Light Emitting Diode

Thermal Design Considerations for the Nichia NFMW48xAR Series LEDs

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The Nichia part numbers NFMW481AR, NFMW484AR, NFMW486AR, NFMW488AR, and NFMW48xAR 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

Thermal design is very important for LEDs since it determines the optical and electrical characteristics (e.g. luminous flux, forward voltage, etc.) of the LEDs and it even affects the lifetime of the LEDs. When performing a thermal evaluation, customers must check how high the junction temperature of the LED will be when the LED is operated in the conditions/environments in which the LED will actually be used.

Nichia's NFMW48xAR series LEDs have a high luminous flux density with a smaller light emitting surface (LES) and a low thermal resistance. This series is also available in four different light output options while keeping the same package size, this allows the series to be used for various applications. The NFMW48xAR series can produce a higher luminous flux than typical LEDs that are operated at 1-3W; the thermal design needs to be appropriate for the chosen application.

This application note provides cautions/suggestions for the thermal design of the chosen application using the NFMW48xAR series LEDs showing the evaluation results to ensure that the required luminous flux for the chosen application is obtained.

2. Structure and key features of the NFMW48xAR Series LEDs

The NFMW48xAR Series LEDs have an outline dimension of 6.5mm×5.8mm×0.8mm with multiple chips mounted on the lead frame. Table 1 shows the detailed information of each LED.

Table 1. The NFMW48xAR Series LED

Characteristics	Unit	NFMW481AR	NFMW484AR	NFMW486AR	NFMW488AR
Number of Chips	-	7	10	12	14
Forward Current[1]	mA	200	200	200	200
Forward Voltage	V	22.9	32.8	39.3	45.9
Power Consumption	W	4.58	6.56	7.86	9.18
Luminous Flux[2]	lm	(640)	(900)	(1060)	(1240)
Maximum Junction Temperature	°C	135	135	135	135
Thermal Resistance (max)	°C/W	3.8	3.4	3.1	2.8

[1] The absolute maximum rating forward current of the LEDs is 250mA.

[2] The luminous flux values are typical values of the LEDs at a color temperature of 5000K and color rendering index of R8000. For further information, refer to the specifications.

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The NFMW48xAR Series LEDs are designed to have a large cathode electrode in order to dissipate the heat efficiently and have a low thermal resistance. Figure 1 shows the outline dimensions of the LEDs.

(Unit: mm)

