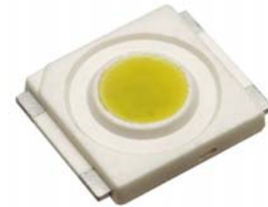
DOMINANT™
Opto Technologies
Innovating Illumination

APPLICATION NOTES:

Thermal Management Of Power LED

Introduction:

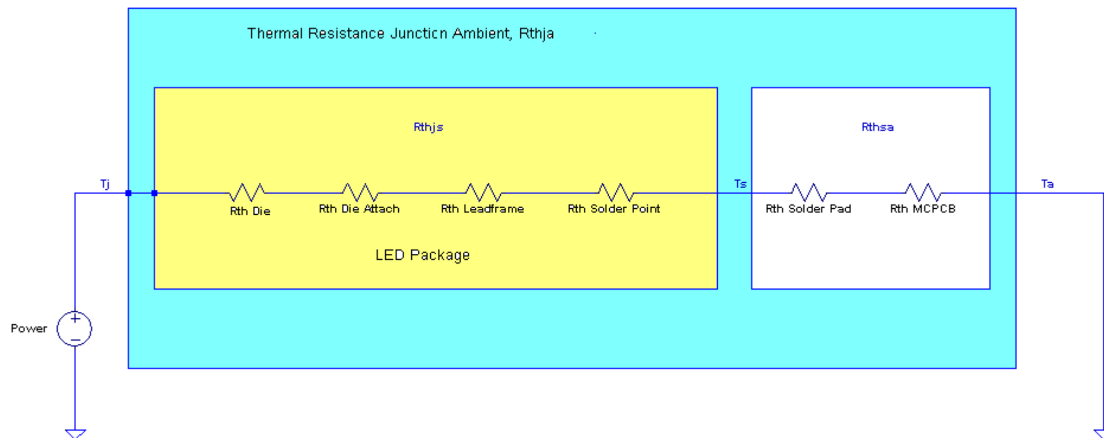
When current flow through a LED; a portion of the electrical energy will be converted into visible light of particular wave length. However a majority of the electrical energy will be converted as unwanted heat at the P-N junction. The heat generated conducts from the junction area through the LED die, then through the package and eventually into the local ambient. This flow of heat is governed by the laws of thermodynamics and the principles of heat transfer.



For high power LED, the thermal consideration of LED design become very critical, since higher junction temperature is associated with reduced operating life and increased IV degradation.

LED Thermal Path And Equivalent Thermal Model

The LED consists of a chip mounted on a lead frame by thermal conductive material. The main thermal path for the heat generated at the P-N junction would be through the bottom of the chip to the lead frame by way of heat conduction. The heat generated will further dissipated through to the metal core PCB (MC PCB) or other substrate used to mount the component. The static equivalent thermal circuit of a high power LED is as depicted below:



Base on electrical model analogy and "Ohm's Thermal Law", the relationship can be derived as per formula below:

$$Tj - Ta = Rthja \times (Vd \times Id) \qquad \text{------ Equation 1}$$

Where Tj = LED junction temperature
Ta = Ambient temperature
Rthja = Thermal resistance junction to ambient
Vd = LED forward voltage
Id = LED forward current

There are various external factors that potentially can cause variation in thermal resistance junction to ambient. Such factors include: the type and size of MC PCB used, air flow velocity from surrounding and etc. Thus when defining Rthja in datasheet, Dominant will specify the type of PCB used together with the PCB pad size where the heat is dissipated (ambient temperature is assumed at 25 Deg C.)

From the static equivalent circuit above, Rthja can be further broken down to 2 parts,

$$Rthja = Rthjs + Rthsa \qquad \text{---- Equation 2}$$

Where Rthjs = Thermal resistance junction to solder point
Rthsa = Thermal resistance solder point to ambient

From "Ohm's Thermal Law":

$$Tj\text{-}Ts = Rthjs \times (Vd \times Id) \qquad \text{---- Equation 3}$$

$$\text{Or} \quad Tj = Rthjs \times (Vd \times Id) + Ts \qquad \text{---- Equation 4}$$

Where Ts = Solder point temperature

Equation 4 is particular important in practical calculation to ensure under specific operating condition, the junction temperature will not exceed absolute maximum Tj rating defined in datasheet.

