Light Emitting Diode

# Thermal Design Considerations for the Nichia NFSWE11A LEDs

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NFSWE11A and NFSW757H refer to Nichia part numbers. These Nichia part numbers 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 an LED is operated, if the heat is not appropriately dissipated it may cause the components and/or materials to deteriorate due to the self-heating of the LED leading to a performance/reliability degradation of the LED (e.g. reduction in the brightness, shorter lifetime, etc.). Proper thermal design is necessary to achieve the performance that is specified in the applicable specification of the LED.

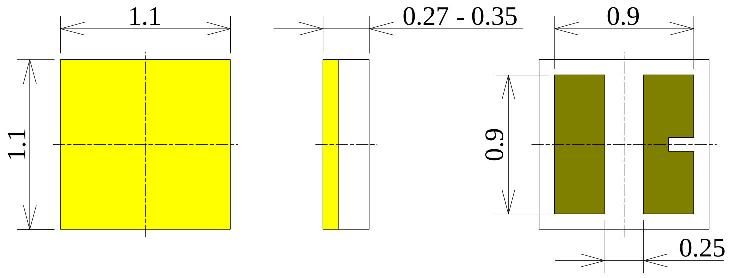
The Nichia NFSWE11A LEDs are intended for general lighting applications and have a package that is compact, low-profile, and light; this LED is perfect for smaller luminaires that could not use larger sized LEDs. Note that the smaller the chosen luminaire is, the more challenging the thermal design and thermal evaluation will be.

This application note provides the thermal design considerations for the NFSWE11A LEDs, the results of the thermal evaluations Nichia performed, and how to evaluate the junction temperature ($T_J$) of the LED in the chosen application.

## 2. Features of the NFSWE11A LEDs

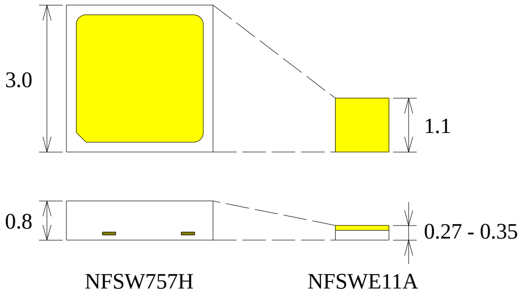
### 2.1 Outline Dimensions

Figure 1 provides the outline dimensions of the NFSWE11A LED. Figure 2 provides comparison images that show the difference in outline dimensions between the NFSWE11A LED and the NFSW757H LED[1]; the NFSW757H LED is an existing Nichia LED whose output power is equivalent to that of the NFSWE11A LED. From Figure 2, it is obvious that the NFSWE11A LEDs are much smaller than existing LEDs that have an equivalent output power; with the NFSWE11A LEDs, it is possible to design very compact, low-profile luminaires.



(unit: mm)

Figure 1. Outline Dimensions of the NFSWE11A LED



(unit: mm)

Figure 2. Size Comparison with an existing LED with an equivalent output power

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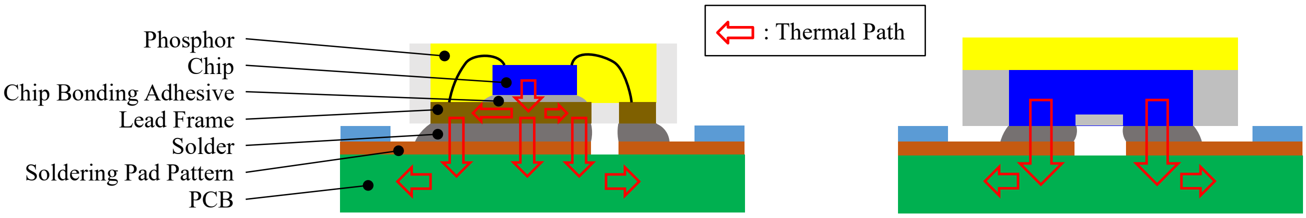
[1] The sorting current for the NFSW757H LEDs is the same as that for the NFSWE11A LEDs: 65mA.

## 2.2 Structure

For a typical LED, the chip is mounted on the lead frame, submount, etc.; in the process when the heat generated from the chip is dissipated to the PCB, the heat goes through the adhesive (e.g. chip bonding adhesive) and the lead frame, submount, etc. For the NFSWE11A LEDs, the chip is soldered directly to the PCB; the heat generated from the chip can be effectively dissipated to the PCB. See Figure 3. Note that although the NFSWE11A LEDs have good heat dissipation performance, proper thermal design is necessary since the LED itself and its electrodes, which are in the thermal path, are too small compared to the amount of the heat generated.



A Typical LED

NFSWE11A LED

Figure 3. LED Heat Dissipation Reference Images

## 2.3 Precautions when Soldering the Electrodes

The NFSWE11A LEDs have large electrodes to improve the placement accuracy (see Figure 4); if solder paste is not applied to a sufficient area between the electrodes and soldering pad pattern, it may cause the heat dissipation performance of the LED to be reduced resulting in reduced reliability (see Figure 5). To achieve the performance that is specified in the applicable specification of the LED, ensure that the electrodes are soldered to the PCB properly.

To achieve the specification's performance for the LED, Nichia recommends each of the electrodes is soldered to the PCB with solder paste covering ≥75% of the electrode. Ensure that an adequate area is covered by solder paste using an X-ray examination, etc. The ratio of the solder joint area to the area of the electrode is calculated using Equation 1.