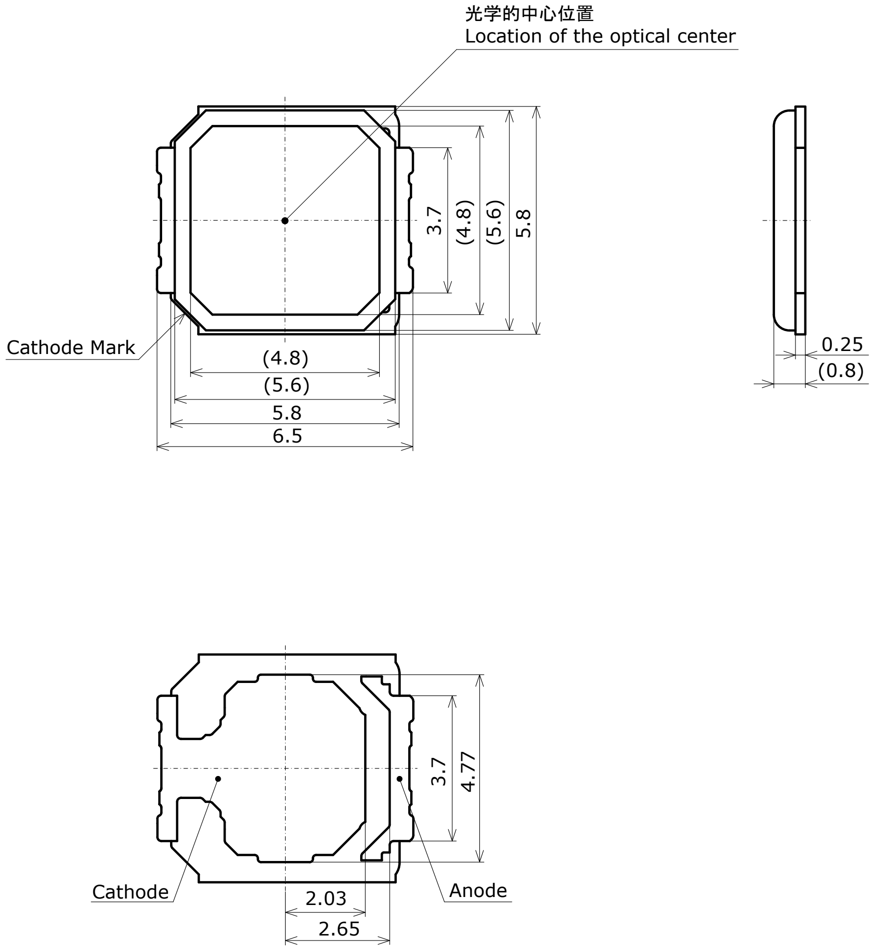


Figure 1. Outline dimensions of the NFMW48xAR Series LEDs (excerpted from the specification)

3. Recommended soldering pad pattern and metal solder stencil aperture

Figure 2 shows a recommended soldering pad pattern and metal solder stencil aperture for the NFMW48xAR Series LEDs.

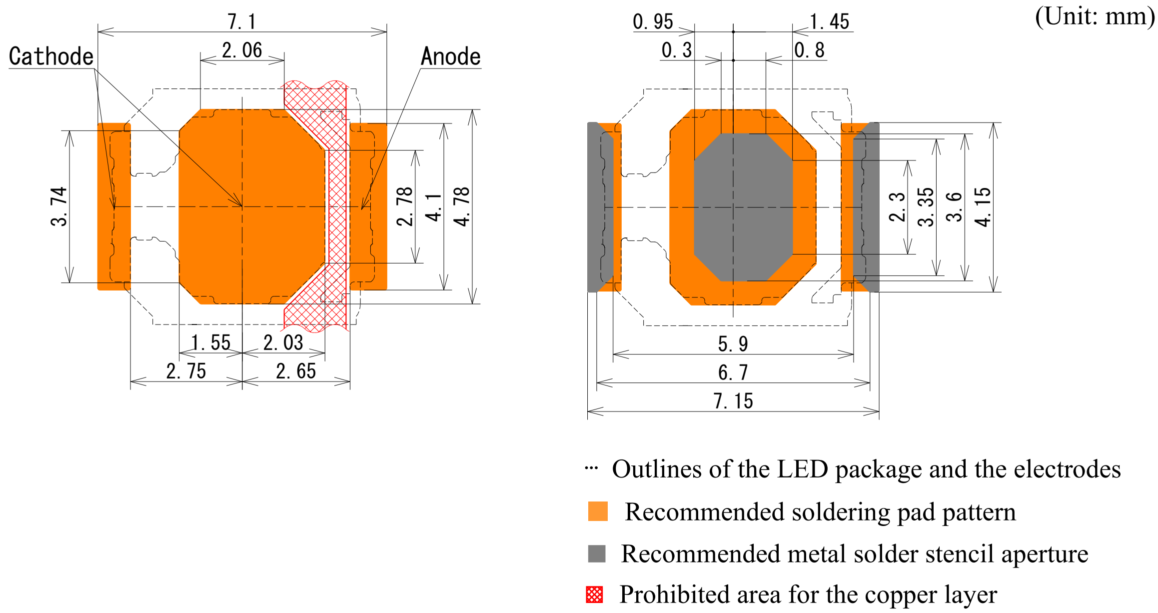


Figure 2. Recommended soldering pad pattern and metal solder stencil aperture for the NFMW48xAR Series LEDs

Precautions:

The electrodes of the NFMW48xAR series LEDs have a complicated shape; depending on the wiring pattern, the anode and cathode may contact each other resulting in a short circuit. There must not be any copper layer in the prohibited area shown in Figure 2.
To improve the heat dissipation performance and transfer the heat more efficiently to the PCB, Solder Mask Defined (SMD) is recommended for the soldering pad pattern. If SMD is used, it must be verified that the solder resist can be applied on the PCB precisely as designed.
Figure 3 shows an example of the wiring patten.