The Ts in equation 4 can be measured by soldering a thermocouple to the lead (usually the lead where the chip is mounted) of the LED when forward biased with specific current. From the Ts measurement, the maximum Tj can be obtained by calculation.

Junction to solder thermal resistances are often mistaken as fix parameters that are independent of the specific heat flow configuration. This stems from the misconception that junction to solder point thermal resistance is solely a function of the component package. In practical the junction to solder thermal resistance will vary with the different cooling environment. As an example, mounting a LED on a different heat dissipation rate heat sink will not only change the junction to ambient thermal resistance but will also change the junction to solder thermal resistance.

When considering thermal management for LED applications, the key factor to consider is the junction to ambient thermal resistance of the system. The approximate junction to solder point thermal resistance is always provided in the data-sheet and this value is good for practical use although it may vary slightly due to external factors. Therefore, the thermal resistance between solder point to ambient will be the key consideration. This resistance is mainly influence by two factors.

- Exposed surface area for heat dissipation.
- Material property.

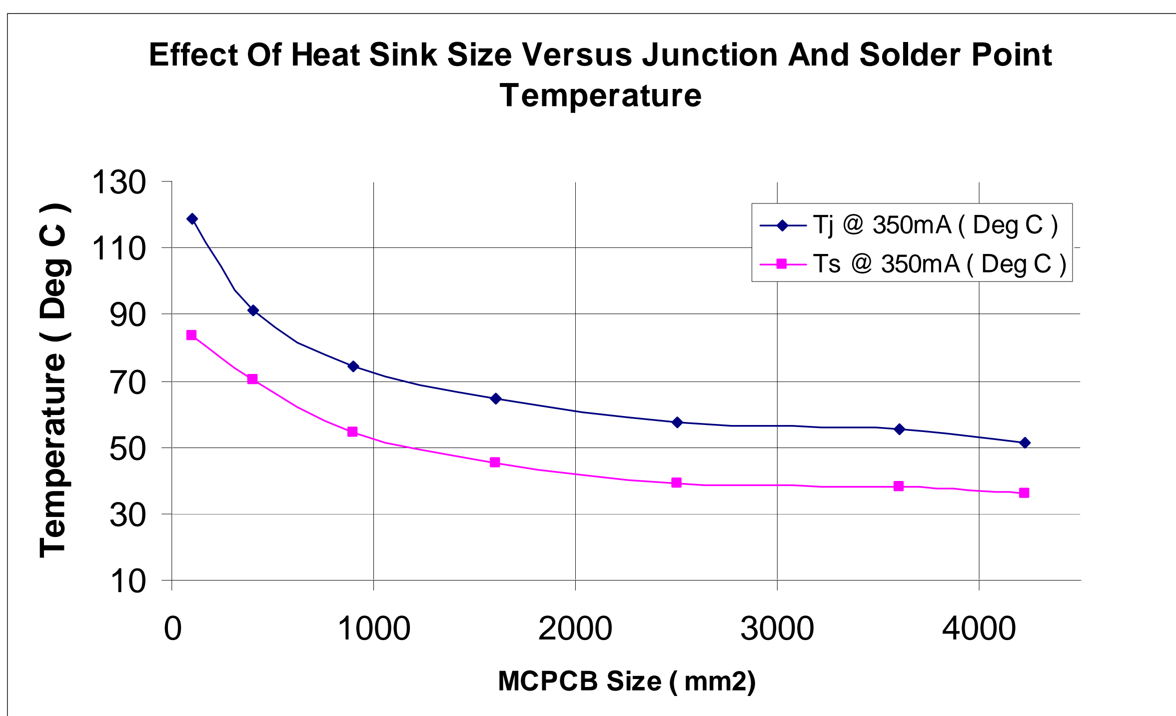
Generally the bigger is the surface area of the heat sink; the better will be the heat dissipation. In most cases, heat is dissipated from heat sink to the ambient via convection. The orientation of the heat sink and surrounding air flow will also influence the thermal behavior. Material property is the second item to consider. Heat sink made from copper for instance has better thermal performance compared to the same one made of aluminum.

