Thermal management design of LEDs

1. Introduction

Today, there are various applications in every field. In response to this increase in various applications, Nichia Corporation is producing mini power LEDs and high power LEDs that can be driven at high currents. Mini power LED are suitable for less brightness or small output applications, such as back lighting systems, indicators, and so on. On the other hand, high power LEDs are suitable for applications that need extremely high brightness or high output, such as automotive headlights, interior lighting, etc. In many cases, LEDs are mounted in narrow spaces for applications that use mini power LEDs. In this case, heat management is one of the most important factors in the application. In contrast, for high power LED applications, the designer must consider how to manage heat, in order to enhance the performance of the LEDs. If heat management is not considered, the lifetime of the LED will be significantly decreased, or the LED will fail. In this document, we cover basic ideas of how to handle heat management by giving examples with Nichia's high power LEDs.

2. Heat Release Procedure

The maximum ambient temperature at which LEDs can be used is determined by the PN junction temperature (Tj). When the junction temperature reaches its upper limits it is called the maximum junction temperature (Tj_{MAX}). So, in the heat management design, designers must know what Tj they are operating at, and whether the product will reach the Tjmax or not. If designers can keep the Tj low, they will achieve longer life for the LEDs. This, in turn, will achieve longer life for their products.

Next, we introduce the concept of "thermal resistance" in order to assume Tj. See fig.1(Structure of NCCW022). The LED is composed of a die heat sink, D/B resin, encapsulating resin, heat resisting package, and optical lens. The PCB and solder pad will be added when mounting the LED on a PCB. A thermal circuit is the expression used to explain the thermal slope from ambient temperature (Ta) to Tj. You can use the thermal circuit as an electrical circuit analogy by using the factor " thermal resistance" expressed as (ºC /W).

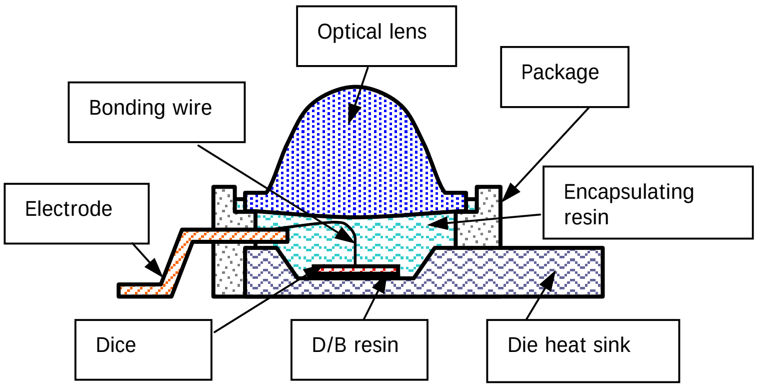


Fig.1 Structure of NCCW022

2-1 Heat Model Method

In Fig.2, the thermal resistance from Tj to Ta is defined as Rja (ºC /W). Tj is expressed by Equation (1).
(W is power consumption (W).)

Tj=Ta+Rja · W · · · (1)

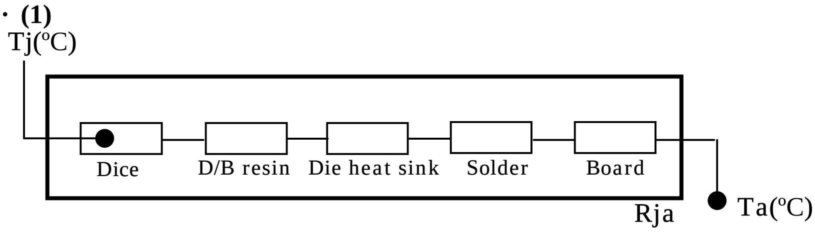


Fig.2 The thermal circuit indicates the thermal resistance from the ambient temperature (Ta) to the dice.

This can also be calculated by using the surface temperature of the die heat sink (Tc) (Fig.4). The thermal resistance from Tj to Tc is defined as Rjc (ºC /W), and the thermal resistance from Tc to Ta is defined as Rca (ºC /W)(Fig3), so Tj can also be expressed by equation(2).