Equation 1:

Area of the solder joint except for non-bonding area (e.g. voids)/Area of the electrode×100

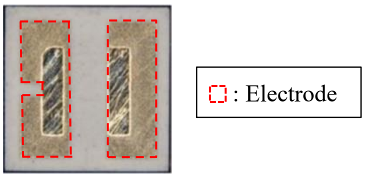


Figure 4. Appearance of the Back of the NFSWE11A LED

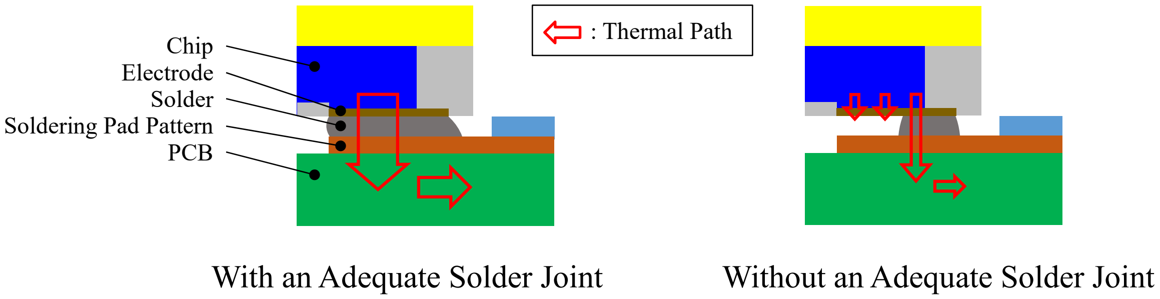


Figure 5. LED Heat Dissipation Reference Images for the NFSWE11A LED

## 3. Thermal Design Considerations

### 3.1 Thermal Resistance Model and Descriptions of the Terms

Figures 6 and 7 show a thermal resistance model for the NFSWE11A LED. Table 1 shows the terms and descriptions that are used herein. When performing a thermal evaluation with the chosen application, ensure that the $T_B$ is measured adjacent to the LED.

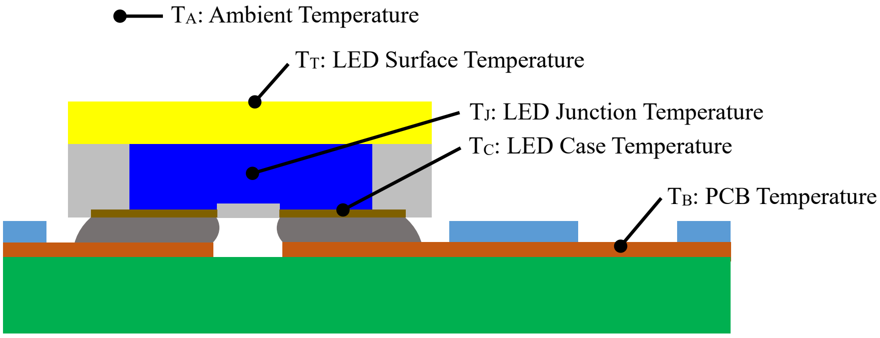


Figure 6. Cross-sectional View of the NFSWE11A LED

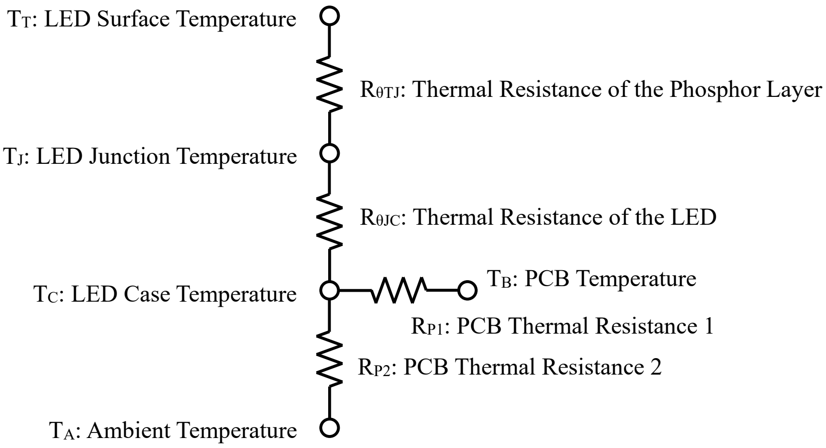


Figure 7. Simplified Thermal Resistance Model for the NFSWE11A LED

Table 1. Terms and Descriptions Related to Thermal Design

| Term | Symbol | Descriptions |
|---|---|---|
| Ambient Temperature | $T_A$ | The ambient temperature of the LED. If the heat dissipation of the chosen application 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. |
| LED Surface Temperature | $T_T$ | The temperature of the emitting surface of the LED. |
| LED Junction Temperature | $T_J$ | The temperature of the LED chip. The $T_J$ must not exceed the absolute maximum junction temperature; the absolute maximum junction temperature for the NFSWE11A LED is 135°C.<br>Note that the lower the $T_J$ is, the longer the lifetime of the LED will be. |
| LED Case Temperature | $T_C$ | The temperature of the electrode of the LED. As noted in the specification, the $T_C$ is used in a thermal simulation; it cannot be measured once the LED is soldered to the PCB. |
| PCB Temperature | $T_B$ | For the NFSWE11A LED, the $T_C$ cannot be measured; instead, the temperature of the soldering pad pattern on the PCB is measured with a thermocouple. |
| Thermal Resistance of the Phosphor Layer | $R_{\theta TJ}$ | The thermal resistance from the LED chip to the emitting surface of the LED. |
| Thermal Resistance of the LED | $R_{\theta JC}$ | The thermal resistance from the LED chip to the electrode of the LED. As noted in the specification, the $R_{\theta JC}$ is obtained according to the measurement/calculation methods detailed in JESD 51-1. |
| Thermal Resistance from the LED to the PCB | $R_{\theta JB}$ | The thermal resistance from the LED chip to the $T_B$ measurement point on the PCB: $R_{\theta JB} = R_{\theta JC} + R_{P1}$. |
| PCB Thermal Resistance | $R_{P1}$ | The thermal resistance from the $T_C$ point of the LED to the $T_B$ measurement point on the PCB. The value of the $R_{P1}$ varies depending on the geometry of the soldering pad pattern, PCB materials, the thermal performance of the solder paste, the operating conditions, etc. |
| | $R_{P2}$ | The thermal resistance of the PCB. The value of the $R_{P2}$ varies depending on the thermal performance of the PCB and other components of the chosen application that affect the heat dissipation performance. |

### 3.2 Materials for PCBs

To achieve the performance and reliability that are specified in the applicable specification of the LED, it is important to select a proper PCB for the LED considering its power consumption (i.e. amount of the heat generated from the LED). Table 2 provides typical PCB materials and their advantages/ disadvantages.

