Light Emitting Diode

Thermal Design Guide for the Nichia NWSU333B (U365, U385) or NWSU333B-D4 (U365) LEDs

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The Nichia part number NWSU333B and NWSU333B-D4 within this document is merely Nichia's part number for these Nichia products and are not related nor bear any resemblance to any other company's product that might bear a trademark.

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1. Overview

The light output of LEDs decreases due to the effect of heat generation. When LEDs are operated above the maximum LED junction temperature (T_{JMAX}), the reliability will drop significantly. In order to use the NWSU333B and NWSU333B-D4 LED with high performance and high reliability, it is important to design the heat dissipation so that the junction temperature (T_J) does not exceed the T_{JMAX} of 100°C.
This application note covers the effect on the T_J when two types of mounted boards are driven with different heat dissipation configurations.

- T_J when one LED is mounted on the board and driven by two different heat dissipation configurations
- T_J when nine LEDs are mounted on the board and driven by three different heat dissipation configurations

2. T_J Measurement Method

The following equation can be used to calculate the T_J.

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

T_J : LED Junction Temperature (°C)
T_S : Soldering Temperature (°C)
$R_{\theta JS}$: Thermal Resistance from Junction to T_S Measurement Point (°C/W)
W : Input Power (W) = I_F(A)×V_F(V)

The specifications of the NWSU333B and NWSU333B-D4 are as follows:

Symbol	Condition	NWSU333B・NWSU333B-D4		NWSU333B	
		U365		U385	
		Typ	Max	Typ	Max
$R_{\theta JS}$ (°C/W)	-	1.68	2.08	1.68	2.08
V_F (V)	I_F=3500mA	3.85	-	3.70	-

Absolute Maximum Ratings (T_S=25°C):

I_{FMAX} (mA)	4500
I_{FPMAX} (mA)	6000
T_{opr} (°C)	-10～85
T_{JMAX} (°C)	100

I_F : Forward Current (mA)
I_{FP} : Pulse Forward Current (mA)
I_{FP} conditions : pulse width ≤10ms and duty cycle ≤10%
T_{opr} : Operating Temperature (°C)

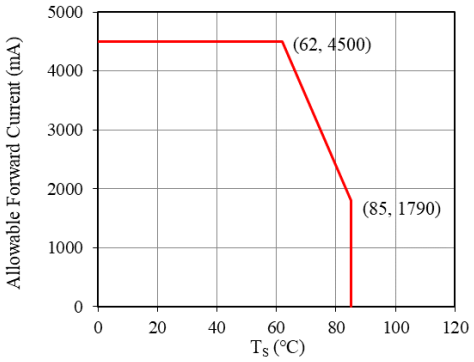


Figure 1. T_S vs Allowable Forward Current

3. T_S Measurement Point

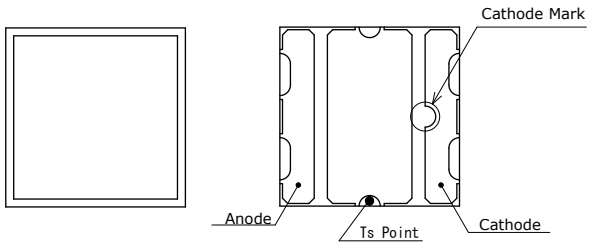


Figure 2. T_S Measurement point (NWSU333B)

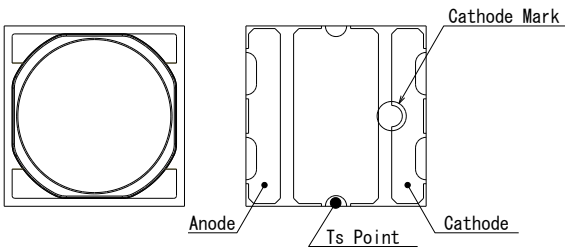


Figure 3. T_S Measurement point (NWSU333B-D4)

4. Heat Dissipation Configuration and T_J Measurement Results

The T_J was confirmed by changing the heat dissipation configuration when one LED was mounted on the board and when nine LEDs were mounted.

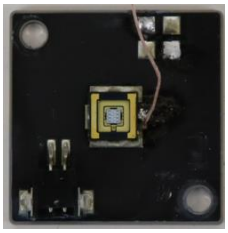
4-1. T_J when one LED is mounted on the board and driven by two different heat dissipation configurations

Heat dissipation configuration 4-1-1, One LED on the board + Heatsink A

The specification of the board is as follows:

Thickness(mm)			Outline dimensions (mm)
Copper foil	Insulation layer	Copper base	
0.105	0.120	1.5	30 × 30

The thermal conductivity of the copper foil and copper base is 390W/m·K and that of the insulation layer is 4.5W/m·K.



