temperature can be calculated by using the solder joint temperature measured with a thermocouple, the thermal resistance ($R_{\theta JS}$), and the input power (the forward voltage [V_F] × the operating current [I_F]).
For the equation and the thermal resistance required for the calculation, refer to Equation 1 and Table 3 below, or the applicable specification. Nichia recommends using the maximum thermal resistance to have a margin for the design.

Equation 1: $T_J = T_S + R_{\theta JS} \times W$

T_J = LED Junction Temperature (˚C)
T_S = Solder Joint Temperature (˚C)
$R_{\theta JS}$ = Thermal Resistance from the LED Chip to the Solder Joint (˚C/W)
W = Input Power (W)

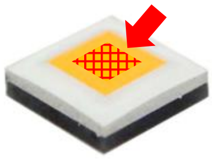
Table 3. Thermal Resistance ($R_{\theta JS}$) of the NVSW719AC LED[4]

	Unit	Typ.	Max.
Thermal Resistance ($R_{\theta JS}$)	˚C/W	2.5	3.5

[3] The calculation method used by Nichia may be changed without notice for improvements of the measurement accuracy.
[4] The maximum value is for reference purposes only (PCB used: the aluminum thickness = 1.5mm, the copper layer thickness = 35μm).

4.3 How to Measure the LED Surface Temperature (T_T)

When measuring the LED surface temperature (T_T), use a non-contact type thermal imaging camera. If a contact type measurement device such as a thermocouple is used, the sensor and/or the adhesive used for attaching the thermocouple are exposed to light and their temperatures become high, which may result in inaccurate measurement values.
When measuring the LED surface temperature (T_T), ensure that the temperature of the center area of the emitting surface is measured as shown in Figure 16. Note that when the resolution of the thermal imaging camera is low, the temperature is averaged, which may also result in inaccurate measurement; use a thermal imaging camera with a resolution suitable for the size of the chosen application.
If the LED is covered with an optical lens and/or cover, it is impossible to measure the LED surface temperature (T_T) using infrared thermography. In this case, it is necessary to calculate the approximate LED surface temperature (T_T) based on the solder joint temperature (T_S) measured by a thermocouple. For the relationship between the solder joint temperature (T_S) and the LED surface temperature (T_T), refer to the evaluation results in Sections 5 and 6.



Emissivity used for Measurement: 0.95

Figure 16. Measurement Location for the LED Surface Temperature

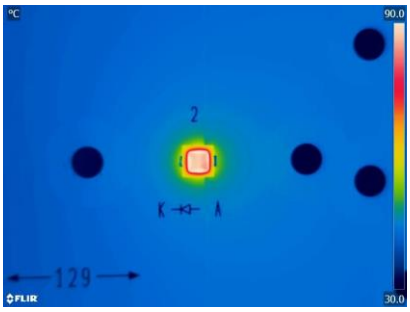


Figure 17. Example of Measurement Using a Thermal Imaging Camera

5. Thermal Evaluation

Nichia measured the solder joint temperature (T_S) and the LED surface temperature (T_T).

5.1 Evaluation Conditions

5.1.1 Evaluated LEDs

In white LEDs, the lower the color temperature and/or the higher the color rendering index, the higher the phosphor concentration, causing the amount of heat generated from the phosphors to increase accordingly. In this evaluation, the LEDs with the following ranks were used as representative samples that have a large or small amount of heat.

Sample 1: NVSW719AC LEDs with color rank of sm27 (equivalent to color temperature 2700K), and color rendering index (CRI) of R9050 (equivalent to Ra≥90)

Sample 2: NVSW719AC LEDs with color rank of sm40 (equivalent to color temperature 4000K), and color rendering index (CRI) of R9050 (equivalent to Ra≥90)

Sample 3: NVSW719AC LEDs with color rank of sm50 (equivalent to color temperature 5000K), and color rendering index (CRI) of R9050 (equivalent to Ra≥90)

Sample 4: NVSW719AC LEDs with color rank of Cr70 (equivalent to color temperature 7000K), and color rendering index (CRI) of Rnn (Ra is not specified.)