Below is an example of Dominant 1W white SPNova thermal variation with different size of MC PCB at ambient temperature =25 Deg C. For this assessment the LED is attached at the center of a square aluminium metal core PCB with 1.5mm thickness. The initial size of the PCB is 65 mm x 65 mm, and is gradually sawn away until the dimension reaching 10

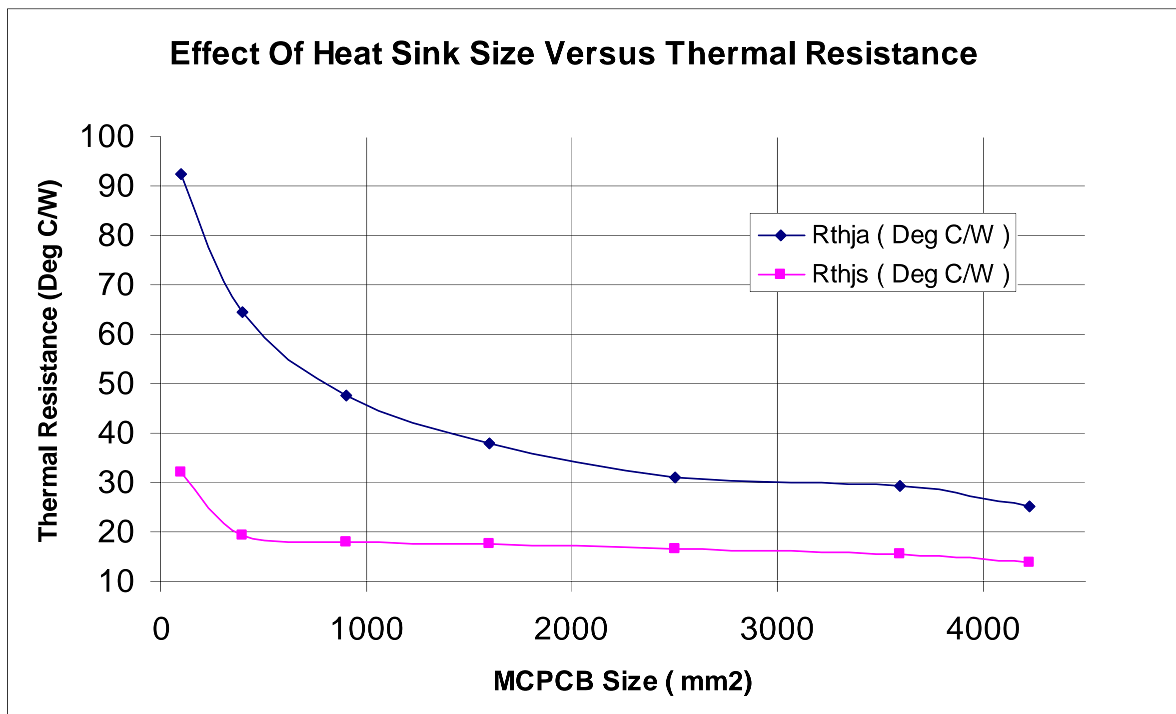
mm x 10 mm. Tj, Ta, Rthja and Rthjs is measured at each PCB dimension. The summary of the assessment is depicted in the graph 1 and 2 below.

From graph 1, it is evident that the LED operating junction temperature can be maintain at very low level by using a larger heat sink, only limited by customer product design and dimension constrain.

From graph 2, we can see the Rthjs is not fix for a LED package, but reduce with the increase of the heat sink dimension.



Graph 1 : Effect Of Heat sink Size On The Junction To Ambient And Junction To Solder Point Temperature



Graph 2 : Effect Of Heat sink Size On Rthja And Rthjs

Example Of Junction Temperature Calculation.

