Light Emitting Diode

Thermal Design Guide for the Nichia NC4U334BR (U280) LEDs

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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 NC4U334BR 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 110°C. Since the NC4U334BR requires a high input power it generates a larger amount of heat.

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 NC4U334BR are as follows:

Symbol	Condition	NC4U334BR	
		U280	
		Typ	Max
$R_{\theta JS}$ (°C/W)	-	2.8	3.1
V_F (V)	I_F=350mA	22.5	-

Absolute Maximum Ratings (T_S=25°C):

I_{FMAX} (mA)	500
I_{FPMAX} (mA)	600
T_{opr} (°C)	-10～85
T_{JMAX} (°C)	110

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)

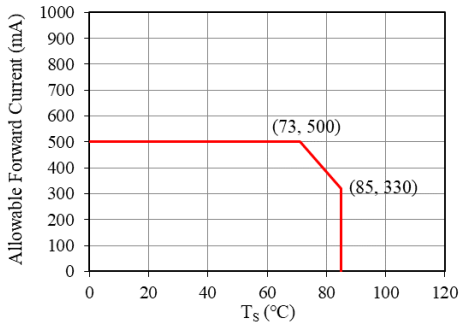


Figure 1. T_S vs Allowable Forward Current

3. T_S Measurement Point

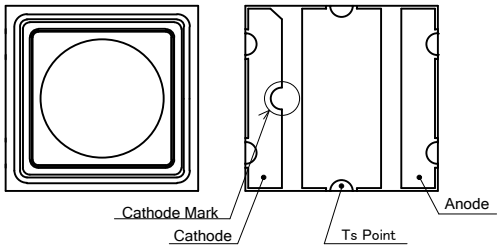


Figure 2. T_S Measurement point

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.

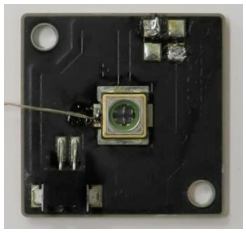
4-1. T_J when one LED is mounted on the board and driven by two different heat dissipation configurations

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

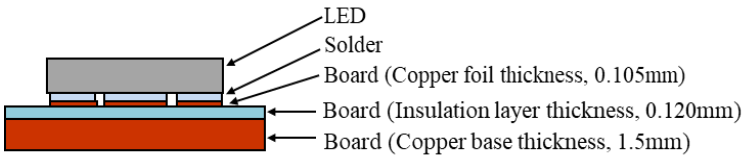


Figure 3. Structure of the board + LED

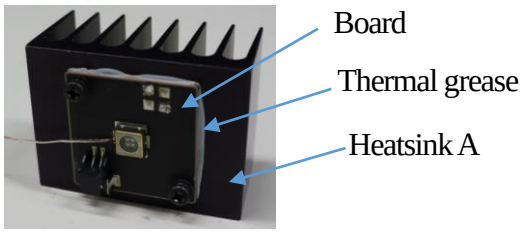
The specification of heatsink A is as follows:

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	NC4U334BR	U280	0.35	20.6	7.2	70	92
			0.50	21.0	10.5	87	120



Picture 2. Evaluated light source 4-1-1

When heatsink A was used, the T_J reached 120°C when 0.50A 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

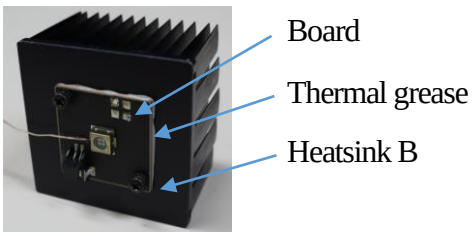
The specification of heatsink B is as follows:

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	NC4U334BR	U280	0.35	20.6	7.2	61	83
			0.50	21.1	10.6	73	106



Picture 3. Evaluated light source 4-1-2

When heatsink B was used, the T_J reached 106°C when 0.50A was applied and did not exceed the T_{JMAX}. This confirms that by increasing the size of the heatsink, it is possible to cool the system even in an air-cooled environment.

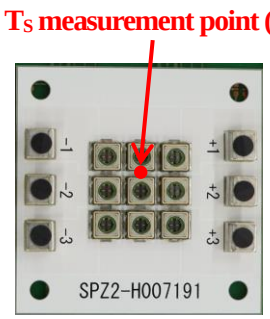
4-2. T_J when nine LEDs are mounted on the board and driven by three different heat dissipation configurations

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

The specification of the board is as follows:

Thickness(mm)			Outline dimensions (mm)	Internal circuit	LED mounting pitch (mm)
Copper foil	Insulation layer	Copper base			
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 4. Board appearance and measurements points

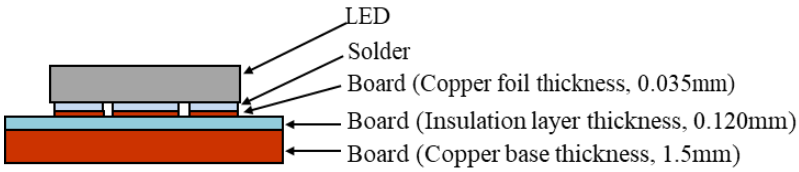


Figure 4. Structure of the board + LED

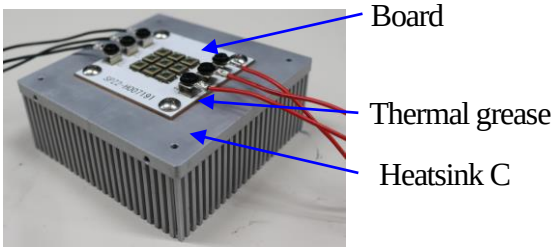
The specification of heatsink C is as follows:

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	NC4U334BR	U280	0.35	19.6	6.9	137	158



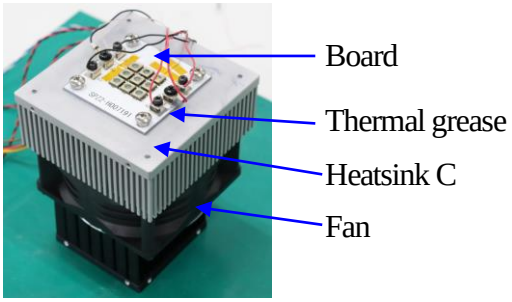
Picture 5. Evaluated light source 4-2-1

In this heat dissipation configuration, the T_J reached 158°C when 0.35A was applied, exceeding the T_{JMAX}.
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.

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 6. Evaluated light source configuration, 4-2-2

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	NC4U334BR	U280	0.35	20.5	7.2	49	71
			0.50	21.0	10.5	58	91

With this heat dissipation configuration, the T_{JMAX} was not exceeded even when 0.50A was applied. By attaching a fan, the heat dissipation is improved and cooling is possible.

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

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

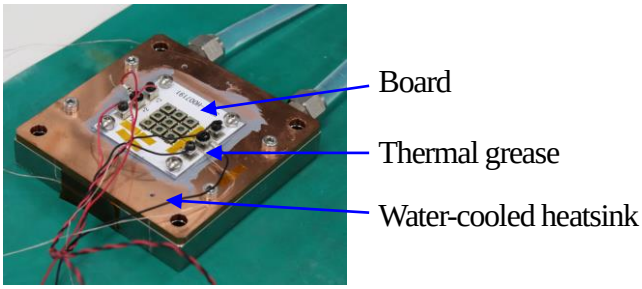
Heatsink		Water temperature (°C)	Water flow rate (L/min)	Thermal resistance (°C/W)
Material	Size (mm)			
Cu	120 × 120 × t25	25	5.6	0.01

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

The measurement results of the board + water-cooled heatsink shown in Picture 7 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	NC4U334BR	U280	0.35	20.8	7.3	38	61
			0.50	21.4	10.7	44	77

Even with this heat dissipation configuration, when 0.50A was applied, it did not exceed the T_{JMAX} of 110°C. With water cooling, it can be adequately cooled.



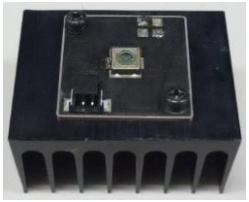
Picture 7. Evaluated light source 4-2-3

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 5).

Picture 8.
Fins facing vertical
(Nichia uses this orientation)



Picture 9.
Fins facing down
(This orientation obstructs the air flow)

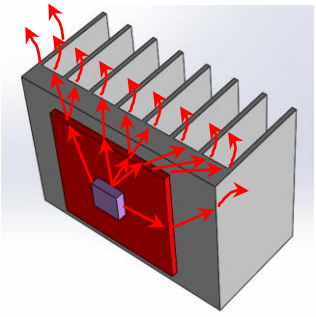


Figure 5.
Image of the heat path when fins are facing vertical

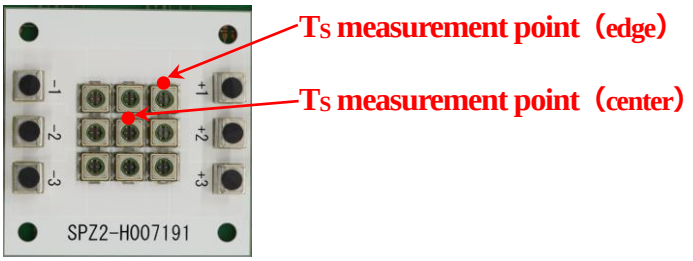
As an example of the increase in the T_S when the air flow is obstructed, the T_J was measured when the fins were facing vertical and when the fins were facing down. The following table shows the measurement results verified with heatsink A.

T_A (°C)	Part number	Wavelength Rank	Heatsink orientation	I_F (A)	V_F (V)	W (W)	T_S (°C)	T_J (°C)
25	NC4U334BR	U280	Fins vertical	0.35	20.6	7.2	70	92
				0.50	21.0	10.5	87	120
			Fins downward	0.35	20.5	7.2	78	100
				0.50	20.9	10.5	97	129

Compared to the case where the fins are facing vertical, the T_S is increased by about 10°C when the fins were facing down.
When designing the system, pay attention to the orientation of the fins when installing the heatsink.

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 10. 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	NC4U334BR	U280	0.35	center	20.5	7.2	49	71
				edge	20.6	7.2	46	68
			0.50	center	21.0	10.5	58	91
				edge	21.1	10.6	57	90

According to these results, the T_J is slightly 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

If the number of mounted LEDs is one or if a sufficient pitch width is used, it may be possible to design with only a heatsink without exceeding the T_{JMAX} by increasing the heatsink size.
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 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.

The absolute maximum ratings for the NC4U334BR LED per the Nichia specification:
I_F=0.50A, T_{JMAX}=110°C
Nichia will not guarantee the LEDs if used above these ratings.

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