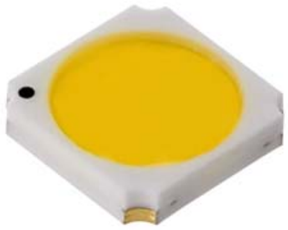
Heat Dissipation Design of Power Lighting LED GSPW16□ 3JTE



1. Introduction

The invention of the blue light-emitting diode has made it possible to produce white light by mixing it with yellow light emitted by a phosphor of a blue LED. Furthermore, improvement of the light emitting efficiency of the blue element has allowed LEDs to be used for lighting purposes, where it was previously only used for indicators and as backlights for relatively small LCD panels.

Lighting LEDs are noted for their function and performance of illuminating things more brightly than conventional lamps, and must provide as much light as possible. For this reason, lighting LED packages are designed to emit a large amount of light by means of a large current. On the other hand, while the power that is applied to the LED element is output as light, most of it is released as heat energy. Therefore, lighting LEDs allow a large current to flow through them, and are made of a material and structure that can also efficiently release a large amount of heat to the outside.

When using such an LED in lighting equipment, the equipment must be designed so that the heat generated by the LED is efficiently dissipated both inside and outside the equipment. This document discusses some points that should be considered regarding the heat dissipation design of a lighting LED as reference for designing various lighting fixtures.

2. LED Structure and Thermal Characteristics

The current that is applied to an LED element is converted to light in the PN junction of the element and released to the outside. Any current that is not converted to light is converted to heat in the junction and released to the outside. The heat generating mechanism is the same for conventional LEDs and lighting LEDs.

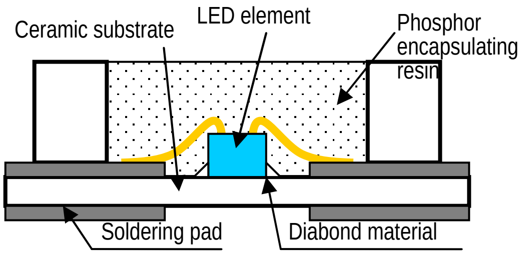


Fig. 1 Structure of GSPW16□3JTE

Fig. 1 shows the structure of a 1W-class LED (product number GSPW16 □ 3JTE) designed for lighting purposes. This LED package uses a ceramic base material with high heat conductivity. Fig. 2 shows a thermal resistance model in the case where the LED with a structure shown in Fig. 1 is mounted on a substrate and attached to a radiation fin.

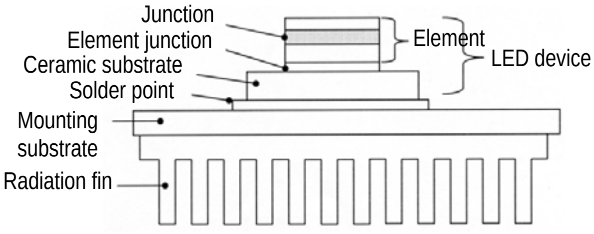


Fig. 2 Heat dissipation structure

The heat that is generated from the junction of the LED element is dissipated along various routes, but the route shown in Fig. 3 is the most predominant. In Fig. 3, the thermal resistance value from the solder to the surrounding depends on the mounting condition. It is a simplified model of thermal resistance, as the thermal conductivity of the LED element from the junction to the soldering pad and of other components listed in Stanley product specifications is a product-specific value unaffected by mounting conditions. Therefore, as product specifications, thermal resistance is listed as the Rthj-s value, or the integrated value of material-specific thermal resistance of a product.

The temperature at the junction is called junction temperature, and the maximum temperature is listed as the specification value to ensure reliability of the LED element. Table 1 shows the thermal specifications of GSPW16□3JTE.

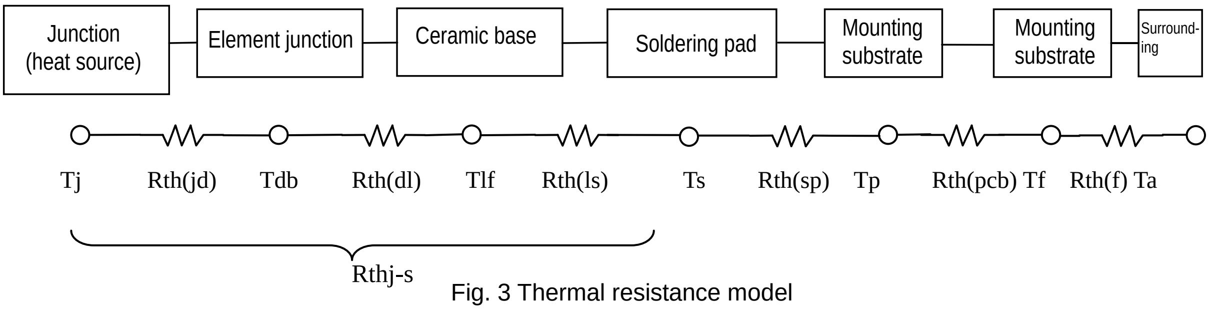


Fig. 3 Thermal resistance model

Item	Min.	Typ.	Max.	Unit
Thermal Resistance 【Junction – Solder point】	—	20	—	[°C/W]
Maximum Junction Temperature	—	—	150	[°C]