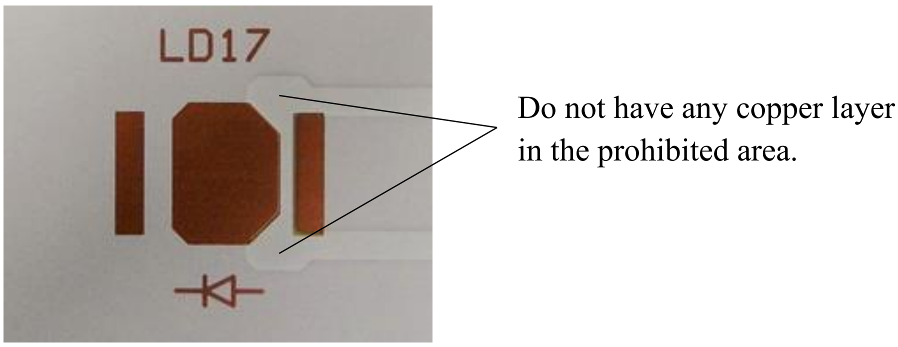


Figure 3. An example of the wiring pattern

4. Materials for PCBs

4.1 Materials for PCBs

In general, glass epoxy substrates (hereinafter referred to as "FR4 substrate"), glass composite substrates with high heat dissipation (hereinafter referred to as "CEM3 substrate"), and aluminum substrates are widely used as PCBs to attach the LEDs. The material of the PCB (i.e. glass epoxy, glass composite, aluminum, etc.) should be selected based on the specifications of the LED being used, the forward current that will be applied to the LED, and the required heat dissipation performance for the chosen luminaire.

If Nichia's NFMW48xAR Series LEDs are intended to be used to emit a high luminous flux, an aluminum substrate may often be selected for better heat dissipation. However, if they are used to emit a low luminous flux, an FR4 substrate or a CEM3 substrate with a high thermal conductivity can be used.

To determine how the heat dissipation performance varies depending on the material of the PCB, Nichia performed evaluations using the NFMW488AR LEDs; the NFMW488AR LEDs emit the highest luminous flux among the other LEDs in the series. Refer to Section 4.2 for the evaluation results.

4.2 Heat dissipation performance of each PCB material

4.2.1 The test PCBs

Nichia performed a thermal evaluation with different PCBs (i.e. different materials and different outline dimensions) to determine how the heat dissipation of the NFMW488AR LEDs varies. Table 2 shows the outline dimensions of the test PCBs and Table 3 shows the materials of the test PCBs.

Table 2. Outline dimensions of the test PCBs

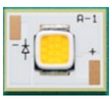
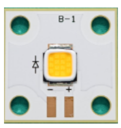
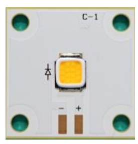
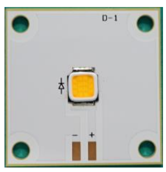
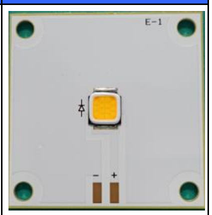
Item	A	B	C	D	E
Picture of the Appearance					
Outline Dimensions of the PCB	12mm×15mm	20mm×20mm	25mm×25mm	30mm×30mm	35mm×35mm
Area of the PCB	180mm^2	400mm^2	625mm^2	900mm^2	1225mm^2

Table 3. Materials of the test PCBs

Item	Unit	FR4 Substrate[3]	CEM3 Substrate[3]	Aluminum Substrate
Thermal Conductivity	W/m·K	0.4	1.5	2.1[4]
Thickness of the Copper Layer	μm	35	35	35
Thickness of the PCB	mm	1.0	1.0	1.1

[3] For the FR4 and CEM3 substrates, non-plated through hole, double-sided PCBs were used.

[4] The thermal conductivity for the aluminum substrates was the thermal conductivity of the insulating layer. The thickness of the insulating layer was 120μm.

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4.2.2 Evaluation conditions

In this thermal evaluation, Nichia attached each test PCB to a heatsink and measured the temperature of the solder joint after the saturation temperature had been reached. The LED and other test materials used are shown below. See Figure 4 for a picture of a test PCB attached to a heatsink.