Tj=Tc+Rjc · W · · · (2)

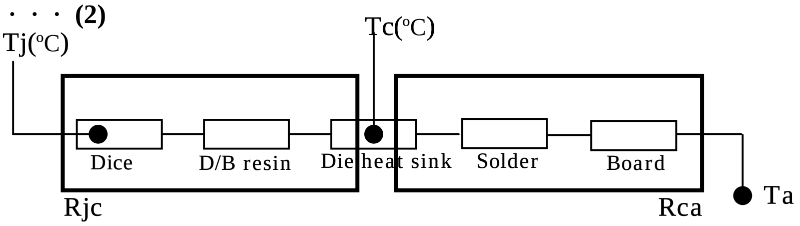


Fig3. The thermal circuit indicates the thermal resistance from Tj to Tc and from Tc to Ta.

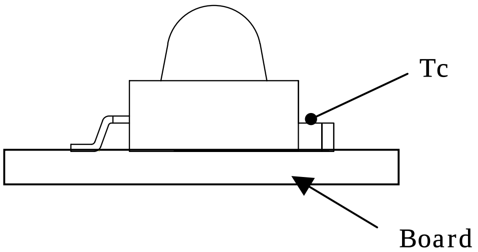


Fig4. Tc measuring point

2-2 Calculating Tj

(a) Calculating Tj by the Vf measurement method (Rja derivation by experiment)
Generally, the forward voltage of the diode (Vf) changes depending on the temperature. (When constant current is input, the temperature will rise, and Vf will decrease. When calculating Tj, Vf should be measured by using pulse current whose heat is repressed as much as possible when the current is input. In other words, you should monitor Vf when Ta=Tj.) Beforehand, if you know the characteristics and the previously measured correlation between temperature and Vf, and if you measure the Vf when you input current, you will know Tj. By using this Vf measurement method, by measuring Tj and Ta at the heat saturation, and at the same time by using input power (W), you can work out the following equation.

Rja=(Tj-Ta)/W

Now, by using Equation (1), you can calculate Tj by using any ambient temperature.

(b) Finding Tj by using the Tc Measurement
Tc can be determined by knowing the temperature measurement, and input power (W) can be determined by the electrical measurement. In the case of NCCW022, Tj and Tc are constant with a certain width differential, although Rja changes depending on the PCB. By using the reasons above, it is possible to determine Tj by measuring Tc.

(See 3-3 Tc-Tj correlation)

3. Essential Points for Design Applications

The following methods can be used to lower Tj.

①Keeping the power consumption (W) lower.
②Keeping the ambient temperature (Ta) lower.
③Design the application to make (Rca) lower

3-1 More Effective Heat Release

The thermal resistance for a single LED is constant, and independent upon what kind of PCB is used. So, the design of the heat release pathway from LED to bonding point to Ta is very important for the heat release design.

When you are designing, Rca is determined according to following points.

- What kind of adhesive is selected to bond the LED and the board (solder or heat sensitive adhesive)
- What kind of PCB is selected
- How the pattern of PCB is selected
- How the PCB size is selected
- Whether or not you use a heat sink fin for cooling down
- If using a heat sink fin, which kind of shape and/or material is selected
- If a cooling system, like forced air, is introduced in the application or not.

3-2 Example of a Heat Release Board

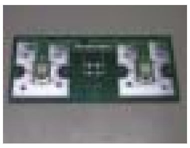
Here, we introduce typical board materials and determining Rja by the Vf measurement method when NCCW022 is mounted (Table 1).
We will also introduce Rca by measuring the thermo couple.
Rca can be calculated by using the following equation,

Rca=(Tc-Ta)/W

Board A

Board B

Board C



Main material	NO. of LEDs	Size	Rca	Rja
Alminium	1	Size: 30×30, t=1.7mm Copper Area/1LED: Face 330mm^2 t=0.105mm	26℃/W	46℃/W
FR-4	5	Size: 127×26, t=1.7mm Copper Area/1LED: Face 164mm^2 t=0.07mm, Back 253mm^2 t=0.07mm	46℃/W	73℃/W
FR-4	2	Size: 120×50, t=1.6mm Copper Area/1LED: Face 1180mm^2 t=0.07mm, Back 1600mm^2 t=0.07mm	23℃/W	39℃/W