Picture 1. Board appearance (NWSU333B)

Picture 2. Board appearance (NWSU333B-D4)

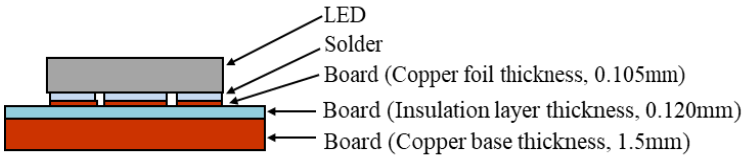


Figure 4. Structure of the board + LED

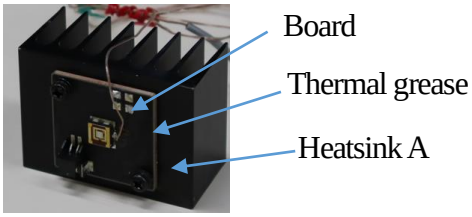
The specification of heatsink A is as follows:

Heatsink A			Fin			Thermal resistance (°C/W)
Material	Size (mm)	Thickness of the base Material (mm)	Number of fins	Size (mm)	Arrangement	
Al	50 × 38 × t25	5	8	1 × 38	8 × 1	5.70

Thermal conductivity of thermal grease is 5.3W/m·K.

The measurement results for the above combinations are shown in the table below:

T_A (°C)	Part number	Wavelength Rank	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B NWSU333B-D4	U365	3.5	3.6	12.6	83	109
			4.5	3.7	16.7	101	136
	NWSU333B	U385	3.5	3.5	12.3	75	100
			4.5	3.6	16.2	90	124



Picture 3. Evaluated light source 4-1-1 (NWSU333B)

With heat dissipation configuration 4-1-1 using the U385 rank, the T_J exceeded 100°C even when 3.5A was applied, exceeding the T_{JMAX}.
Since cooling is not possible with this heat dissipation configuration, Nichia performed another evaluation where the size of the heatsink was increased.

Heat dissipation configuration 4-1-2, One LED on the board + Heatsink B

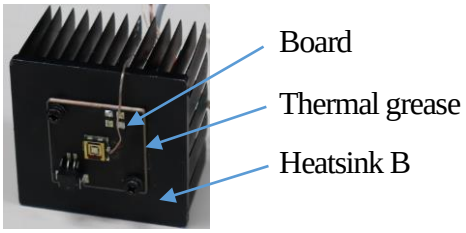
The specification of heatsink B is as follows:

Heatsink B			Fin			Thermal resistance (°C/W)
Material	Size (mm)	Thickness of the base Material (mm)	Number of fins	Size (mm)	Arrangement	
Al	53 × 53 × t35	4	64	0.8 × 9	13 × 5	4.25

Thermal conductivity of thermal grease is 5.3W/m·K.

The results of the evaluation with heatsink B are shown below:

T_A (°C)	Part number	Wavelength Rank	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B NWSU333B-D4	U365	3.5	3.7	13.0	73	100
			4.5	3.7	16.7	87	122
	NWSU333B	U385	3.5	3.6	12.6	65	91
			4.5	3.6	16.2	76	110



Picture 4. Evaluated light source 4-1-2 (NWSU333B)

In this heat dissipation configuration, when 3.5A was applied for the U385, the T_J was 91°C and did not exceed the T_{JMAX}. When 3.5A was applied for the U365, the T_J was 100°C and exceeded the T_{JMAX}. 100°C. However, by increasing the size of the heatsink from A to B, the heat dissipation performance was improved and the T_J was lowered.
If only one LED is used or if the LEDs are mounted with a wide enough pitch, it may be possible to design a product that does not exceed the T_{JMAX} by simply increasing the size of the heatsink.

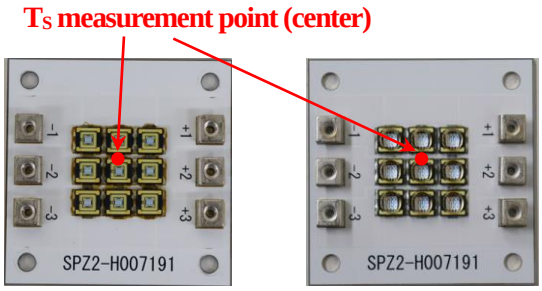
4-2. T_J when nine LEDs are mounted on the board and driven by three different heat dissipation configurations

Heat dissipation configuration 4-2-1, nine LEDs on the board + Heatsink C

The specification of the board is as follows:

Copper foil thickness (mm)	Insulation layer thickness (mm)	Copper base thickness (mm)	Outline dimensions (mm)	Internal circuit	LED mounting pitch (mm)
0.035	0.120	1.5	60 × 60	3 series, 3 parallel	8.2

The thermal conductivity of the copper foil and copper base is 390W/m·K and that of the insulation layer is 4.5W/m·K.