The rated power consumption for the NFSWE11A LED is 0.25W. This means the NFSWE11A LED is operated at a relatively low input power compared to other LEDs. With this low power consumption, the possibility of the LED junction temperature becoming too high is smaller even if the heat dissipation performance of the chosen application is not good; resin-based substrates (e.g. CEM-3, FR-4), which are less thermally conductive and cheaper than metal-core substrates, can be used. Flexible substrates may also be used to make smaller and lighter luminaires. However, note that a flexible substrate that is made from polyimide, etc. has a high thermal resistance; the thermal design may be more challenging.

Table 2. Typical PCB Materials

| PCB Material | | Advantage/Disadvantage | Heat Dissipation[2] |
|---|---|---|---|
| Rigid | Paper Phenol (FR-1) | It is cheaper than other options and the durability and fire-resistance are low; FR-1 PCBs are often used for low-cost, low-performance applications. | Lower than normal |
| | Glass Epoxy (FR-4) | Most commonly used PCB: complicated FR-4 multilayer PCBs are used in electronic devices, etc. FR-4 substrates are often used as the PCB for LEDs. | Good |
| | Glass Composite (CEM-3) | It is cheaper than other options, but the dimensional stability is lower than FR-4 PCBs. | Good |
| | Metal-core | Made of metal with high thermal conductivity (e.g. aluminum, copper); an application using a metal-core PCB can be used at a larger input power than an application using a resin PCB. Metal-core PCBs are used for high power LEDs whose heat cannot be dissipated properly with a resin PCB. | Excellent |
| Flexible (FPC) | | Thin, light, and bendable which enables three-dimensional arrangements for electrical circuits. In recent years, flexible PCBs have started to be used in various types of applications due to the demand for compact and light electric devices. | Lower than normal |

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[2] For reference purposes only, the heat dissipation performance depends on the individual PCB.

### 3.3 Soldering Pad Pattern

Figure 8 shows a recommended soldering pad pattern for the NFSWE11A LEDs. For more information about assembly precautions, refer to the application note: Assembly Precautions for the Nichia NFSWE11A LEDs.

There are two types of copper layer designs to create the soldering pad pattern: Solder Mask Defined (SMD) and Non-solder Mask Defined (NSMD). For SMD, the soldering pad pattern is defined by the aperture of the solder resist with a large copper layer under it. For NSMD, the soldering pad pattern is defined by the dimensions of copper layer. See Figure 9. Generally, NSMD can create a soldering pad pattern that is more precise in size and shape than SMD since the copper layer allows for better control of the dimensional tolerances than the solder resist. However, since the area of the copper layer is smaller for NSMD the heat dissipation performance is better with SMD. Nichia recommends using SMD to create the soldering pad pattern when good thermal dissipation is required. Also, the length of the soldering pad pattern (i.e. area of the soldering pad pattern) affects the heat dissipation performance (i.e. the thermal resistance, etc.) (refer to section 5); the heat dissipation performance of the chosen application can be improved by using SMD and having the copper layer around the LED be as large as possible.

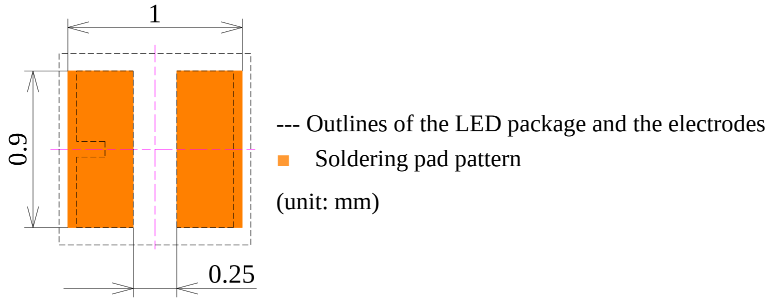

Figure 8. Recommended Soldering Pad Pattern for the NFSWE11A LEDs

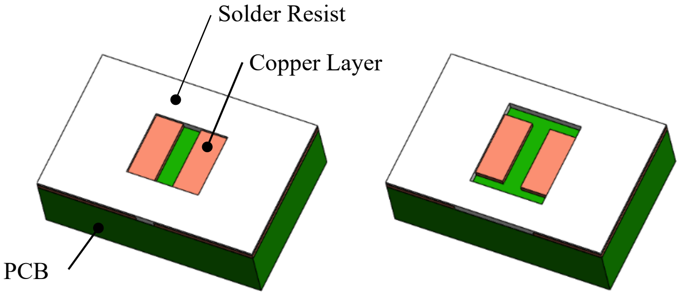

Figure 9. Reference Images of SMD and NSMD

## 4. How to Calculate the Junction Temperature

### 4.1 Calculation Methods

The junction temperature ($T_J$) of the NFSWE11A LEDs is calculated using one of the following two methods:

1. Calculated from the PCB temperature ($T_B$), the input power, and the thermal resistance from the LED to the PCB ($R_{\theta JB}$).
2. Calculated by measuring the ⊿$V_F$ of the LED.

For detailed information on these calculation methods, refer to the application note: Thermal Design Considerations for the Nichia NCSxE17A or NVSxE21A LEDs. Ensure that the $T_J$ does not exceed 135°C (i.e. the absolute maximum junction temperature for the NFSWE11A LEDs) for both calculation methods.

### 4.2 How to Measure the $T_B$

For the NFSWE11A LED, the temperature of the electrode/solder joint cannot be measured due to its structure. Also, since the LED is very compact, if a thermocouple is attached directly to the LED the adhesive and the thermocouple itself will dissipate the heat and that may reduce the accuracy of the measurements. Nichia recommends measuring the $T_B$ at the measurement point on the PCB.