5.1.2 PCB and Heatsink Used

The PCB and heatsink used for this evaluation are as follows:

PCB:
- Material: Aluminum (Thickness: 1mm)
- Insulating Layer:
  - Thermal Conductivity[5]: 2.7W/m・K
  - Thickness: 120μm
- Copper Layer Thickness: 35μm
- Soldering Pad Pattern: See Nichia's recommended pattern on Figures 7 and 8.

Heatsink:
- Dimensions (For Reference): 50mm×38mm×25mm
- Thermal Resistance (For Reference)[6]: 5.77°C/W

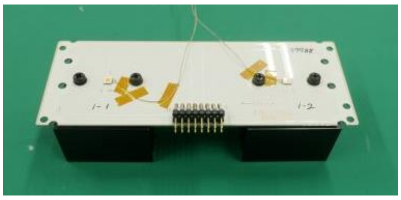


Figure 18. PCB and Heatsink Used for the Evaluation

[5] The thermal conductivity is the value stated in the PCB manufacture's data sheet.
[6] The thermal resistance is the value obtained from a simulation.

5.1.3 Operating Current

Level 1: I_F = 500mA
Level 2: I_F = 1050mA (Sorting Current)
Level 3: I_F = 1500mA (Absolute Maximum Rating Current)

5.2 Evaluation Method

Nichia operated the evaluation LEDs at the ambient temperature (T_A) of 25°C in a windless environment and then measured the solder joint temperature (T_S) and the LED surface temperature (T_T) after the saturation temperature had been reached.
A thermocouple was used for the T_S measurement, and a thermal imaging camera was used for T_T measurement.
In addition, the LED junction temperature was calculated based on the measured T_S and the thermal resistance ($R_{\theta JS}$) of 3.5°C/W.

5.3 Evaluation Results

The measurement results of the solder joint temperatures (T_S) and the LED surface temperatures (T_T) are shown in Figures 19 to 22 as well as the LED junction temperatures (T_J) calculated based on the T_S.