Table 1. Typical board and
Rja calculated by the Vf measurement method as well as the
Rca by measuring the thermo couple

Light Emitting Diode

3-3 Tc-Tj Correlation

As was previously mentioned, Tj and Tc have a constant relationship with a certain width differential. The correlation between Tj, which is calculated by using the Rja from the Vf measurement method, and Tc, which is calculated by using actual measurements, is introduced by the graph indicated in Fig.5.

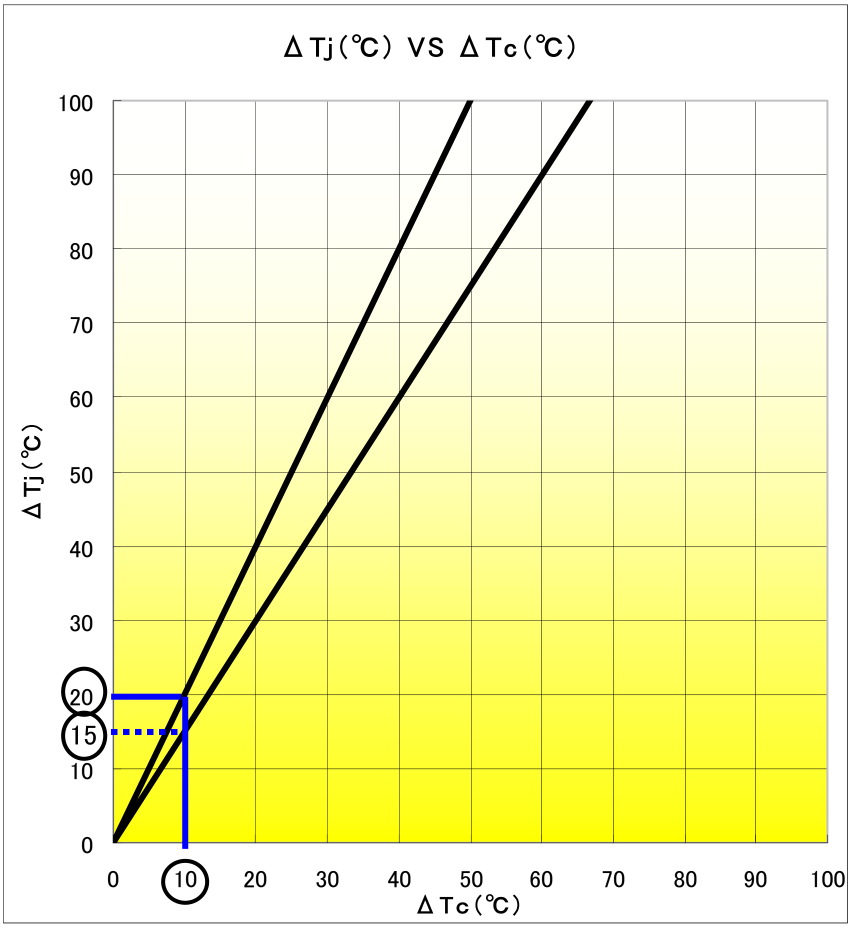


Fig.5. Tj-Tc correlation
△Tj=Tj-Ta △Tc=Tc-Ta

As you can perceive from Fig. 5, the gradient of the line will be within 1.5~2 when using a general PCB.
For example, when Ta=25ºC, 100mA, Tc=35ºC, then △Tc=35ºC-25ºC =10ºC. In this case, by using the graph above, △Tj=15~20ºC, therefore, Tj=Ta+△Tj=40~45ºC.

■Test example

[Test Purpose]

First, we calculated Rja (Tj) by using the Vf measurement method (See Equation (1)). After that, we measured the Tc of the same sample, and by using this information we were able to form the Tc-Tj correlation in Fig.6. Therefore, you can infer Tj from the Tc value since the Tj-Tc correlation, as shown in the experiment, has a certain width differential.