To attach a thermocouple to measure the $T_B$, create an opening in the solder resist whose diameter is 1mm on the surface of the PCB at the point 2.05mm from the center of the LED. Use solder or adhesive with a high thermal conductivity to attach a thermocouple at the opening. Ensure that the flux/adhesive does not adhere to the LED when attaching a thermocouple.

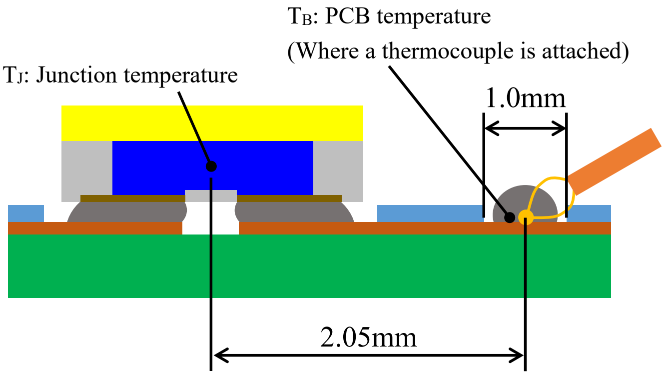

Figure 10. $T_B$ Measurement Point

### 4.3 How to Calculate the $T_J$

The value of the $R_{\theta JB}$, the thermal resistance from the LED chip (i.e. junction) to the $T_B$ measurement point on the PCB, may vary depending on the individual PCB. For reference, Table 3 provides the representative $R_{\theta JB}$ values for the LED that were obtained from the evaluations detailed in section 5.2.2: Calculated $R_{\theta JB}$ on Page 12.

The $T_J$ can be calculated using Equation 2 below.

Equation 2: $T_J$ (°C) = $T_B$ (°C) + Power consumption (W) × $R_{\theta JB}$ (°C/W)

Table 3. Representative $R_{\theta JB}$ Values for Reference Purposes[3]

| LED Rank | PCB | Width of the PCB Trace (mm) | Operating Current (mA) | $R_{\theta JB}$ Value (°C/W) |
|---|---|---|---|---|
| sm50/R8000 | CEM-3 | 0.9 | 65 | 32 |
| sm27/R9050 | FPC | 0.5 | 150 | 75 |

## 5. Thermal Evaluations for the NFSWE11A LEDs

Nichia evaluated the junction temperature ($T_J$) and the thermal resistance from the LED to the PCB ($R_{\theta JB}$) for the NFSWE11A LEDs using different conditions. The values of the $T_J$ and $R_{\theta JB}$ were obtained according to the measurement/calculation methods detailed in JESD 51.

### 5.1 Evaluation Conditions

Nichia performed evaluations using the following conditions and parameters.

Evaluated LEDs:
LED 1: NFSWE11A LED with the color rank of sm50 (equivalent to 5000K)
and CRI rank of R8000
LED 2: NFSWE11A LED with the color rank of sm27 (equivalent to 2700K)
and CRI rank of R9050

The absolute maximum junction temperature ($T_{Jmax}$) for the NFSWE11A LED is 135°C. Since LED 2 is a lower color temperature and has higher color rending, it has more phosphor to emit light which caused more heat to be generated and led to a greater increase in the $T_J$.

PCBs:
PCB 1: CEM-3
PCB 2: FPC (Made from polyimide)

Table 4 provides the details of the PCBs that were used for the evaluations. The evaluations were performed without using other components that may affect the heat dissipation performance of the LED and PCB (e.g. heatsink).

Table 4. PCBs Used for the Evaluations

| PCB | Thermal Conductivity (W/m·K) | Thickness of the Copper Layer (µm) | Thickness of the PCB (mm) |
|---|---|---|---|
| CEM-3 | 1.0 | 35 | 1.2 |
| FPC | 0.4 | 35 | 0.2 |

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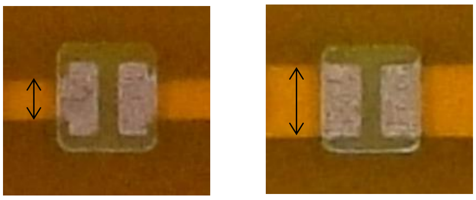
[3] For the values obtained under other conditions, refer to section 5: Thermal Evaluations for the NFSWE11A LEDs.

Soldering pad pattern:
Soldering Pad Pattern: Nichia recommended soldering pad pattern (see Figure 8)
Copper Layer Design: NSMD

Width of the PCB traces:
PCB Trace 1: 0.5mm in width
PCB Trace 2: 0.9mm in width

The PCB trace with the width of 0.5mm is not recommended since it is shorter than the length of the recommended soldering pad pattern (i.e. electrode), the heat is not sufficiently dissipated. See Figure 11.



0.5mm 0.9mm

Figure 11. Width of the PCB Trace

Operating current:
Operating current 1: 65mA (i.e. sorting current)
Operating current 2: 130mA
Operating current 3: 200mA
Operating current 4: 250mA (i.e. absolute maximum rating current)

$T_B$ measurement point:
Refer to section 4.2 How to Measure the $T_B$.

## 5.2 Evaluation Results

### 5.2.1 Junction Temperature ($T_J$)

Figures 12-15 show the evaluation results for the $T_J$.