In Dominant datasheet, the thermal resistance value specified is the maximum value the LED will observed when biased with the maximum allowable forward current.

As an example, from the SPNova RGB LED, NMRTB-USS datasheet, the junction to solder thermal resistance is stated as 50 degree C/W, attached on Dominant recommended metal core PCB. This would be the maximum Rthjs value across the RGB die when all the 3 chips is biased at maximum rated forward current.

The datasheet also has the following typical voltage reading specified at forward current of 250mA.

Electrical Characteristics at Ta=25˚C

Part Number	Vf @ If = 250mA		
	Min. (V)	Typ. (V)	Max. (V)
NMRTB-USS-1			
• Red	2.2	2.5	2.8
• True Green	3.2	3.5	3.8
• Blue	3.2	3.4	3.8

At maximum recommended drive current of 250mA for each chip :

The typical Red chip power dissipation = 2.5V x 250mA = 0.625W

The typical True Green chip power dissipation = 3.5V x 250mA = 0.875W

The typical Blue chip power dissipation = 3.4V x 250mA = 0.85W

Assuming solder point temperature Ts = 50 Deg C by thermal couple measurement.

For equation 4,

Tj = Rthjs x (Vd x Id) + Ts

Tj(Red) = 50Deg C/W x 0.625W + 50 Deg C = 81.25 Deg C

Tj(True Green) = 50Deg C/W x 0.875W + 50 Deg C = 93.75 Deg C

Tj(Blue) = 50Deg C/W x 0.85W + 50 Deg C = 92.50 Deg C

From the calculation above, the junction temperature for all the chip still operate below the absolute maximum rating of 125 Deg C.

Heat Sink Requirement Calculation Example For High Power LED

In practice, a designer must identify four preliminary values before proceed for LED design

VF = Typical LED forward bias voltage
IF = The intended LED forward bias current
Tambient_max = Maximum ambient temperature at which the system must operate. For system with enclosure, the Tamb is the temperature surrounding the LED within the enclosure
Tjunction_max = Maximum LED operating junction temperature. Note that the higher operating LED operating junction temperature, the shorter the LED lifespan

From these data, it can be determine whether an additional heat sink is required or not and the required heat sink thermal resistance.

Example for 1W White SPNova, NPW-TSD, it has the following information stated in datasheet:

Rthja = 60 Deg C/W (Attached on Dominant standard MCPCB Module)
Rthjs = 18 Deg C/W (Attached on Dominant standard MCPCB Module)
VF typical = 3.6 V
If Max = 350mA
Max Junction temperature = 120 Deg C

If the customer application has Tambient_max at 70 Degree, from equation 1 :

Tj = Ta+ Rthja x (Vd x Id)
= 70 + 60 x (3.6 x 0.350)
= 145.6 Deg C

Junction temperature would be much higher than the absolute maximum Tj rating of 120 Deg C.

In order to maintain the Tj of LED at maximum operating temperature of 120 Deg C, the thermal resistance junction to ambient required:

Rthja = (Tjmax – Tamax)/(V x I max)
= (120 – 70)/ (3.6 x 0.35)
= 39.7 Deg C/W

From equation 2, assuming the Rthjs do not vary significantly with the heat sink addition:

Rthsa = Rthja - Rthjs
= 39.7 – 18
= 21.7 Deg C/W

Extra heat sink with thermal resistance better than 21.7 Deg C/W is required to attach to the 1W MCPCB module to achieve this maximum junction temperature target.

Summary:

Thermal management is one of the key areas that need serious attention when designing high power LED. Effective thermal management will prolong the LED lifespan and also reduce the IV drop due to the increasing LED junction temperature. All the description above is only intended to provide a basic guide line for designer when performing LED system design. It is advisable for customer to design a prototype and perform the actual temperature measurement on the module to validate the thermal model. This will help to eliminate the uncertainty due to effect of power density from the adjacent component and also the effect of material/enclosure in direct interaction with the LED module.