[Test Conditions]

・Mounted LED : NCCW022

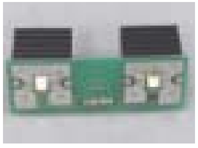
・PCB

Type A

Type B

Type C

Type D



Type E

Types A, B, C correspond respectively to Boards A, B, C in Table 1. Type D is the same as Board C, but it also includes a 10ºC /W heat sink fin on the back. Type E is the LED measured by itself.

・Measuring Conditions
The LED should be mounted by soldering. The Vf measurement method was carried out at 350mA, 10μsec~8000sec pulse time. The Tc measurement was taken at 100, 350, 500, 700mA of current at a constant ambient temperature of 25ºC. In Type E's case, the maximum current should be at 350mA because of the amount of heat released from the single LED. When you are measuring, you should fix the thermo couple (K thermo couple. ϕ0.32) on the top of the die heat sink with solder.

[Test results]

・Rja(ºC /W) according to the Vf measurement method

(SEC)	0.00001	0.0001	0.001	0.01	0.1	1	10	100	1000	8000
TypeA	1	2	5	17	17	18	19	29	45	46
TypeB	1	2	5	17	18	20	25	52	70	73
TypeC	1	2	5	17	18	19	20	29	38	39
TypeD	1	2	5	17	18	19	20	21	23	29
TypeE	1	2	5	17	24	30	63	138	150	150

(℃/W)

Table 2. Measurement of Thermal Resistance by the Vf Measurement Method. The numeric value at 8000sec is defined as Rja. We measured the thermal resistance by applying current to each device. The thermal resistance of a single LED is indicated within the darker bold lines at the beginning of the table.

· Measuring Tc

Type A Ta=25℃

If(mA)	Vf(V)	If×Vf(W)	Tc(℃)	Tj＝Ta＋R_{j-a}×W
100	3.30	0.33	36	40
350	3.71	1.30	61	85
500	3.84	1.92	74	113
700	4.03	2.82	102	155

R_{c-a}=26℃/W ＊R_{j-a}=46℃/W

Type B

If(mA)	Vf(V)	If×Vf(W)	Tc(℃)	Tj＝Ta＋R_{j-a}×W
100	3.29	0.33	43	49
350	3.52	1.23	85	115
500	3.59	1.80	110	156
700	3.85	2.70	148	222

R_{c-a}=46℃/W ＊R_{j-a}=73℃/W

Type C

If(mA)	Vf(V)	If×Vf(W)	Tc(℃)	Tj＝Ta＋R_{j-a}×W
100	3.35	0.34	35	38
350	3.81	1.33	57	77
500	3.97	1.99	71	103
700	4.15	2.91	92	138

R_{c-a}=23℃/W ＊R_{j-a}=39℃/W

Type D

If(mA)	Vf(V)	If×Vf(W)	Tc(℃)	Tj＝Ta＋R_{j-a}×W
100	3.32	0.33	31	35
350	3.68	1.28	43	62
500	3.79	1.90	52	80
700	3.93	2.75	63	105

R_{c-a}=14℃/W ＊R_{j-a}=29℃/W

Type E

If(mA)	Vf(V)	If×Vf(W)	Tc(℃)	Tj＝Ta＋R_{j-a}×W
100	3.08	0.31	63	72
150	3.14	0.47	78	96
250	3.23	0.81	112	147
350	3.30	1.16	141	199

R_{c-a}=104℃/W ＊R_{j-a}=150℃/W

*R_{ja} is calculated by table 2.