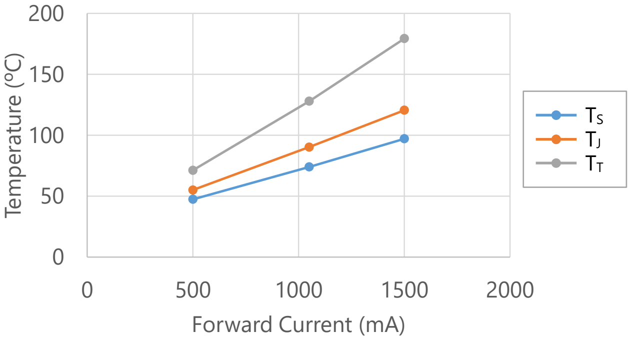


Figure 19. Measurement Results of the LEDs with Rank of sm27/R9050

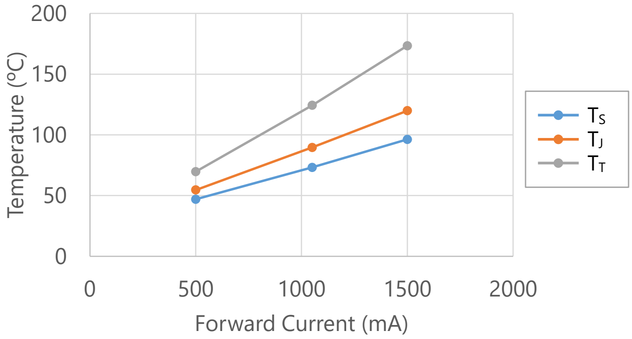


Figure 20. Measurement Results of the LEDs with Rank of sm40/R9050

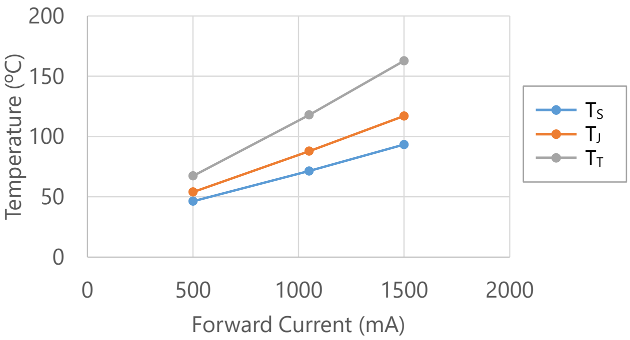


Figure 21. Measurement Results of the LEDs with Rank of sm50/R9050

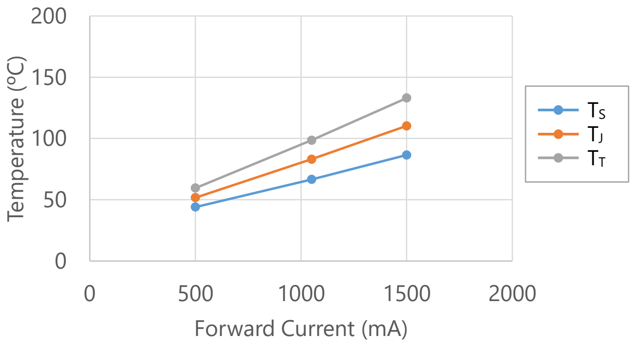


Figure 22. Measurement Results of the LEDs with Rank of Cr70/Rnn

The LED surface temperatures (T_T) are higher than the LED junction temperatures at the operating currents as shown in Figures 19 to 22. Care should be taken because the lower the color temperature is, the higher the LED surface temperature (T_T) will be.
When designing a luminaire, the LED surface temperature (T_T) must be measured as well as the LED junction temperature (T_J) and ensure that the T_J and T_T do not exceed the absolute maximum junction temperature or Nichia's recommended maximum LED surface temperature.

5.4 How to Calculate the LED Surface Temperature (T_T)

Figures 23 to 26 show the thermal resistances ($R_{\theta TS}$) from the LED emitting surface of the LED to the solder joint that were obtained based on Figures 19 to 22. When conducting a thermal evaluation, the approximate LED surface temperature (T_T) can be calculated from the solder joint temperature (T_S) by using these thermal resistances. For the calculation, see Equation 2 below. The thermal resistance used in the calculation should be obtained from the graph data whose combination of the LED rank and forward current are equivalent to those actually used in the chosen application.

