

## Heat Dissipation Design in LEDs

When forward current flows through an LED and the LED emits light, most of the energy consumed is converted into light. However, some of the energy is converted into heat, which causes heat to be generated from the p-n junction and the junction itself to heat up. The heat that occurs in the junction is referred to as the junction temperature, and appropriate dissipation of this heat so that the temperature rise is contained during LED use helps to prolong the lifespan of the LED. This document discusses the heat generated by the LED and some of the issues raised in dealing with it.

### Maximum Junction Temperature ( $T_{jmax}$ )

At Stanley, the maximum junction temperature is set not merely for the element itself. It also takes into consideration a range of factors including the product lifespan and the reliability of other components such as the encapsulating resin and molding resin. The maximum junction temperature is normally one of the maximum ratings listed for a product, and the product is not guaranteed to operate when used in conditions where that temperature is exceeded. In most cases, such use results in faults and/or extreme shortening of the product lifespan.

## LED Structure and Heat Dissipation

Figure 1 shows the structure of an ordinary LED. As the figure illustrates, heat from the junction is dissipated along various routes.

1. Junction - LED element - encapsulating resin - surroundings
2. Junction - LED element - encapsulating resin - lamp housing resin - surroundings
3. Junction - LED element - element adhesive - lead frame - soldering pad - mounting substrate - surroundings
4. Junction - LED element - element adhesive - lead frame - soldering pad - surroundings

### Thermal Resistance Circuits

Of the above heat dissipation routes, those via the encapsulating resin or lamp housing resin have minimal impact. The LED element - element adhesive - lead frame - soldering pad - substrate route is the principal heat dissipation route and has the greatest impact. Accordingly, we will model the heat dissipation route shown in Figure 2.

This model shows that the dissipation value from the element to the solder is determined by the product structure and the materials used in the product, and is specific to each product. So heat dissipation design refers to design that lowers the thermal resistance from the element to the substrate and in the air.

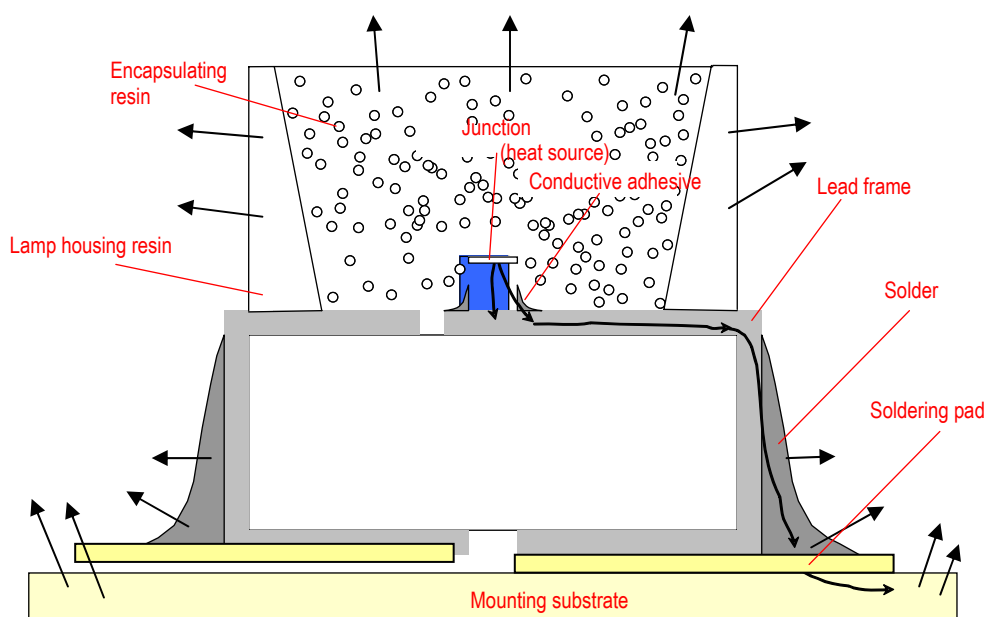


Fig. 1

## Obtaining the Junction Temperature

The thermal resistance value listed in Stanley product specifications is a product-specific value from the p-n junction to the terminal ( $R_{thj-s}$  in Figure 2). The value from the junction to atmosphere ( $R_{thj-a}$ ) is that obtained given the mounting and measurement conditions used at Stanley. So, to obtain the junction temperature ( $T_j$ ) in the actual operating conditions, allowing for factors such as the solder pad pattern and mounting substrate materials, the soldering pad temperature ( $T_s$ ) must be measured. Thermal resistance specifications are normally published for PLCC package products. Typical examples are LEDs with the type of specifications given below.