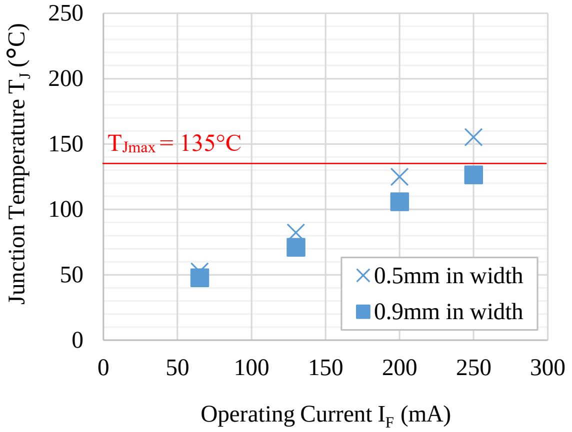


Figure 12. LED 1 (sm50 and R8000) on PCB 1 (CEM-3)

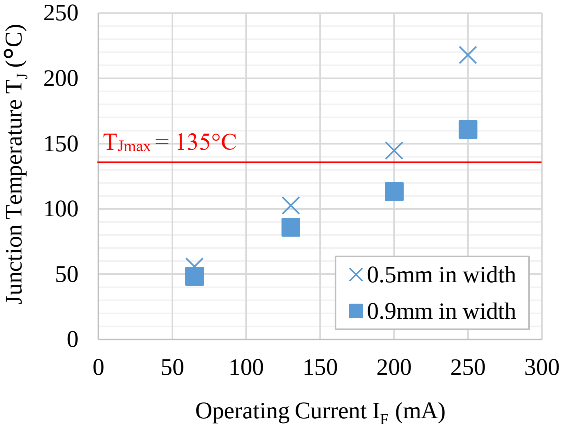


Figure 13. LED 1 (sm50 and R8000) on PCB 2 (FPC)

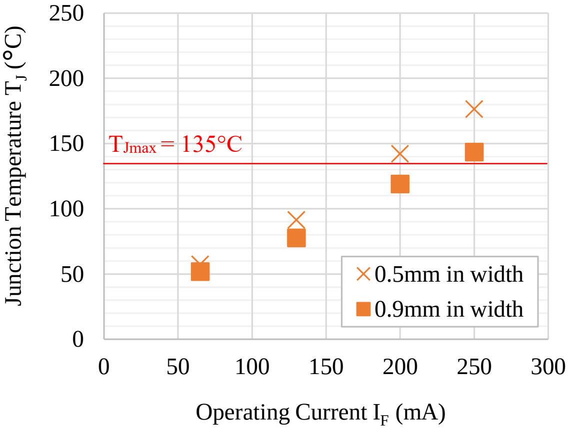


Figure 14. LED 2 (sm27 and R9050) on PCB 1 (CEM-3)

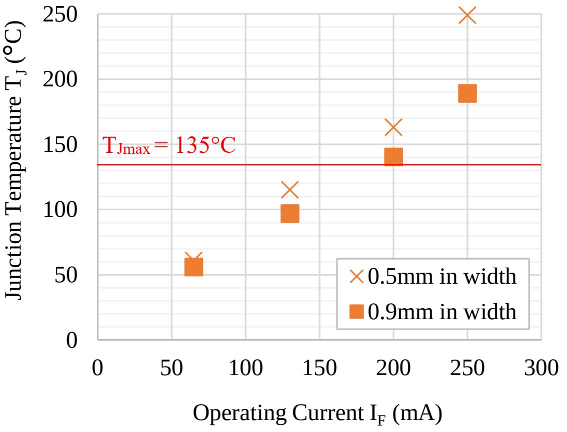


Figure 15. LED 2 (sm27 and R9050) on PCB 2 (FPC)

The evaluation results show that the $T_J$ became higher for LED 2 (sm27 and R9050) than LED 1 (sm50 and R8000) since LED 2 generated more heat from the phosphor. Also, the $T_J$ was higher for PCB 2 (FPC) than PCB 1 (CEM-3), and higher for PCB Trace 1 (0.5mm in width) than PCB Trace 2 (0.9mm in width); PCB 2 and PCB Trace 1 had a lower heat dissipation performance.

The $T_J$ increased proportional to the operating current except for the evaluations using PCB 2 and PCB Trace 1, which were the combination with the lowest heat dissipation, the $T_J$ rapidly increased when the LED was operated at 250mA. That means the heat dissipation performance of the PCB was insufficient for the amount of the heat generated from the LED under those conditions.

For the combination for which the $T_J$ became the highest (i.e. LED 2, PCB 2, and PCB Trace 1), the $T_J$ exceeded 135°C, the absolute maximum junction temperature ($T_{Jmax}$) for the NFSWE11A LED when the LED was operated at approximately ≥150mA. Nichia recommends operating the LED at ≤150mA when using the LED mounted on a resin PCB and without heat dissipating components.

### 5.2.2 Calculated $R_{\theta JB}$

The $R_{\theta JB}$ values were calculated using the $T_J$ and $T_B$ values obtained from the measurements. Figures 16-19 show the evaluation results for the $R_{\theta JB}$.

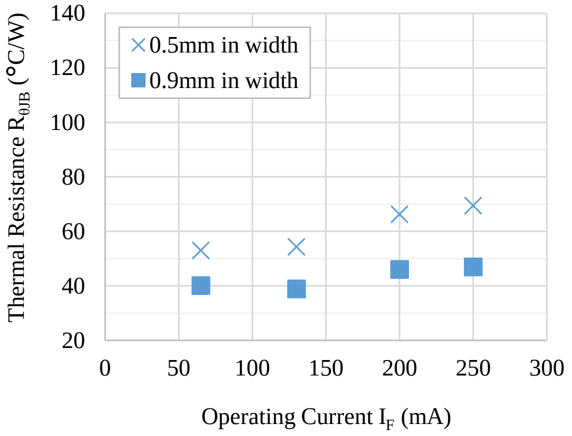


Figure 16. LED 1 (sm50 and R8000) on PCB 1 (CEM-3)