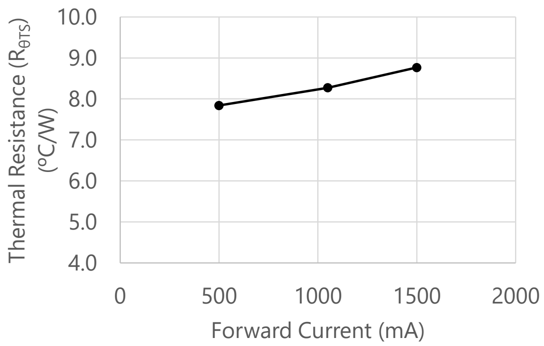


Figure 23. Measurement Results of the LEDs with Rank of sm27/R9050

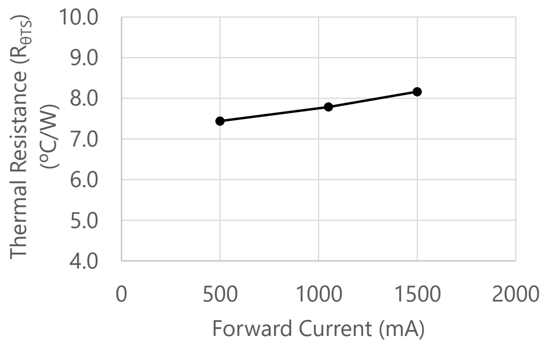


Figure 24. Measurement Results of the LEDs with Rank of sm40/R9050

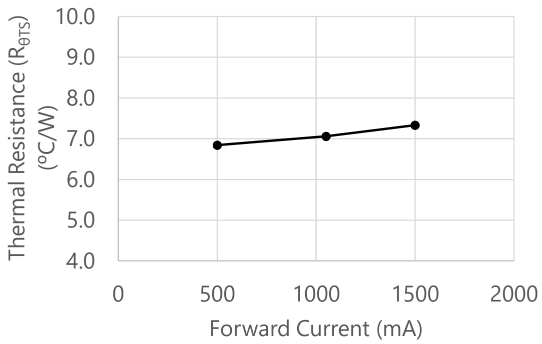


Figure 25. Measurement Results of the LEDs with Rank of sm50/R9050

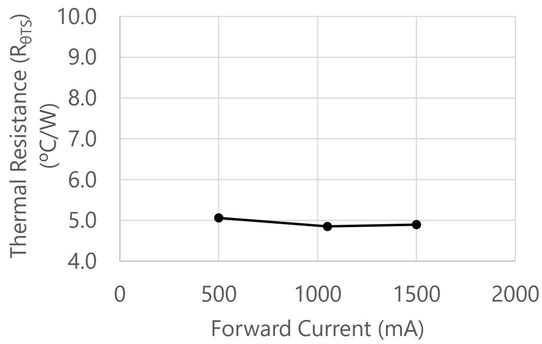


Figure 26. Measurement Results of the LEDs with Rank of Cr70/Rnn

Equation 2: $T_T = T_S + R_{\theta TS} \times W$

T_J = LED Surface Temperature (˚C)
T_S = Solder Joint Temperature (˚C)
$R_{\theta TS}$ = Thermal Resistance from the LED Surface to the Solder Joint (˚C/W)
W = Input Power (W)

6. Examples of Modules with Different Heat Dissipations

Nichia evaluated three modules with different heat dissipations. When considering the thermal design for the chosen application, use the following data for reference purposes.

6.1 Structures/Dimensions of the Modules Used for the Evaluations

Table 4 shows the structures and dimensions of the modules used for the evaluations.

Table4. Structures/Dimensions of the Modules Used for the Evaluations

		Module 1	Module 2	Module 3
Appearance				
LED Used	Part No.	NVSW719AC	Same as Module 1	Same as Module 1
	Color Rank	sm27/R9050	Same as Module 1	Same as Module 1
PCB	Size	Φ20mm	Φ40mm	Φ60mm
	Material	Aluminum (Thickness: 1.0mm)	Same as Module 1	Same as Module 1
	Thermal Conductivity of the Insulating Material[7]	2.7 W/m·K	Same as Module 1	Same as Module 1
Heatsink	Size	Φ23.5mm×14mm	Φ40mm×27mm	66mm×75mm×40mm
	Thermal Resistance[7]	19 ˚C/W	10 ˚C/W	1.9 ˚C/W

6.2 Evaluation Method

Nichia operated the evaluation LEDs at the ambient temperature (T_A) of 25˚C in a windless environment and then measured the solder joint temperature (T_S) and the LED surface temperature (T_T) after the saturation temperature had been reached.
A thermocouple was used for the T_S measurement, and a thermal imaging camera was used for T_T measurement.
In addition, the LED junction temperature (T_J) was calculated based on the measured T_S and the thermal resistance ($R_{\theta JS}$) of 3.5˚C/W.

[7] The thermal conductivity is the value stated in the PCB manufacture's data sheet.

6.3 Evaluation Results

The evaluation results are shown in Figures 27, 28, and 29.