- LED:
  the NFMW488A LED with the color temperature of 2700K and the color rendering index of R8000. Forward current: I_F=200mA
- Thermal grease:
  SCH-30 manufactured by Sunhayato Corp.
  Thermal conductivity: 0.84W/m·K
- Heatsink:
  100mm (L)×100mm (W)×10mm (H).
  Thermal resistance: 3.0°C/W. Weight: 0.2kg

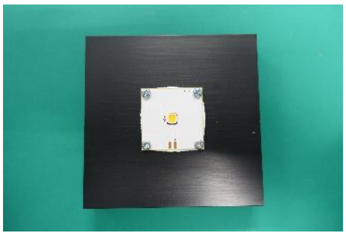

Figure 4. Test PCB attached to a heatsink

4.2.3 Results of the thermal evaluation

The evaluation results show that the junction temperature (T_J) of the LED significantly varied depending on the PCB material. When the forward current (I_F) was 200mA, the T_J of the LED attached to the aluminum substrate was the lowest. For the CEM3 and FR4 substrates, the T_J exceeded the absolute maximum rating T_J.
Regarding the relationship between the T_J and the size of the PCBs, it was confirmed that the size of the PCBs did not affect the heat dissipation much for the aluminum substrate. For the FR4 substrate, the heat dissipation performance was greatly reduced when the size of the PCBs was < 400mm^2. See Figure 5 for the detailed results.

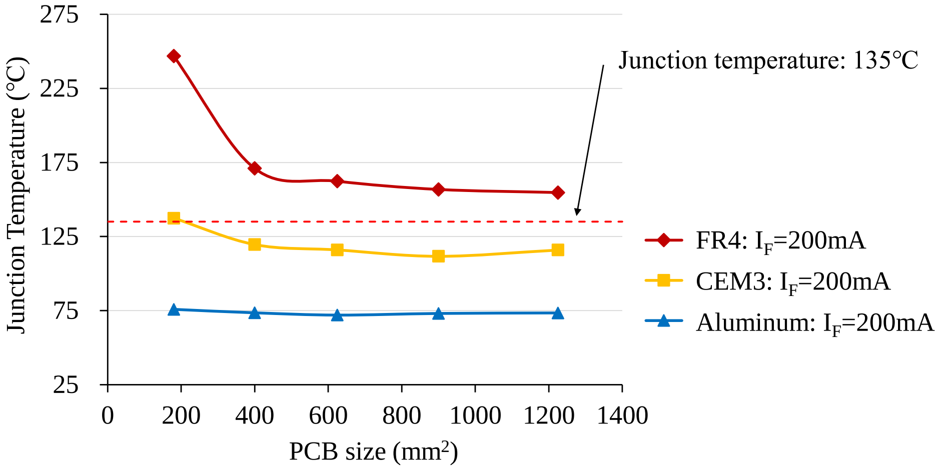

Figure 5. Evaluation results per PCB material

To calculate the T_J, the following equation was used:

$$T_J = T_S + R_{\theta JS} \cdot W$$

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

4.3 Heat dissipation of the FR4 and CEM3 substrates

This thermal evaluation was performed using the FR4 and CEM3 substrates with different forward currents (I_F) applied to the LED since the absolute maximum rating T_J was exceeded with the FR4 and CEM3 substrates in the evaluation described in section 4.2. Except for the I_F, all the conditions of this evaluation were the same as in the evaluation in section 4.2. See Figures 6 and 7 for the results.