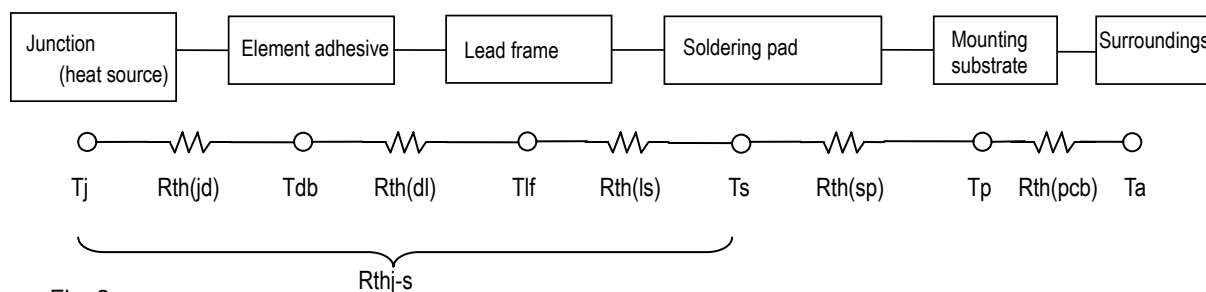


Fig. 2

Forward current  $30[mA]$

Forward voltage  $3.5[V]$

Input power

$$30[mA] \times 3.5[V] = 105[mW]$$

Thermal resistance  $R_{thj-s}$   $100[C^\circ / W]$

If this product is used at 30 mA, the temperature difference between the junction and terminal can be obtained using the following equation:

Temperature difference

$$100[C^\circ / W] \times 0.105[W] = 10.5[C^\circ]$$

The result indicates that the junction temperature is  $10.5^\circ C$  higher than the terminal temperature. The next question to consider is how the junction temperature differs if this product is used under 2 different sets of mounting conditions. Given an ambient temperature ( $T_a$ ) of  $30^\circ C$ , the junction temperature is obtained by adding 10.5 to the measured terminal temperature ( $T_s$ ) under each set of conditions. The heat resistance between the junction and the surrounding air ( $R_{thj-a}$ ) can be calculated from the input power and the difference between the ambient temperature and the junction temperature.

Thermal resistance ( $R_{thj-a}$ ) = (Junction temperature ( $T_j$ ) – Ambient temperature ( $T_a$ )) ÷ Input power

	$T_a$	$T_s$	$T_j$	$R_{thj-a}$
Condition 1 (good heat dissipation)	30	50	60.5	290
Condition 2 (poor heat dissipation)	30	70	80.5	481

In differing operating conditions such as these, the junction temperature can be obtained through calculation by measuring the terminal temperature.