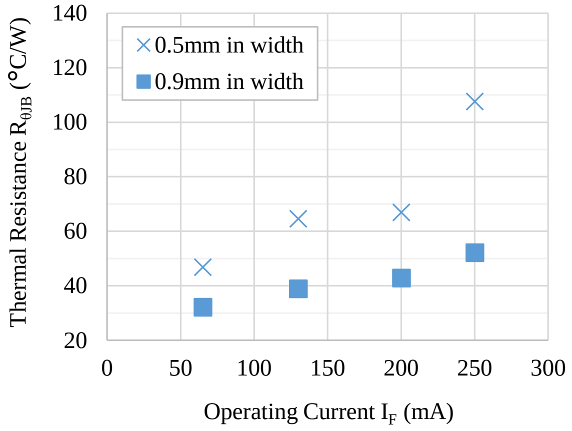


Figure 17. LED 1 (sm50 and R8000) on PCB 2 (FPC)

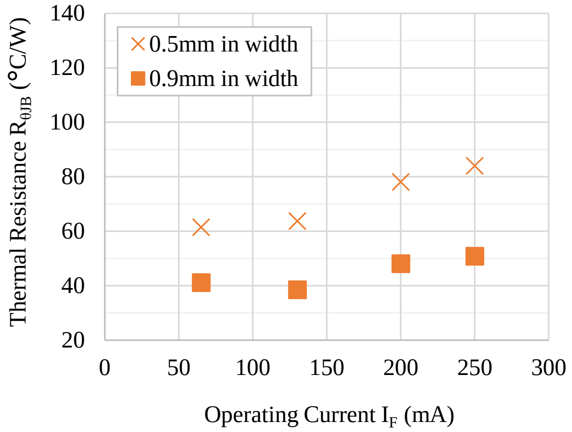


Figure 18. LED 2 (sm27 and R9050) on PCB 1 (CEM-3)

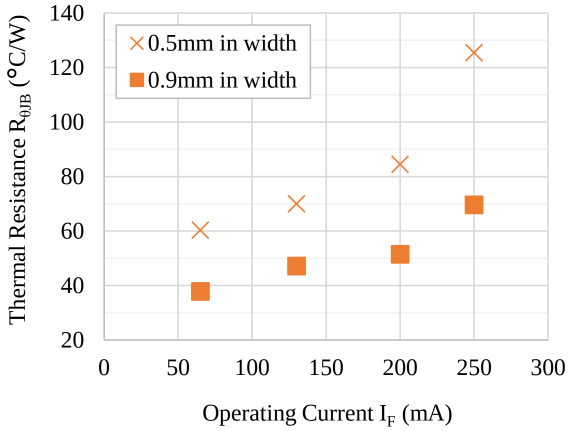


Figure 19. LED 2 (sm27 and R9050) on PCB 2 (FPC)

The evaluation results indicate that the $R_{\theta JB}$ was greatly affected by the width of the PCB trace since the $T_B$ was measured at a point on the PCB trace. Assuming the LED would be used in a compact application, the evaluations were performed using an NSMD copper layer design. If the restrictions for the design and size of the PCB allow, the $R_{\theta JB}$ can be lowered by using SMD and having the width of the PCB trace as large as possible.
The evaluation results also show that the $R_{\theta JB}$ rapidly increased when a high current was applied to the LED that was mounted on PCB 2 (FPC) with PCB Trace 1 (0.5mm in width) since the combination had a lower heat dissipation performance; this behavior was similar to that of the $T_J$ as detailed in section 5.2.1. That means the heat dissipation performance of the PCB was not sufficient for the amount of the heat generated from the LED under those conditions.

If the $R_{\theta JB}$ is known, the $T_J$ can be calculated using the measured $T_B$. As the evaluation results indicate, the values of the $R_{\theta JB}$ may greatly vary depending on the conditions. For the evaluations performed at

operating currents of ≤150mA (i.e. the currents at which the $T_J$ was kept under 135˚C), the highest $R_{\theta JB}$ was 75˚C/W (for the PCB trace with the width of 0.5mm and operating current of 150mA[4]. See Figure 19) and the lowest $R_{\theta JB}$ was 32˚C/W (for the PCB trace with the width of 0.9mm and operating current of 65mA. See Figure 17); the difference between them was very large.
When the $R_{\theta JB}$ is used to calculate the $T_J$, select the value of the $R_{\theta JB}$ that was obtained under the evaluation conditions closest to the conditions being used for the chosen application. Note that the values shown above are for reference purposes only and the $R_{\theta JB}$ may vary depending on the conditions/environments in which the LED will actually be used.

## 6. Thermal Evaluations Using an Infrared Thermal Imaging Camera

### 6.1 LED Surface Temperature ($T_T$)

Generally, a white LED creates white light by mixing blue light and yellow light; the blue LED chip emits blue light and part of it is converted to yellow light by the phosphor. In this color conversion process, there will be an energy loss (i.e. heat generation). Both the LED chip and the phosphor are heat sources within the LED (see Figure 20). Note that if the resin-based components used in the LED are exposed to high temperatures, they may rapidly degrade causing adverse effects on the performance and/or reliability of the LED.
Based on the heat resistance temperatures of the components used in the LED and the relationship between the $T_T$ and $T_J$ of the LED detailed in section 6.3.2, Nichia recommends that both the $T_T$ and $T_J$ do not exceed 135˚C

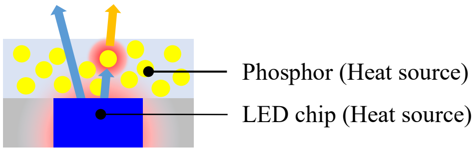


Figure 20. Reference Image of Heat Generation for a White LED

### 6.2 How to Measure the $T_T$

The $T_T$ cannot be measured accurately with a thermocouple since the adhesive used to attach the thermocouple will generate heat when the LED is illuminated. Nichia recommends performing a non-contact temperature measurement using an infrared thermal imaging camera (see Figure 21). With an infrared thermal imaging camera, it is possible to identify the hottest LED on the PCB, to detect any LEDs that are generating heat abnormally, etc. since the camera can evaluate the temperature distribution.
Ensure that the $T_T$ is measured at the center of the emitting surface (i.e. where the temperature is highest); prior to measuring the $T_T$, operate the LED for long enough to stabilize the temperature. The following are other precautions for measuring the $T_T$ using an infrared thermal imaging camera.