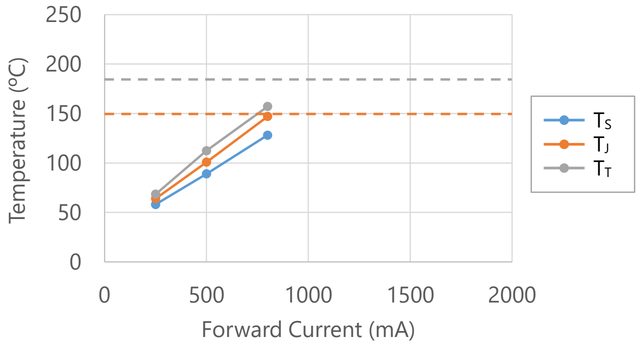


Figure 27. Measurement Results of Module 1 (Φ20mm)

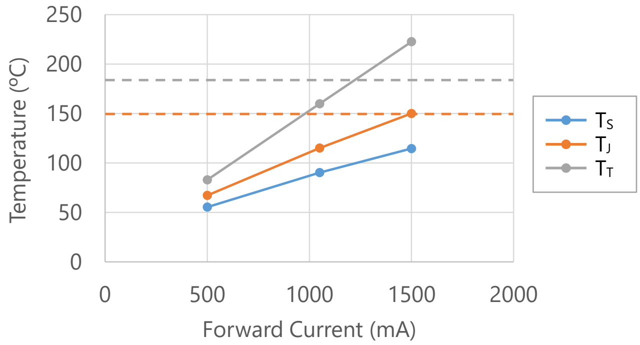


Figure 28. Measurement Results of Module 2 (Φ40mm)

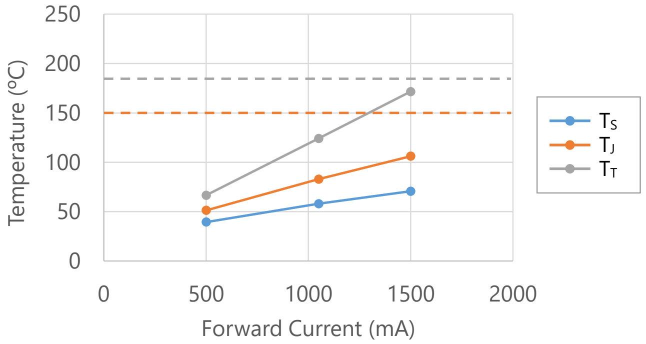
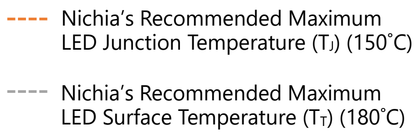


Figure 29. Measurement Results of Module 3 (Φ60mm)



In the case of Module 1 with a low heat dissipation due to the small-sized heatsink, the LED junction temperature (T_J) reaches to the absolute maximum junction temperature at I_F=800mA; thus, applying a forward current exceeding I_F=800mA must be avoided. In the case of Module 2, the LED surface temperature (T_T) exceeds Nichia's recommended maximum LED surface temperature of 180˚C at I_F=1200mA; thus, applying a forward current exceeding I_F=1200mA is not recommended. To achieve higher output power for the NVSW719AC LEDs, the heat dissipation must be equivalent to Module 3, where the T_J and T_T did not exceed the absolute maximum junction temperature or Nichia's recommended maximum LED surface temperature, or it must have higher heat dissipation than Module 3.
The evaluation results shown in this application note were obtained at an ambient temperature of T_A=25˚C. When designing a luminaire, it is necessary to consider the ambient temperature rise resulting from the LED being hermetically sealed with an optical cover and/or housing.

7. Summary

To maximize the high luminance and the high output power of the NVSW719AC LEDs, efficient thermal dissipation is essential. Customers are required to perform sufficient thermal evaluations of the chosen application prior to use by using this application note as a reference and to ensure that the chosen application has an enough margin.
The evaluation results and the thermal resistances ($R_{\theta JS}$) detailed in this application note were obtained under Nichia's evaluation conditions and environments. These results and measurement values may vary depending on the conditions and environments in which the chosen application is actually used; these results and values should be used for reference purposes only.

Light Emitting Diode

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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