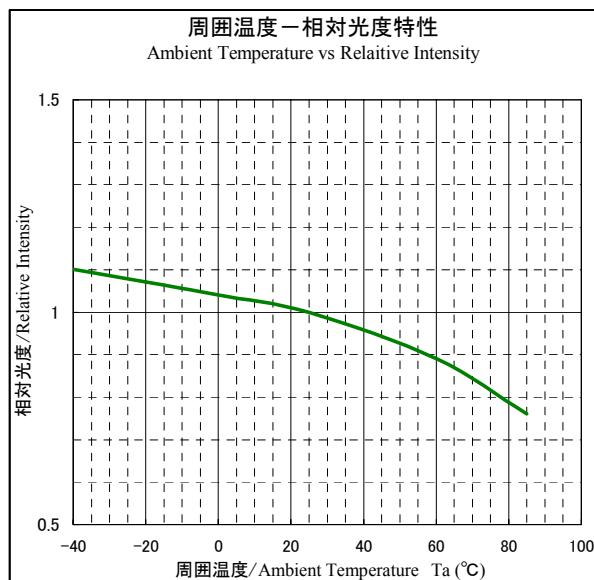
## Effects on Lifespan

The heat generated in the junction is transmitted to the entire product and raises its temperature, significantly impacting on the product's lifespan. The lifespan of a product is determined not only by the element, but by the combined outcomes of deterioration in other components, such as the resins and adhesives used, and how those deteriorations interact. Temperature has a significant impact on those outcomes. For example, when a product with a failure rate of 4.42 FIT at a junction temperature  $25^\circ C$  is used with a junction

temperature of 85°C, the failure rate is 21.2 FIT. This is a logical value obtained through calculation, whereas in reality, complex factors may accelerate the deterioration. For this reason, it is advisable to trial any product in its actual operating conditions.

## Effects on Optical Characteristics

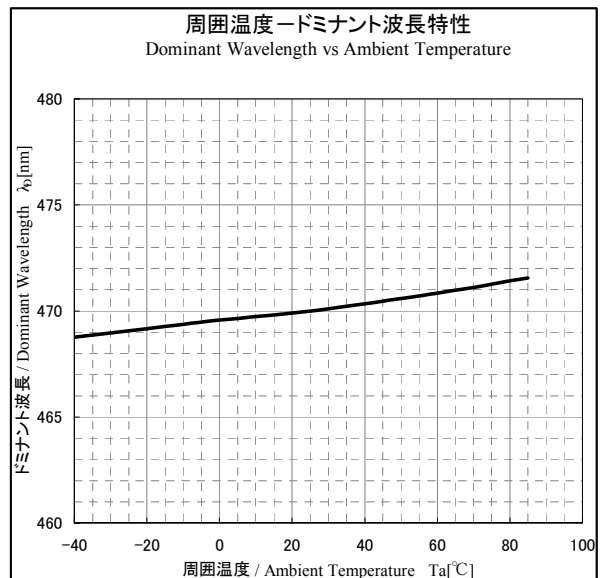
As the junction temperature rises, the efficiency with which it converts current to light decreases. This means that rises in junction temperature lead to declines in LED brightness when a constant-current drive is used. Graph 1 illustrates an example in which the junction temperature is varied by changing the ambient temperature while the current remains fixed. A design with good heat dissipation is required in order to minimize declines in luminous intensity due to junction temperature increase.



Graph 1

Rises in the junction temperature also change the spectrum of the light emitted by the element itself, altering the dominant wavelength. In products that use fluorescent material, the effects of heat can also lower the efficiency of the fluorescent material, which changes the proportion of fluorescence relative to the light emitted from the element, thereby changing the color of the light.

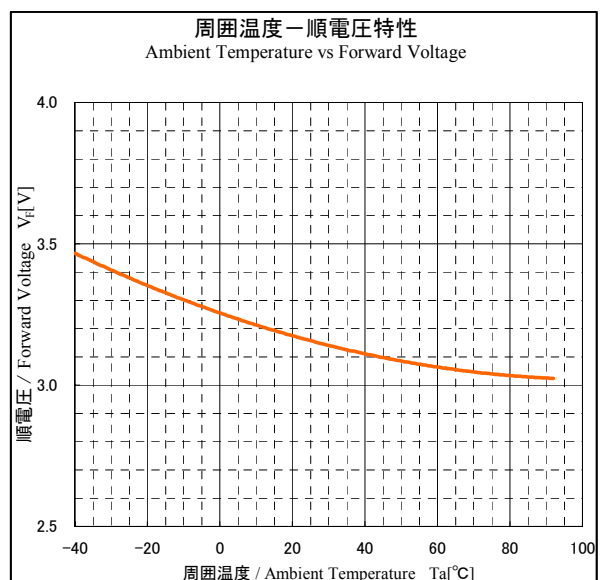
Given all of the above, we recommend that products be designed to allow sufficient heat dissipation to avoid any declines in luminous intensity, and that the actual appearance of the product be checked in those conditions. (Graph 2)