- There will be measurement variations for an infrared thermal imaging camera due to the measurement conditions/environments; ensure that the thermal design for the chosen application has sufficient margins/tolerances.

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[4] The $R_{\theta JB}$ value at 150mA was estimated based on the values at 130mA and 200mA.

- Select an infrared thermal imaging camera that has sufficient resolution. The $T_T$ may vary depending on where it is measured on the LED surface; the $T_T$ values may be different at the center (i.e. right above the LED chip) and at an edge of the surface. See Figure 21. With an infrared thermal imaging camera whose resolution is insufficient, the $T_T$ may be measured to be lower than the actual temperature since the different temperatures on the LED surface cannot be captured independently with the camera and will be averaged.

- If foreign materials (e.g. flux, dust, particles, etc.) have adhered to the LED surface, the $T_T$ may not be measured accurately.

- For a high-density application, the temperatures of the LEDs that are placed in the middle of the PCB tend to become higher than those of the other LEDs due to the heat generated from the adjacent LEDs. The temperature distribution on the PCB may be uneven depending on the conditions of the PCB; evaluate the temperature distribution within the chosen application prior to use.

- If the LED is used with an optical component that has a low heat resistance temperature, ensure that there are no issues caused by the heat of the LED surface prior to use.

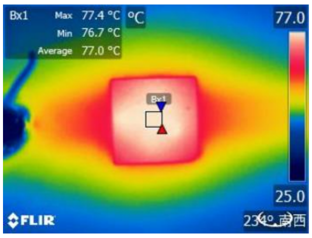

Figure 21. Example of a Temperature Measurement with an Infrared Thermal Imaging Camera

### 6.3 Evaluation Results

Nichia measured the $T_B$ and $T_T$ using the same conditions for the evaluations detailed in section 5; the $T_B$ was measured with a thermocouple and the $T_T$ was measured with an infrared thermal imaging camera. The difference between the $T_T$ and $T_J$ was also evaluated.

### 6.3.1 Evaluation Results for the $T_T$ Measured with an Infrared Thermal Imaging Camera

Figures 22-25 show the values of the $T_T$ measured with an infrared thermal imaging camera.

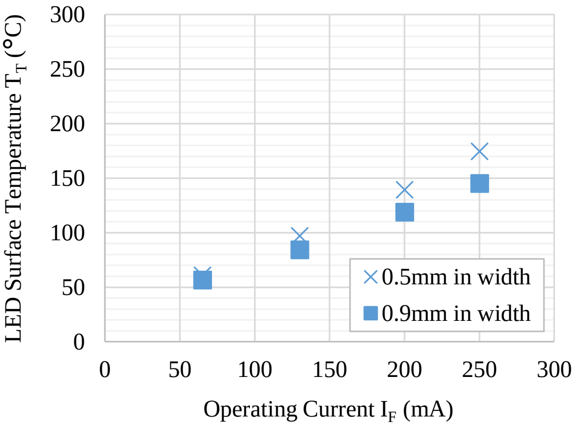

Figure 22. LED 1 (sm50 and R8000) on PCB 1 (CEM-3)

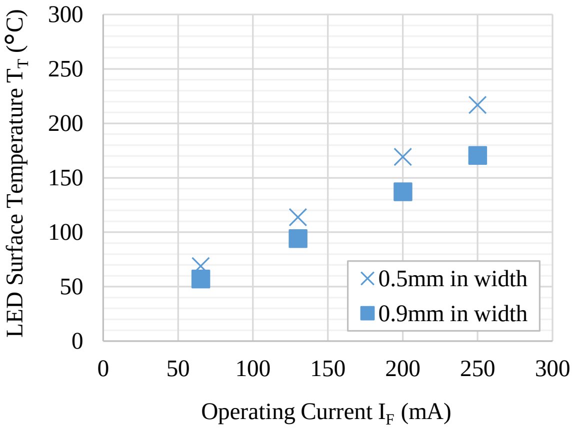

Figure 23. LED 1 (sm50 and R8000) on PCB 2 (FPC)

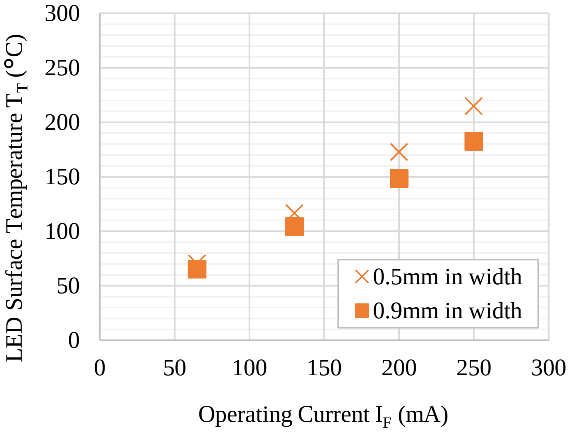

Figure 24. LED 2 (sm27 and R9050) on PCB 1 (CEM-3)

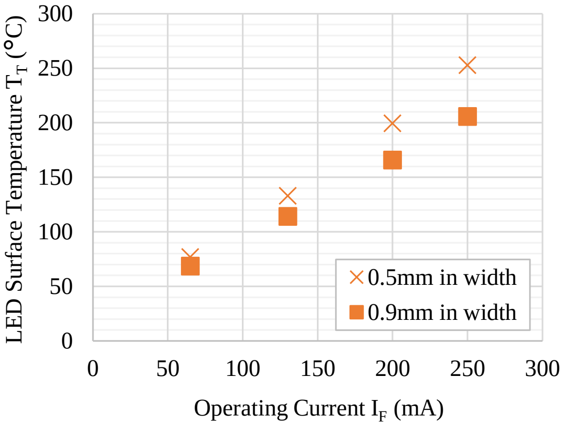

Figure 25. LED 2 (sm27 and R9050) on PCB 2 (FPC)

The $T_T$ increased in proportion to the increase of the operating current. The increase in the $T_T$ was larger for LED 2 (sm27 and R9050) since more heat was generated from the phosphor for LED 2 than for LED 1 (sm50 and R8000).

