Thermal measurement for LEDs

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One of the most critical design parameters in an LED illumination system is the system’s ability to draw heat away from the LED package.

High operating temperatures at the LED junction affect the performance of the LED adversely, resulting in color shifts and decreased light output and lifetime for the LED package. Therefore, monitoring the LED junction temperature is paramount for the overall system performance.

Unlike LED drive current and forward voltage that can be measured easily, LED junction temperature cannot be measured directly, and must be calculated. This article provides guidelines for measuring the solder point temperatures and calculating the approximate junction temperature for various LEDs from Osram Opto Semiconductors used in solid state lighting (SSL) applications.

Leadframe packages

Two LEDs used for various SSL applications with leadframe packages are the Topled Plus and the Golden Dragon product family. Fig. 1 shows the basic internal construction of the former.

Within the housing, the semiconductor chip and the ESD diode are mounted to the wider leads of the package and make contact with the other side by means of wire bonding. In addition to providing mounting and electrical connection to the circuit board, the wider leads of the package also dissipate the heat that arises during operation.

The Topled has a typical thermal resistance of 40°K/W from junction to solder point. To measure the solder point temperature, the thermocouple is attached to the wider lead of the LED package. Fig. 2 shows the thermocouple attach position.

The basic equation governing the calculation of junction temperature of the LED on measuring the solder point temperature is as follows:

\[ T_J = T_s + R_{thJS} \cdot P_D \]  (1)

where:
- \( T_J \) = Junction temperature of the LED.
- \( T_s \) = Solder point temperature of the LED.
- \( R_{thJS} \) = Thermal resistance from junction to solder point.
- \( P_D \) = Heat dissipated across the LED.

The Golden Dragon product family is based on a thermally-optimised package design consisting of the semiconductor chip directly mounted on an integrated heat sink that acts as a heat spreader in a prefabricated plastic housing with connection contacts. The LED yields a typical thermal resistance of 6.5°K/W from junction to solder point. Fig. 3 shows the LED’s internal construction and the primary path of heat transfer.

Recording the temperature directly adjacent to the housing on the long side of the package by means of a thermo element on the circuit board is recommended. Steady state temperature gradient to the heat sink is negligible in this case.

Ceramic package

The Oslon SSL is a compact power LED in a ceramic housing used for various SSL applications. The internal construction
Engineering consists of a semiconductor chip mounted on a ceramic carrier and over-molded silicone lens. The thermal pad is electrically isolated from anode and cathode pads. It has a typical thermal resistance of 7°C/W from junction to solder point and a maximum thermal resistance of 9.4°C/W. Fig. 5 shows the package and the pad layout.

The ceramic package with the three pads provides an effective channel for the heat transfer for the die. The thermocouple should be attached as close as possible to the package to measure the solder point temperature. When mounted on a printed circuit board, the pads are not easily accessible for attaching a thermocouple. One way to get around this problem is to extend the copper area for the thermal pad and to place the thermocouple on this copper area.

Fig. 6 shows recommended copper area for solder pad layout. The extended copper area...
Thermal resistance substrate technologies

The Oslon SSL can be mounted on two-layer FR4, multi-layer FR4 or metal core printed circuit board (MCPCB). To ensure optimal operation, the thermal resistance path between the LED and the ambient should be as low as feasible. An FR4 board, although cost-effective, has very low thermal conductivity compared to an MCPCB.

When using a thermocouple to measure the solder point temperature, the thermocouple is fixed directly along the ceramic housing of the package on the thermal pad. However, to get a useable result, the gap between the solder pad temperature and the reading point has to be considered for the calculation of the junction temperature. This operation-related correlation factor is defined as the thermal resistance between the thermocouple attach and the solder point. With this factor taken into consideration, the equation for calculating junction temperature of the LED is:

\[ T_j = (R_{thJS} + R_{thS-TC}) \cdot PD + T_{TC} \]  

(2)

where

- \( T_j \) = Junction temperature of the LED.
- \( R_{thJS} \) = Thermal resistance from junction to solder point.
- \( R_{thS-TC} \) = Thermal resistance from thermocouple attach to solder point.
- \( PD \) = Heat dissipated across the LED.
- \( T_{TC} \) = Temperature at thermocouple attach.

The method of numerical analysis is used to show the thermal performance on MCPCB and FR4 MCPCB (laminated). The goal of the analysis is comparison under the same environmental conditions.

The geometry and material data, as well as the standard boundary conditions, are listed in Table 1.

Thermal analysis

For MCPCB, the dielectric used has a thermal conductivity of 1.3 W/m-K and a thickness of 75 μm. The maximum thermal resistance of 9.6°K/W (\( R_{thS-TC} \)) for the Oslon LED is considered for the analysis. Fig. 8 shows the setup of the LED on an MCPCB on a heat sink while Fig. 9 shows the thermocouple attach point on the extended thermal pad. Fig. 10 shows the temperatures at various points (junction, solder point and thermocouple attach points) for this analysis.

Substituting the values in Eqn. (2) for an FR4 dielectric \( R_{thS-TC} \sim 10°K/W \). These results indicate that the additional thermal resistance from solder point to thermocouple attach point must be considered to calculate the accurate junction temperature of the LED based on the substrate technology employed.

A similar analysis with the same boundary conditions was performed with an FR4 dielectric (see Fig. 11).

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