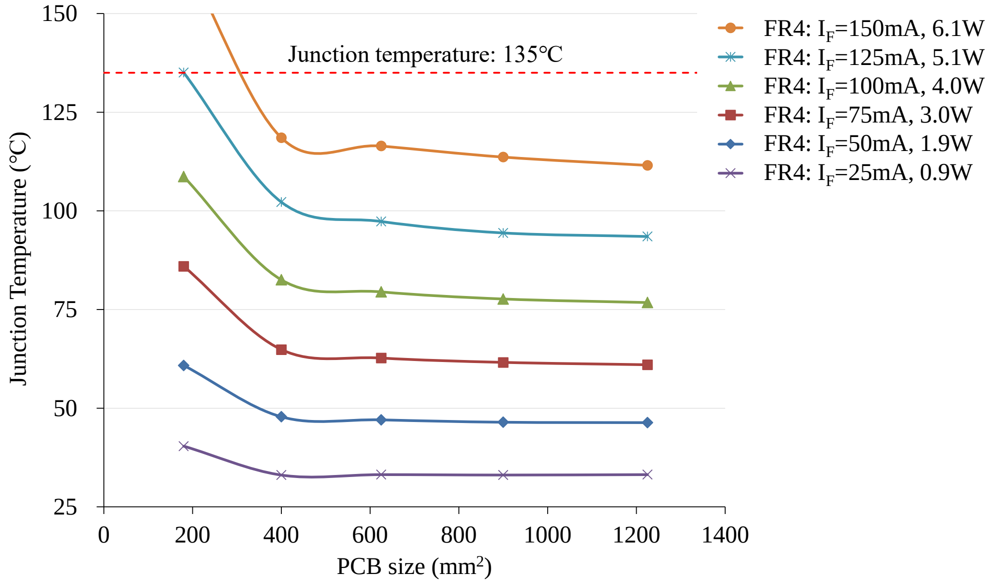

Figure 6. Results of the evaluation using the FR4 substrate

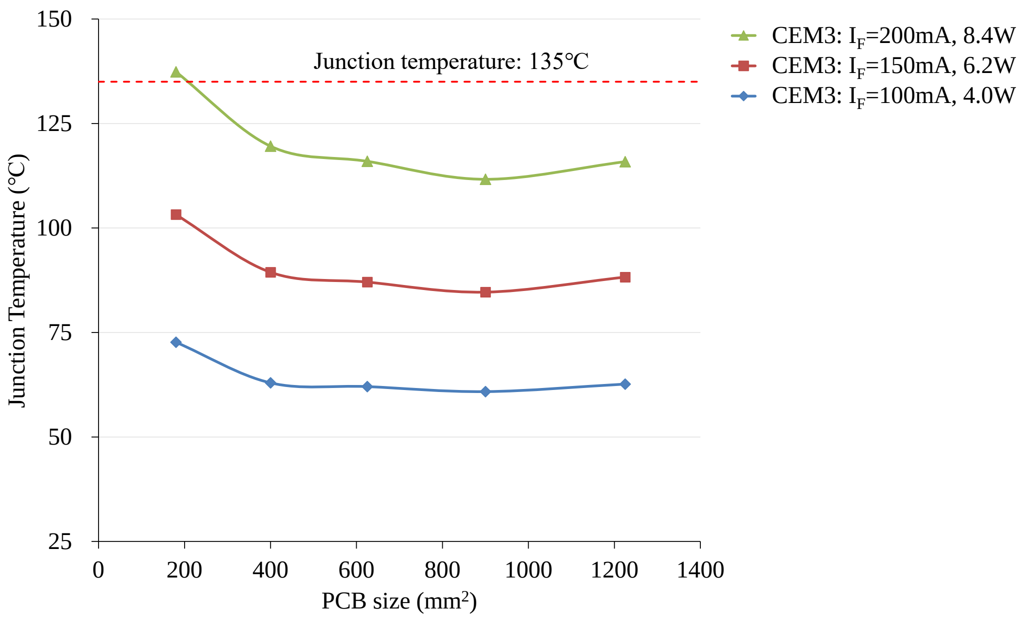

Figure 7. Results of the evaluation using the CEM3 substrate

The evaluation results show that the T_J was below the absolute maximum rating (i.e. 135°C) when the I_F was ≤100mA for the FR4 substrate and when the I_F was ≤150mA for the CEM3 substrate. Although the T_J will vary depending on the heat dissipation performance of the chosen luminaire, the evaluation results indicate that the FR4 and CEM3 substrate can be used when the LED is operated at a low enough I_F.