Graph 2

## Effects on Electrical Characteristics

As the junction temperature rises, the required forward voltage decreases, even when the same forward current is applied. As a result, it is possible for the current flow to exceed the rating when a constant voltage circuit is used. (Graph 3)

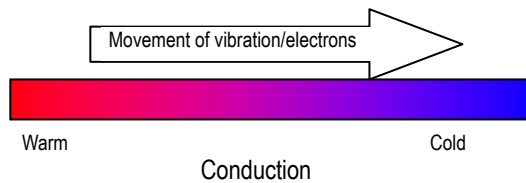


Graph 3

An understanding of other aspects of the basic behavior of heat and its governing principles helps contribute to good product design. Reference to these is advisable.

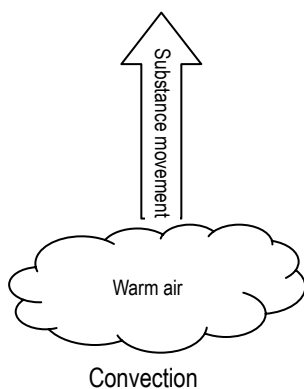
## Conduction

Conduction is the movement of heat that accompanies the movement of vibrations or electrons. It is a phenomenon that occurs when a warm material touches a cold material, as shown in the figure below. The ease with which heat travels is determined by the thermal conductivity specific to the materials involved and by the temperature difference, distance and contact area between the materials heat travels to and from.



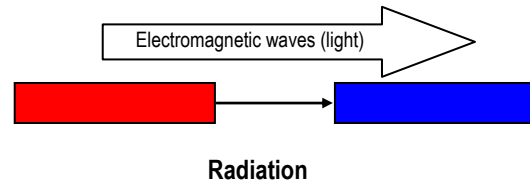
## Convection

Convection is the movement of heat that accompanies the movement of substances. The figure below shows an example in which heat moves due to the rise of warm air. The ease with which heat moves is determined by the ease of convection. For example, a fan can be used to forcibly induce convection and cooling can use a heat sink to provide convection cooling.



## Radiation

Radiation is the movement of heat via electromagnetic waves such as infrared rays. The figure on the right shows radiation from a warm substance to a cold substance. Electromagnetic waves are emitted from the cold substance as well as from the warm substance, but because cold substances absorb a larger proportion of the waves, the result is that the temperature of the cold substance increases.



## Examples of Heat Dissipation Design and Heat-dissipating Measures

1. Use metal substrates with good thermal conductivity, such as aluminum substrates. Epoxy resin substrates are inexpensive, but their thermal conductivity is poor. Using a larger surface area is also effective in dissipating heat.
2. Make the resist on the substrate as thin as possible. Because insulating materials are normally poor conductors of heat, measures such as using thinner resist coatings are effective.
3. Increase the size of soldering patterns. (Fig. 3)
4. Use heat sinks. Use a material such as aluminum that has good thermal conductivity as the heat sink, use a large surface area and use an adhesive with good thermal conductivity to stick the heat sink to the substrate.
5. Do not seal LEDs into confined spaces and keep them away from other LEDs and heat-emitting components.

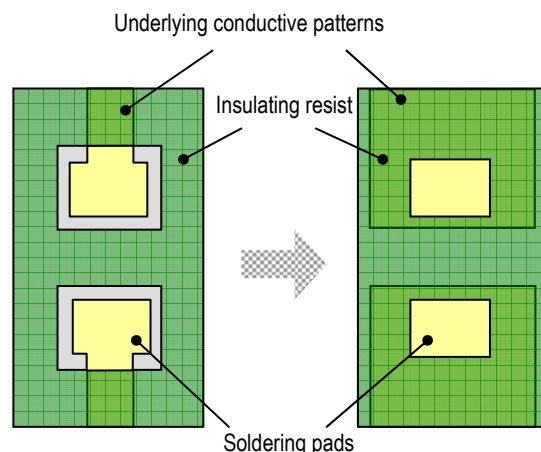


Fig. 3