Basic Thermal Management in VLED Applications

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High power visible LEDs have the potential to operate efficiently for long lifetimes. However, there are several common misconceptions about visible LEDs and heat, which can lead to the deteriorating performance of an LED if the junction region becomes overheated. Some fundamental factors to consider when determining how thermal issues affect LED assemblies include ambient temperature of the environment, power input and optical output, means of heat dissipation, and thermal properties of the materials.

Two factors that directly affect the longevity of LEDs are: 1) operating current, and 2) operating junction temperature.

For any given application, the current through the LED determines how much heat is generated. Few, if any, high power LEDs have a primary package that allows them to be operated at full rating in a normal environment without some assistance from a secondary heat dissipation system. It is common for the package to be thermally coupled to some form of heatsink with sufficient surface area to dissipate the heat.

LEDs, which generate heat at an extremely high rate, can be encapsulated in small packages, which are poor dissipaters of heat. The area of a chip that generates 1 watt of heat is about 1mm2 , so the generation rate of heat is 100W/cm2 . In volumetric terms this is around 10W/mm3 for a chip that is 0.1mm thick, or 10kW/cm3 (160kW/in3).

Although it is only one watt, the surface area that is available to conduct heat away from the junction is also extremely small – typically limited to the backside of each chip.

Over temperature is the single greatest cause of LED failure. Most manufacturers of LED chips specify a maximum operating temperature for the junction region of about 130o C. This is an absolute maximum, and sustained operation near this value will cause long term damage. A more realistic design value to accommodate changes of ambient temperature would be around 80o C, or a junction temperature 55o C hotter than 25o C ambient air.

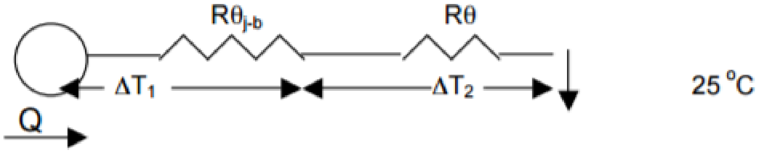
Thermal Conductivity

Minimizing junction temperature rise involves selecting a material with high thermal conductivity to draw heat away from the LED chip; and ensure that the selected material has adequate surface area to transfer that heat to the atmosphere.

Thermal resistance (measured in °C/W) for packaged LED devices is often published on the data sheet as Rθj-b representing the ‘Junction to Board’ temperature difference between the junction and the area of the PC board adjacent to the device, for each watt of input power.

The total Rθ of any system must encompass the complete path from heat source to the air, in a series combination of all the relevant elements.

As shown below, if we take the value of Rθj-b as a starting point, then by measurement it is simple enough to find an approximate value of Rθ for the remainder of the system.



For any value of Q, if we can measure ΔT2, then $R\theta = Q / \Delta T2$ The basic objective of a practical design is to control the value of Tj. For any system, the absolute value of Tj (o C) = Amb. + ΔT1 + ΔT2

Since ΔT1 is fixed for some value of input power Q, the temperature of the junction is elevated above this, in absolute terms, by an amount equal to ΔT2 ………. (= Q x Rθ). Thus, to minimize junction temperature rise, one must either reduce heat input (Q) or the thermal resistance of the material (Rθ). As we will see, reducing Rθ is preferable.

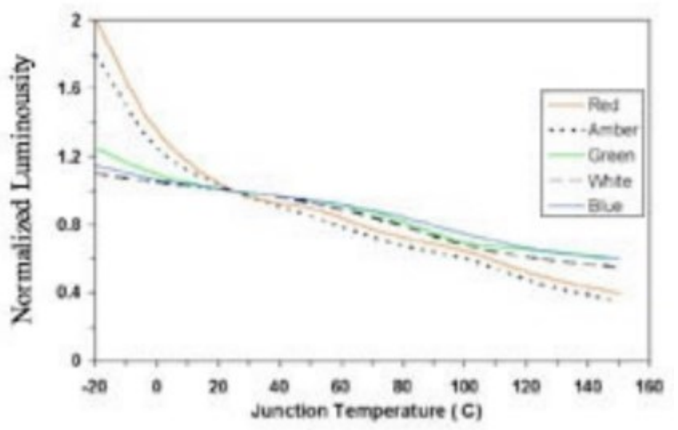
Reducing the input power (Q) can be as simple as reducing the LED current. Reducing Rθ, however, may be difficult in some circumstances.