Picture 5. Board appearance (NWSU333B)

Picture 6. Board appearance (NWSU333B-D4)

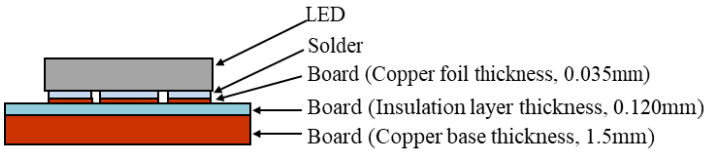


Figure 5. Structure of the board + LED

The specification of heatsink C is as follows:

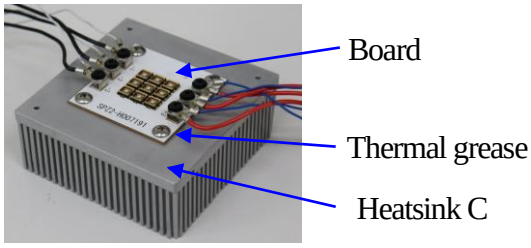
Heatsink C			Fin			Thermal resistance (°C/W)
Material	Size (mm)	Thickness of the base Material (mm)	Number of fins	Size (mm)	Arrangement	
Al	100 × 100 × t40	7	625	2 × 2	25 × 25	0.52

Thermal conductivity of thermal grease is 5.3W/m·K.

The measurement results for the above combinations are shown in the table below:

T_A (°C)	Part number	Wavelength Rank	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B	U385	3.5	3.4	11.9	146	171

In this heat dissipation configuration, the T_{JMAX} was significantly exceeded even when 3.5A was applied to the U385. The higher the current value and the shorter the wavelength, the more severe the heat dissipation.
When mounting LEDs with high density, the temperature rise is too large to be cooled by the heatsink alone, Nichia performed another evaluation using forced air cooling with a fan.

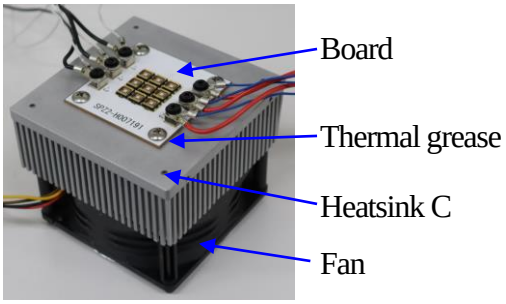


Picture 7. Evaluated light source 4-2-1 (NWSU333B)

Heat dissipation configuration 4-2-2, nine LEDs on the board + Heatsink with fan (heatsink C with fan attached)

The specification of the fan is as follows:

Fan		
Size (mm)	Volume flow (m^3/min)	Static pressure (Pa)
92 × 92 × t38	5.05	385



Picture 8. Evaluated light source 4-2-2 (NWSU333B)

The measurement results of the heat dissipation configuration 4-2-1 with a fan attached are shown below:

T_A (°C)	Part number	Wavelength Rank	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B NWSU333B-D4	U365	3.5	3.7	13.0	55	82
			4.5	3.7	16.7	66	101
	NWSU333B	U385	3.5	3.6	12.6	50	76
			4.5	3.6	16.2	56	90

In this heat dissipation configuration, the T_{JMAX} was exceeded only when 4.5A was applied for U365. By attaching a fan, the heat dissipation was improved significantly. For U365, the heatsink size should be increased or the pitch width should be widened a little more to provide adequate cooling.

Heat dissipation configuration 4-2-3, nine LEDs on the board + Water-cooled Heatsink

The specification of the water-cooled heatsink is as follows:

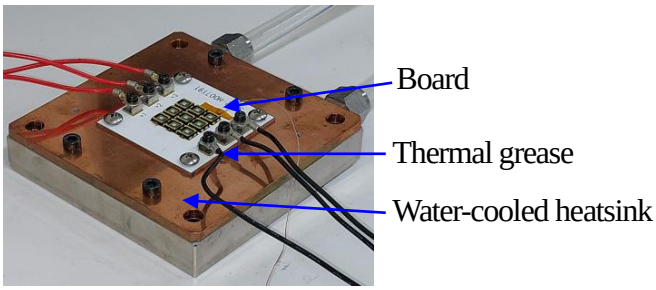
Heatsink		Water temperature (°C)	Water flow rate (L/min)	Thermal resistance (°C/W)
Material	Size (mm)			
Cu	120 × 120 × t25	25	5.6	0.01

Thermal conductivity of thermal grease is 5.3W/m·K.