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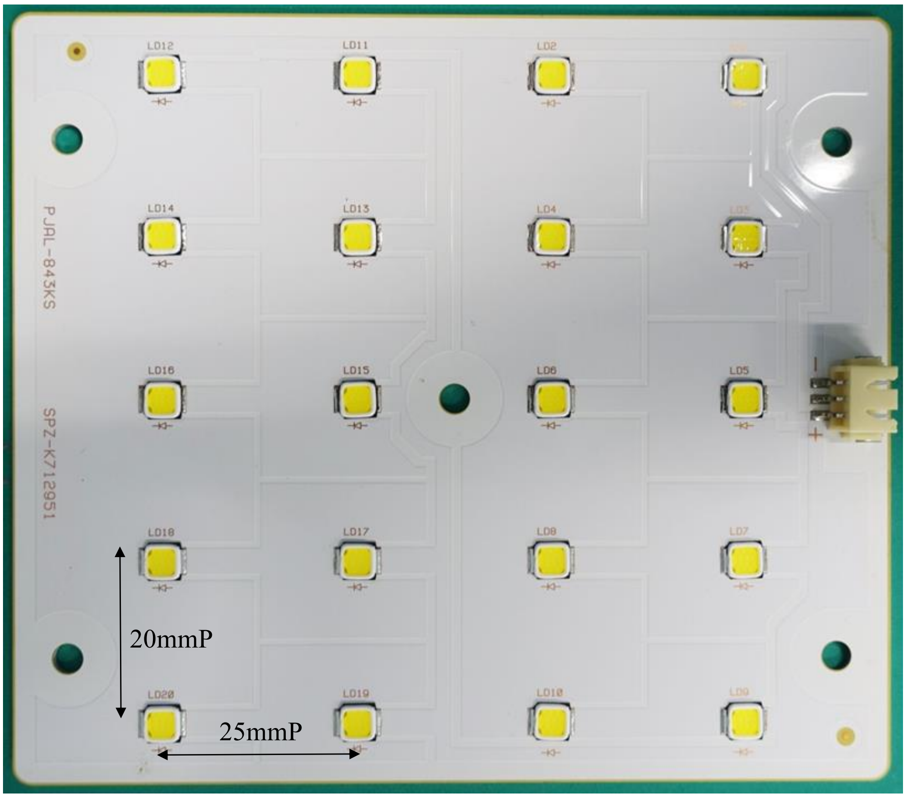
5. Thermal evaluation of the light source modules

5.1 Test light source modules and evaluation conditions

In section 4, Nichia describes the thermal evaluations performed with the PCBs that have one LED attached on each of them; in this section, Nichia describes the thermal evaluations performed with PCBs that have multiple LEDs attached on each of them (i.e. the light source module). Table 4 provides the detailed information of the light source modules used for the evaluation.

Table 4. Test light source modules

Item	Details
Test Light Source Module	
Outline Dimensions of the Substrate	119mm (L)×136mm (W)
LEDs Used and the Number of Attached LEDs	The NFMW488AR LEDs with the color temperature of 5000K and the color rendering index of R70, 20 LEDs
LED Pitch[5]	20mm (H), 25mm (W)
Circuit Configuration	10 arrays connected in parallel, each with 2 LEDs connected in series
Thermal Grease	SCH-301 manufactured by Sunhayato Corp. Thermal conductivity: 0.84W/m·K
Heatsink	250mm (L)×200mm (W)×40mm (H). Thermal resistance: 0.45°C/W. Weight: 2.4kg. Material: Aluminum

[5] The LEDs were aligned in a manner where each LED had an area larger than 400mm^2 to dissipate the heat, taking the evaluation result described in section 4 (i.e. the relationship between the size of the substrate and heat dissipation performance) into consideration.

Table 5 provides the detailed information of the substrates used for the evaluation.

Table 5. Test substrates

Item	Unit	CEM3 Substrate	Aluminum Substrate
Thermal Conductivity	W/m·K	1.5	2.1 (Thickness of the insulating layer: 120μm)
Thickness of the Copper Layer	μm	35 (Non-through hole double-sided substrate)	35
Thickness of the Substrate	mm	1.0	1.1
P/N and Manufacturer	-	R-1586(H) manufactured by Panasonic Corporation	NRA-8 manufactured by NIPPON RIKA KOGYOSHO CO., LTD.

5.2 Results of the thermal evaluation

In this thermal evaluation, the forward current (I_F) of 50-100mA was applied to each LED attached on a CEM3 substrate and the forward current (I_F) of 100-200mA was applied to each LED attached on an aluminum substrate. See Figure 8 and Table 6 for the results.