Table 1 Thermal specifications of GSPW16□3JTE

3. Estimation of Junction Temperature

The junction of an LED element is composed of an extremely thin semiconductor layer only several hundred μm thick, which makes it impossible to measure the temperature directly at the junction. Therefore, it is estimated by measuring the above-mentioned specification value of thermal resistance and the temperature (Ts) at the solder point of the product.

Formula 1 shows how junction temperature can be estimated.

$$Tj = Rth_{j-s} \times I_F \times V_F + Ts$$ Formula 1

Tj: Junction temperature
Rthj-s: Thermal resistance of the LED (from the junction to soldering pad)
IF: Forward current
VF: Forward voltage
Ts: Solder point temperature

The temperature at the solder point is determined by the mounting conditions of the product, the base material, and the existence of a radiation fin. Even when the same current is applied to the LED, Ts varies according to the difference in heat dissipation characteristics. By keeping Ts low, junction temperature can also be lowered. The maximum rating of junction temperature is 150°C, so it is important to keep within this value when designing lighting equipment. A general correlation exists between LED junction temperature and lifespan, so that the lower the junction temperature the less deterioration occurs to the light flux. Thus, keeping Ts low is also important when designing lighting equipment to provide long service life.

4. Heat Dissipation of the Mounting Substrate

As mentioned above, the thermal characteristic of a single LED is specific to each product, so maintaining good heat dissipation is largely dependent on the mounting substrate and other conditions. The mounting substrate not only needs to have a good heat dissipation characteristic, but it must also function as an electric connection and provide a current to the LED. In addition to substrates that are commonly used in electric devices, metal substrates are also effective, as they deliver good thermal conductivity. Table 2 shows the thermal conductivity of representative materials that are used as a mounting substrate. Base materials with improved thermal conductivity compared to conventional materials are daily being developed through the efforts of substrate manufacturers, but the values shown in Table 2 are typical thermal conductivity values.

FR-4, which is used for mounting an ordinary electronic circuit, has a 500 times lower thermal conductivity compared to aluminum, copper, and other metal substrates.

Material	Thermal conductivity [W/m・K]
FR-4	0.4
Aluminum	236
Copper	398

Table 2 Thermal conductivity of substrate materials

The following example shows the thermal resistance of an FR-4 and aluminum substrate using the same mounting pad recommended by Stanley (Fig. 4). It does not take into account the heat dissipation effect of the pad.

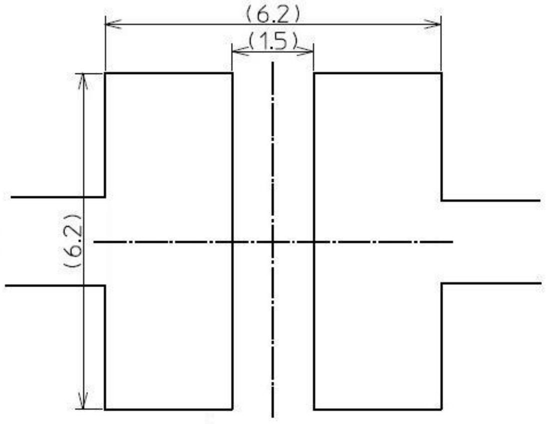


Fig. 4 Standard mounting pad

Mounting substrate specification	Thermal resistance after lighting for 1,000 seconds at IF=350mA [°C/W]
FR-4 Base material thickness: 1.6 mm Copper thickness: 35 µm	100
Aluminum Base material thickness: 1.6 mm	40

Table 3 Comparison of thermal resistance using a standard pad

Table 3 shows a comparison of thermal resistance. Thermal resistance was measured without a radiation fin attached to the substrate, after lighting the LED for 1,000 seconds (approx. 15 minutes) with a forward current of 350 mA. This means thermal resistance was measured under a thermally saturated condition. As evident by the results, the difference in thermal conductivity of the base materials is directly reflected in their thermal resistance values.

Table 4 shows a comparison of thermal resistance between an FR-4 substrate with an improved mounting pad and an FR-4 substrate with an improved conductive pattern. As shown in Figs. 5 and 6, the conductive pattern is made of upper and lower layers connected by through-hole vias. Figs. 7 and 8 respectively show the LED mounting surface and rear surface of the test-produced substrate. The copper pattern is the same size as the substrate to obtain the best possible heating dissipating effect.