The measurement results of the board + water-cooled heatsink shown in Picture 9 are shown below:

T_A (°C)	Part number	Wavelength Rank	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B NWSU333B-D4	U365	3.5	3.7	13.0	39	66
			4.5	3.8	17.1	44	80
	NWSU333B	U385	3.5	3.6	12.6	35	61
			4.5	3.7	16.7	39	74

In this heat dissipation configuration, using the U365 rank, there was enough margin to not exceed the T_{JMAX} even when 4.5A was applied. For the U365, water-cooling is recommended since even forced air cooling with a fan may not be sufficient.



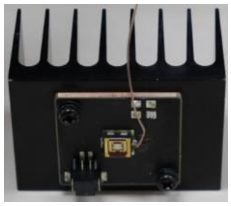
Picture 9. Evaluated light source 4-2-3 (NWSU333B)

5. Design Considerations

5-1. Heat Dissipation Performance Depends on the Heatsink Orientation

The performance of naturally air-cooled heatsinks varies depending on the orientation of the fins of the heatsink. Since the T_S will increase when warm air accumulates, it is important that the air movement is not obstructed. At Nichia, the fins are placed to face vertically to allow warm air to escape from the top (See Figure 6).

When designing the system, pay attention to the orientation of the fins when installing the heatsink.



Picture 10.
Fins facing vertical
(Nichia uses this orientation)

Picture 11.
Fins facing down
(This orientation obstructs the air flow)

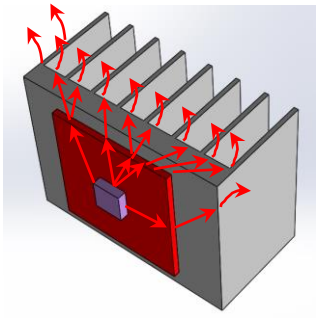
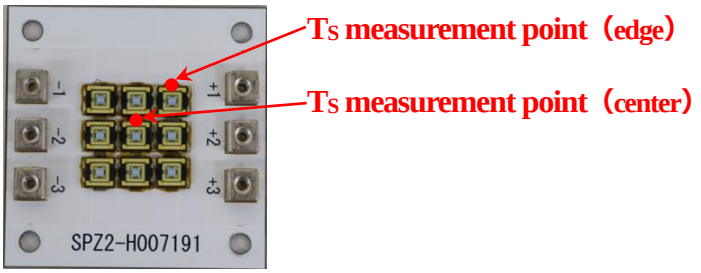


Figure 6.
Image of the heat path when fins are facing vertical

5-2. Heat Dissipation Performance Depends on the Mounted Position when Multiple LEDs are Used

When multiple LEDs are mounted, the T_S varies depending on the mounting pitch and position. As an example, Nichia compared the T_S and T_J between the center and the edge of the LEDs when nine LEDs were mounted in heat dissipation configuration 4-2-2. The results are shown below.



Picture 12. T_S measurement position of an LOB with nine LEDs

Heat dissipation configuration 4-2-2, nine LEDs on the board + Heatsink with fan (heatsink C with fan attached)

T_A (°C)	Part number	Wavelength Rank	I_F (A)	T_S measurement point	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NWSU333B NWSU333B-D4	U365	3.5	center	3.7	13.0	55	82
				edge	3.7	13.0	47	74
			4.5	center	3.7	16.7	66	101
				edge	3.7	16.7	55	90

According to these results, the T_J is about 10°C lower for the LEDs at the edges than for the LEDs in the center. Therefore, the LED in the center position should be used to measure the T_S for the thermal design since that is where the T_J is the highest.

6. Summary

When mounting multiple LEDs with high density, it is difficult to keep the LEDs within the T_{JMAX} limit with only a heatsink; however, if a sufficient pitch width is used, a fan is attached to the heatsink, or if water cooling is used, it is possible to keep the LEDs within the T_{JMAX} limit. For high density configurations, heat interference occurs between adjacent LEDs, resulting in poor heat dissipation, making it necessary to use a sufficient pitch width or use forced air or water cooling. An appropriate method should be selected after sufficient verification.

The absolute maximum ratings for the NWSU333B and NWSU333B-D4 LED per the Nichia specification:

I_F=4.5A, T_{JMAX}=100°C

Nichia will not guarantee the LEDs if used above these ratings.

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