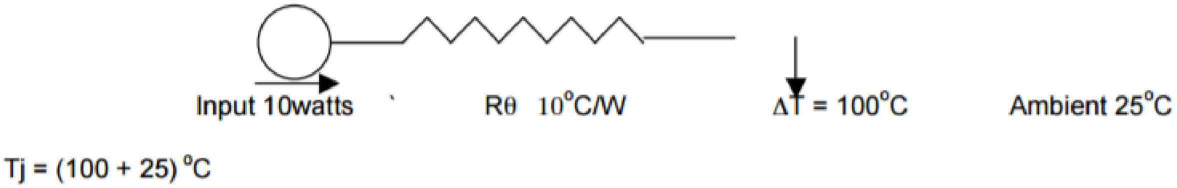
The most critical factor is the interface between the thermal system and the ambient air. The transfer of heat energy into the air by radiation is the least effective part of any system and has a direct relationship with the available surface area for any given surface. I.e., Rθ will be reduced if the surface area is increased.

Temperature Dependencies

Several parameters have a direct dependence on the junction temperature. The first and most important relationship is the loss of light output with elevated temperature. As can be seen from figure 1, a significant loss of output, near 50%, is expected when the junction is permitted to operate at around 130o C. Even at modest operating temperatures, such as 80o C, there can be a 20% loss of output, so the aim is to keep the junction as cool as possible to maximize the output.

In the example below, it is shown that there is little to be gained by driving high output LEDs at the limit of their operating temperature rating.





If the load in the diagram above is a blue LED, then from the graph we can see that for a junction temperature of 125o C the LED output has fallen to 65%. By reducing the input power (current) to 8W, the junction temperature falls to 105o C, and the output rises to 75%.

But this is 75% of only 80% (=60%), because the output is directly proportional to current, which has been reduced by 20%. So the difference in actual light energy generated in this system at 8W and at 10W is only 5% for the additional 2W of input. Put another way, by increasing the input energy by 20% of rating, the net gain of output is only 5%. The preferred action to increase the output (effectiveness) of any system is to reduce Rθ.

Minimizing Temperature Rise

The most common means of dissipating heat from LED components is by use of a heatsink. Where the total heat to be dissipated is small compared to the surface area and volume of an assembly, and can be identified with a particular component, it is often sufficient to use a local heat spreading heatsink inside an enclosure. Where this is ineffective, components are often mounted on a heatsink that is located outside the enclosure. When enclosing an LED load with significant heat dissipation, the challenge becomes to make the enclosure itself act like a heatsink.

To dissipate heat from the surface of an enclosure, the enclosure ideally has a surface that is optimized for radiant heat transfer, is manufactured from material with good thermal conductivity and is configured to have low thermal resistance.

The maximum temperature of any thermal system will be found at the source of the heat, thus, if we assume that a device is at rest with all parts cooled to the temperature of the ambient air, then at switch-on dissipation commences and the active component heats up. There is an initial warming up period, during which the energy required to raise the temperature of the component parts is being stored. As the warming process proceeds, the dissipation rate increases exponentially as the components heat up until the input equals the output, equilibrium is reached and the temperature profile is stable.

Conclusion

Heat management in VLED applications is essential to the lifespan of LEDs. Utilizing materials with high thermal conductivity and incorporating a heatsink into the design are several factors that will result in a thermally efficient device suitable for high power LEDs.