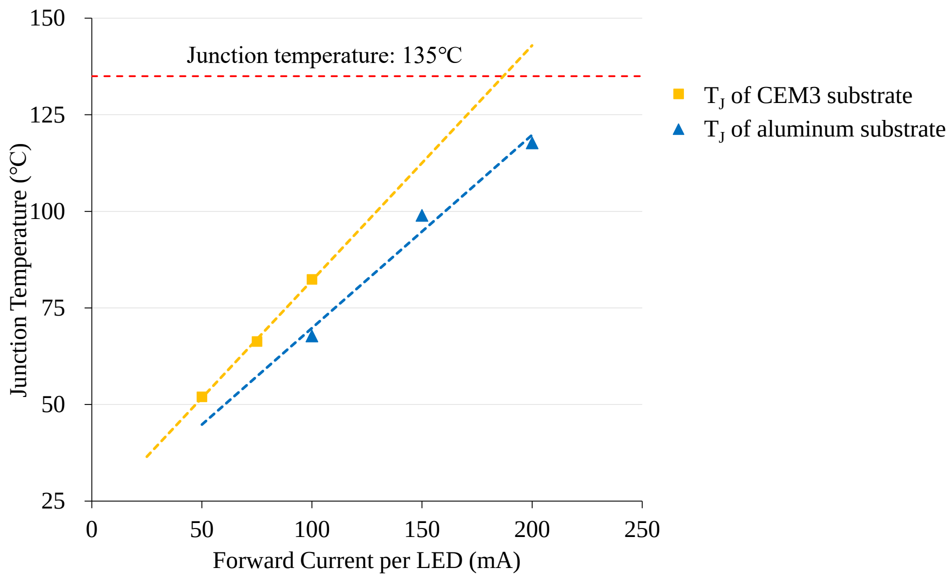


Figure 8. Results of the evaluation using the test light source

Table 6. Optical characteristics of the test light source modules and the evaluation results

	CEM3 Substrate			Aluminum Substrate		
Forward Current (I_F) (mA/LED)	50	75	100	100	150	200
Operating Current of the Module (mA)	500	750	1000	1000	1500	2000
Operating Voltage of the Module (V)	77.4	78.7	79.9	80.6	82.9	84.8
Power Dissipation (W)	38.7	59.0	79.7	80.6	124.4	169.6
Luminous Flux (lm)	6746	9555	11887	12608	17148	20365
Luminous Efficacy (lm/W)	174.3	161.9	149.1	156.4	137.9	120.1
Temperature of the Solder Joint (°C)[6]	46.6	58.1	71.2	56.4	81.5	94.0
Junction Temperature (°C)[7]	52.0	66.3	82.4	67.7	98.9	117.7
Ambient Temperature (°C)	24.6	24.8	24.9	25.0	25.3	25.4

[6] The temperatures of the solder joint were measured using a thermocouple after the saturation temperature had been reached.

[7] The junction temperatures (T_J) were calculated using the thermal resistance of the LED: $R_{\theta JS}$=2.8°C/W

Figure 8 shows that the junction temperatures (T_J) were lower with the aluminum substrate than with the CEM3 substrate, the same result as obtained in the evaluations described in section 4.

Table 6 shows that the luminous efficacy of the LED at the same forward current (I_F) was higher with the aluminum substrate than with the CEM3 substrate.

In section 5.3, Nichia provides the evaluation results using a thermal imaging camera and the detailed information of the CEM3 and the aluminum substrates.

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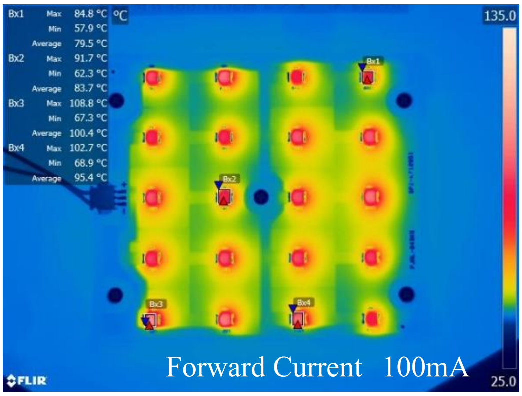
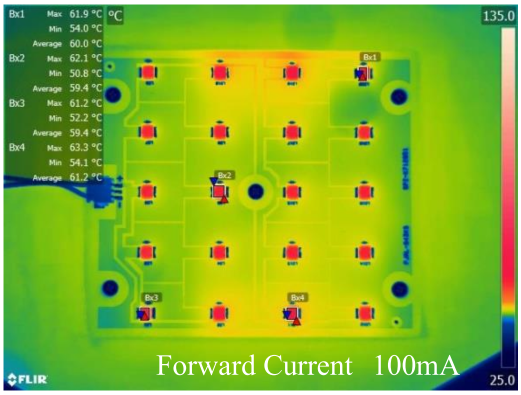
5.3 Comparing light source module characteristics between a CEM3 substrate and an aluminum substrate.