Table3. Correlation between Current Consumption and Tj, Tc based on Actual Measurements

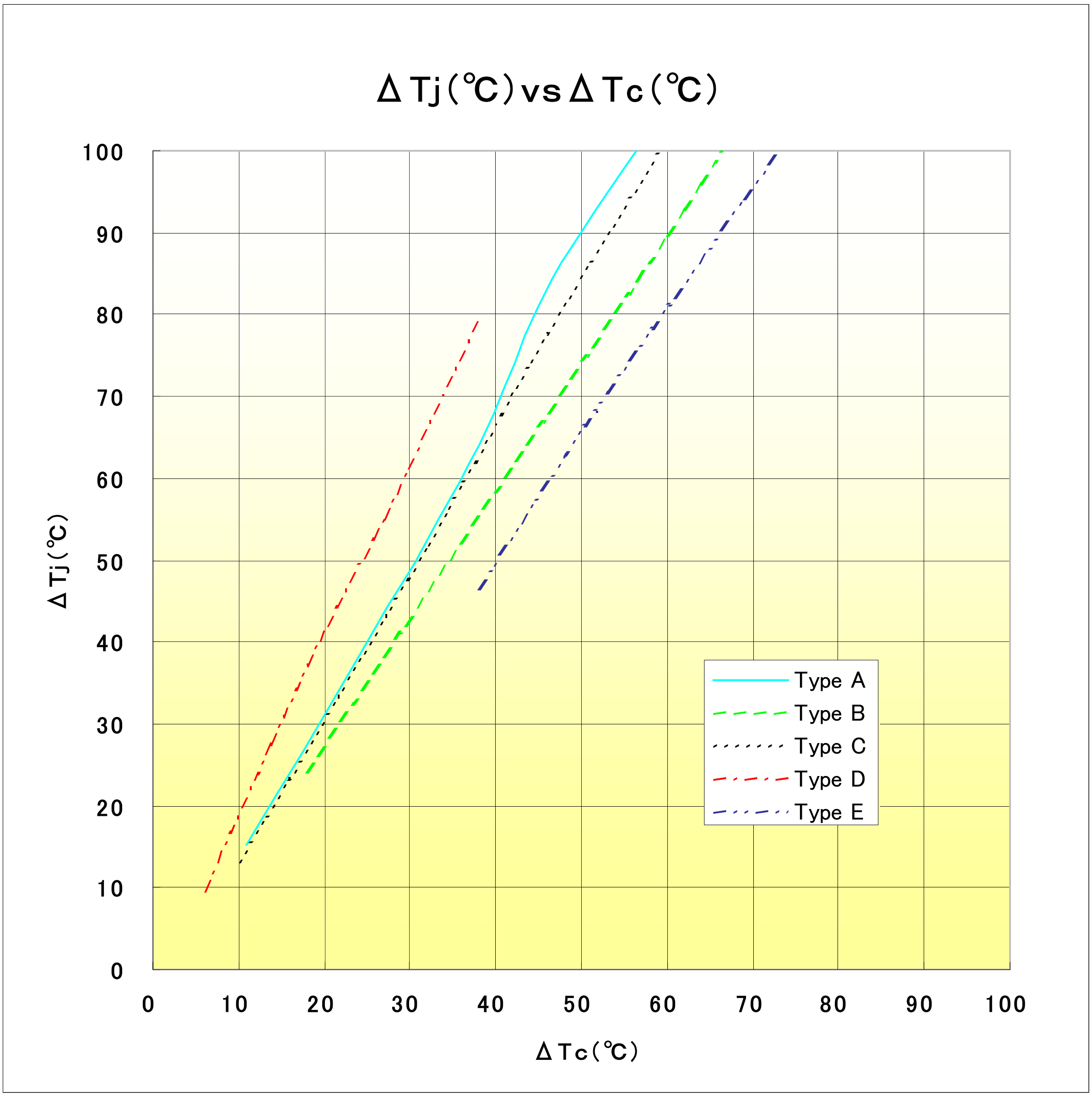


Fig.6 The graph indicates the correlation between the Tj, calculated by the Vf measurement method, and the actual Tc measurement value.

△Tj=Tj-Ta △Tc=Tc-Ta

- When the gradient is smaller, there is a smaller degree of heat release.
- Based on the experimental results of Type A, B, C and D, you can infer that the gradient has a constant range as indicated in Fig.5.
- If you measure Tc, you can assume a certain level of Tj.