### 6.3.2 Relationship between the $T_T$ and $T_J$

Nichia calculated the $T_J$ using the measured $T_T$ and $T_B$ to evaluate the difference between the $T_T$ and $T_J$. Figures 26-29 show the results.

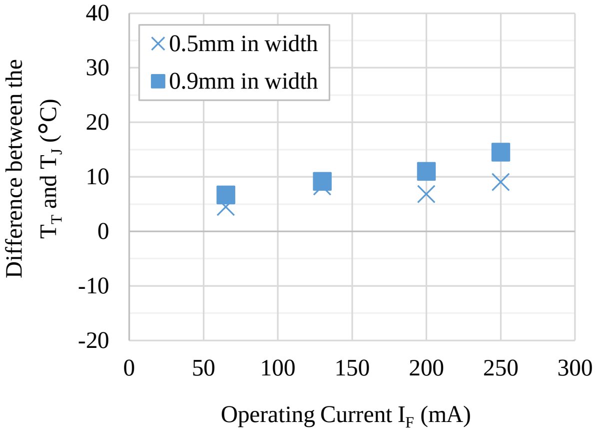

Figure 26. LED 1 (sm50 and R8000) on PCB 1 (CEM-3)

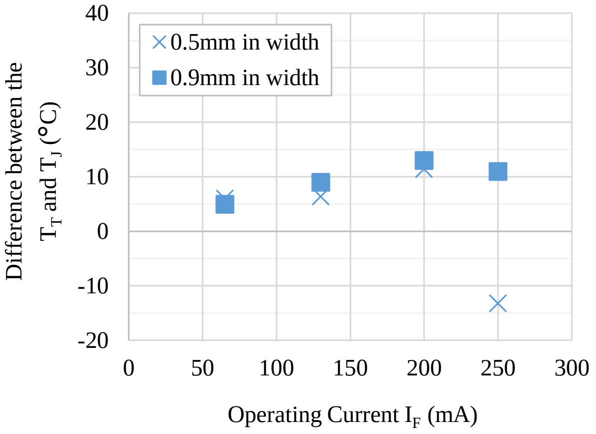

Figure 27. LED 1 (sm50 and R8000) on PCB 2 (FPC)

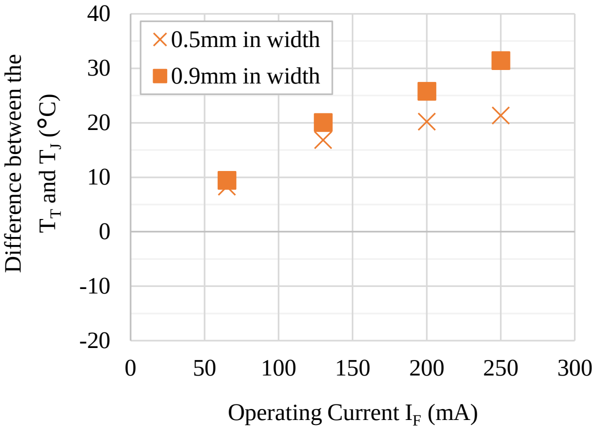

Figure 28. LED 2 (sm27 and R9050) on PCB 1 (CEM-3)

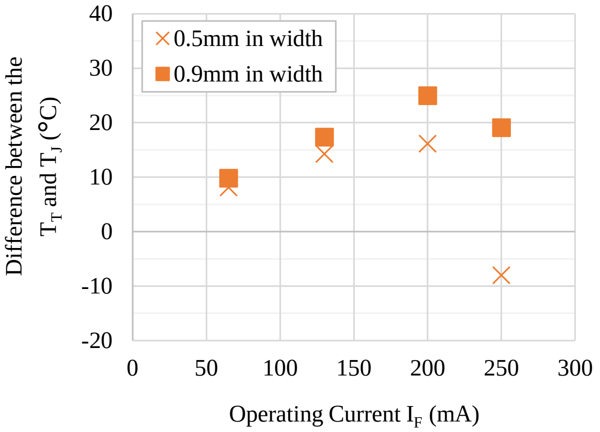

Figure 29. LED 2 (sm27 and R9050) on PCB 2 (FPC)

The evaluation results show that for this LED, the $T_T$ became higher than the $T_J$. The results also show that the higher the operating current was, the difference between the $T_T$ and $T_J$ became larger since the amount of the heat generated from the phosphor increased. However, as in the case of the evaluation results detailed in section 5, the $T_J$ became higher than the $T_T$ for the LED that was mounted on PCB 2 (FPC) with PCB Trace 1 (0.5mm in width) since the $T_J$ became too high for the heat dissipation performance of the PCB.

Using these evaluation results, the $T_J$ can be estimated from the $T_T$ measured with an infrared thermal imaging camera. The results indicate that the difference between the $T_T$ and $T_J$ was very small for LED 1 (sm50 and R8000). Especially when it was operated at 65mA (i.e. sorting current), the difference was only ≤10°C; it is considered that the $T_T$ and $T_J$ will be almost the same under these conditions.

## 7. Summary

For the NFSWE11A LED, the thermal design and temperature measurement are challenging since the LED itself is very small and the applications into which the LED will be assembled may also be compact. However, if the increase of the junction temperature and surface temperature of the LED is controlled by ensuring proper thermal design, the LED can expand the design flexibility of the luminaires.

Ensure that the content herein is taken into consideration for the thermal design and the temperature measurement for the chosen application. Note that the thermal resistance values provided herein are the values obtained under Nichia's evaluation conditions/measurements environments and for reference purposes only; they may vary depending on the chosen operation conditions/environments. In addition, Nichia recommends the chosen thermal design has sufficient margins/tolerances.

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