Table 7. Comparison of the light source modules between a CEM3 and an aluminum substrate

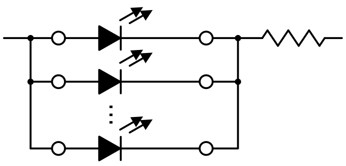
	CEM3 Substrate	Aluminum Substrate
Image of the Temperature Distribution Taken with a Thermal Imaging Camera		
Heat Dissipation	・Suitable for low luminous flux applications ・The heat generated from the LEDs is dissipated radially. However, the temperature distribution on the surface of the substrate is uneven. ・Poor heat transference to the heatsink (i.e. large difference in temperature between the heatsink and substrate). ・Thermal grease is necessary when attaching the substrate to a heatsink for a better heat dissipation performance. ・The temperatures of some of the LEDs are higher because the substrate is not attached to the heatsink appropriately under those LEDs (i.e. the adhesion strength between the heatsink and substrate is lower).	・Suitable for high luminous flux applications ・The heat generated from the LEDs is dissipated evenly across the substrate. ・Good heat transference to the heatsink (i.e. small difference in temperature between the heatsink and substrate). ・The temperatures of some of the LEDs are higher because the substrate is not attached to the heatsink appropriately under those LEDs; however, this is still a better result than with the CEM3 substrate.
Solder Crack	・Since the NFMW48xAR LEDs are a resin package, the difference in the coefficient of thermal expansion between the LED and the substrate is small and the occurrence of solder cracks is low. ・The coefficient of thermal expansion of the substrate: 19-23×10^{-6}	・Since the NFMW48xAR LEDs are a resin package, the difference in the coefficient of thermal expansion between the LED and the substrate is small and the occurrence of solder cracks is low. ・The coefficient of thermal expansion of the substrate: 24×10^{-6}
Dielectric Strength	・The withstand voltage performance can be increased by having an enough creepage distance.	・The dielectric strength depends on the dielectric strength of the insulating layer. The withstand voltage performance is not high. ・ The maximum allowable operating voltage that can be applied is limited; if the circuit voltage will be ≥100V, ensure that the dielectric strength of the insulating layer has no issues.

5.4 Circuit design considerations for the light source modules

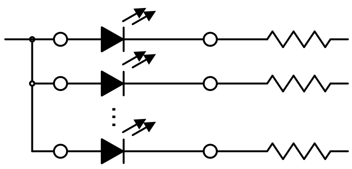
In this evaluation, the junction temperatures (T_J) of some of the LEDs attached to the light source modules became higher. It was because the LEDs were connected in parallel with each other and the forward current flow to each one varied. In this circuit configuration, a current over the absolute maximum rating may be applied to some LEDs affecting the reliability performance of the product. When designing the circuit configuration of the LEDs for the chosen application, ensure that the requirements/recommendations below are taken into consideration:

- Nichia recommends that each LED is operated at a constant current.
- The circuit must be designed to ensure that the Absolute Maximum Ratings are not exceeded for each LED.
- In the case of operating at a constant voltage, Circuit B is recommended. If Circuit A is used, it may cause the currents flowing through the LEDs to vary due to the variation in the forward voltage characteristics of the LEDs on the circuit.

(A)



(B)



For any questions regarding the design of the light source modules using the LEDs (e.g. forward voltage distribution of the LED, LED ranks, etc.), contact a local Nichia sales representative.

6. Summary

The NFMW48xAR series LEDs have high heat dissipation to enable them to be used for various applications. When designing the light source module with the LEDs, select the substrate that is suitable for the required heat dissipation performance for the chosen application by considering the results of the thermal evaluations described herein. In addition to the temperature measurements with a thermocouple, evaluating the temperature distribution using a thermal imaging camera is also useful.

This application note has provided cautions/suggestions for the thermal design of the chosen application using the NFMW48xAR series LEDs showing the evaluation results. However, the results are examples for reference purposes only and may be different depending on the LED part number and/or the chosen operating conditions/environment. Sufficient verification must be done prior to use to ensure there are no issues for the chosen application.

Light Emitting Diode

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