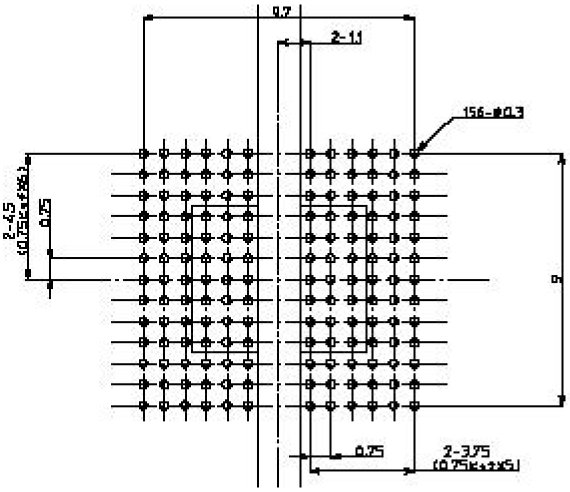


Fig. 5 Improved mounting pad and pattern

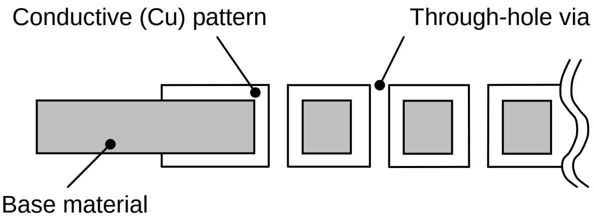


Fig. 6 Substrate cross section

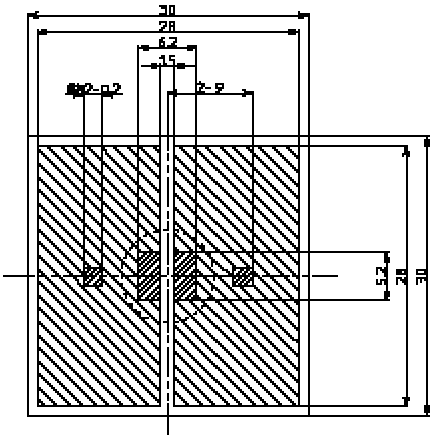


Fig. 7 LED mounting surface

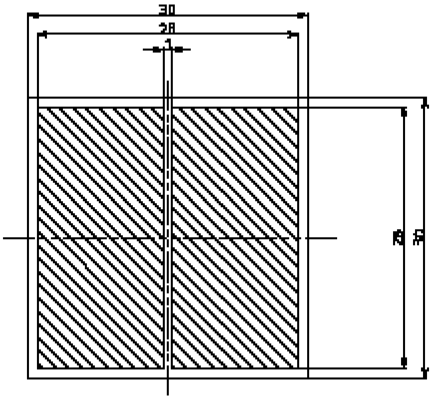


Fig. 8 Rear surface

As with the previous measurement results, Table 4 shows thermal resistance measured with no radiation fin, after lighting the LED for 1,000 seconds with a forward current of 350 mA. Compared with the results in Table 3, it is clear that FR-4 has poor thermal conductivity, but with some improvement in mounting pattern, it can deliver the same thermal resistance as a metal substrate. It also shows that a difference in the thickness of the copper pattern could create a difference in thermal resistance of around 7˚C. This should be taken into consideration when designing lighting equipment.

Substrate specification	Thermal resistance [°C/W]
Base material thickness: 1.6mm Copper foil thickness: 35 µm	57
Base material thickness: 1.6mm Copper foil thickness: 18 µm	65

Table 4 Thermal resistance of an FR-4 substrate

5. Estimation of Solder Point Temperature

Above, heat dissipation characteristics according to the material and mounting pattern of mounting substrates were shown in comparison with thermal resistance values. The measurement of thermal resistance must be based on the temperature dependence of the forward voltage in an LED element, and requires a dedicated measuring instrument with high voltage measuring precision. In order to evaluate heat dissipation without measuring thermal resistance, it is best to measure the temperature at the solder point of the LED and estimate the junction temperature using formula 1, as discussed above.

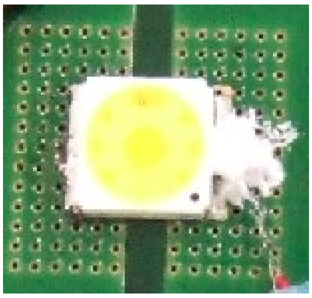


Fig. 9 Measurement of terminal temperature using a thermocouple

The temperature at the solder point is measured as follows.

Fig. 9 shows an example of temperature measurement by attaching a thermocouple to the solder point. The thermocouple must constantly be in contact with the solder point. In this example, it is secured in place with a thermal conductive silicon. When using silicon, it is best to choose a silicon material that cures to some extent after application. We recommend Sunhayato Corporation’s SCV-22.