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Package-related thermal resistance of LEDs

Application Note

Valid for:
LEDs from OSRAM Opto Semiconductors

Abstract

This application note provides information on the definition and specification of the thermal resistance R_{th} for LEDs and IREDs (IR emitting diodes). In addition, information can be found on how the thermal resistance is measured at OSRAM Opto Semiconductors and on the different R_{th} values specified in the data sheets.

Further information:
Please also refer to the application notes "Thermal management of light sources based on SMD LEDs" and "The thermal measurement point of LEDs" for further information.

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A. Introduction

In order to achieve the expected reliability, lifetime and optimal performance of LEDs, especially for high-power LEDs, appropriate thermal management is of the utmost importance. One of the key parameters for good thermal management is the temperature of the active semiconductor layer designated as the junction temperature. The manufacturer's recommended maximum junction temperature should therefore not be exceeded during operation, in order to prevent damage to the component. Ideally, the junction temperature should be kept as low as possible for the given application.

Due to the design principle of the LEDs, the junction temperature of the LED can not be measured directly.

B. Thermal resistance R_{th}

The thermal resistance R_{th} is defined as the ratio of the temperature increase ΔT to the heat dissipation Q and is ultimately a measure of the capability of the system to transport heat.

$$R_{th} = \frac{\Delta T}{\dot{Q}}$$

For LEDs the temperature increase is caused by the portion of the electrical power that is not transformed into light, i.e. the dissipated heat. The temperature difference ΔT is defined as the difference between the inner temperature of the semiconductor chip, the junction temperature T_J of the LED, and an external reference temperature. The latter is the solder point temperature T_S respectively the board temperature T_B, depending on the LED design. Q represents the heat transfer rate.

$$R_{th\ \mathrm{JS\ real}} = \frac{\Delta T}{\dot{Q}} = \frac{T_J - T_S}{\frac{dQ}{dt}} = \frac{T_J - T_S}{P_{el} - \Phi_e}$$

Knowledge of the thermal resistance R_{th} of an LED is important to:

- Determine the junction temperature that arises in the LED under operating conditions.
- Determine the maximum allowable external reference temperature for a given internal temperature and power dissipation.
- Evaluate measures for the dissipation of heat (= thermal performance).

Detailed information on the thermal management of LEDs can be found in the application note “Thermal management of light sources based on SMT LEDs”.

C. Thermal measurement point

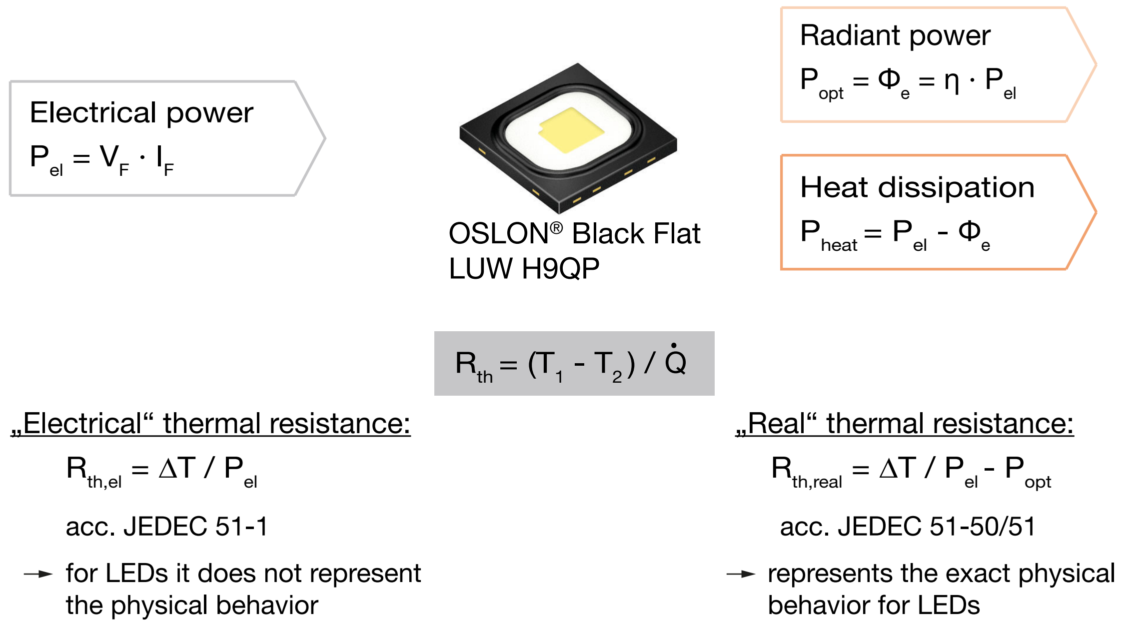
As previously mentioned, the external reference point temperature is defined as the solder point temperature respectively the board temperature, depending on the package type. For most OSRAM Opto Semiconductors SMT LEDs (e.g. lead-frame based, ceramic package) the reference point temperature is defined as the “solder point” T_S. For LEDs with a metal core substrate such as the OSRAM OSTAR® Headlamp Pro or for LEDs specially designed for gluing such as the OSLON® Submount, the reference point refers to the “board” temperature T_B.

Detailed information on how to determine the measurement point of LEDs including various examples can be found in the application note “The thermal measurement point of LEDs”. Information on how to measure the temperature with thermocouples are given in the application note “Temperature measurement with thermocouples”.

D. Determination of the thermal resistance $R_{th,JS}$

Due to historical reasons, there are two different definitions of the thermal resistance used for LEDs. Firstly, the electrical thermal resistance $R_{th\ el}$ was defined for traditional (non-opto) semiconductor components (MOSFET, transistors, logic devices). Here, the electrical power consumed in total is used for the calculation of the $R_{th\ el}$. The energy leaving the package in the form of light/radiation is not taken into consideration (see JEDEC 51-1 and Figure 1)[5],[6]. Until 2012 only the electrical R_{th} was defined by standards. As the efficiency of the LEDs increased (typ. $\eta \sim 25 - 50$ %) and thus more of the electrical power was converted into optical power, a specific thermal resistance was introduced for LEDs. This thermal resistance is called the real thermal resistance $R_{th\ real}$ and considers the decoupled optical power of the LED. Here, the actual flow of heat that is dissipated through the package is taken into account (see JEDEC 51-50/51)[1,2].

Figure 1: Electrical versus real thermal resistance

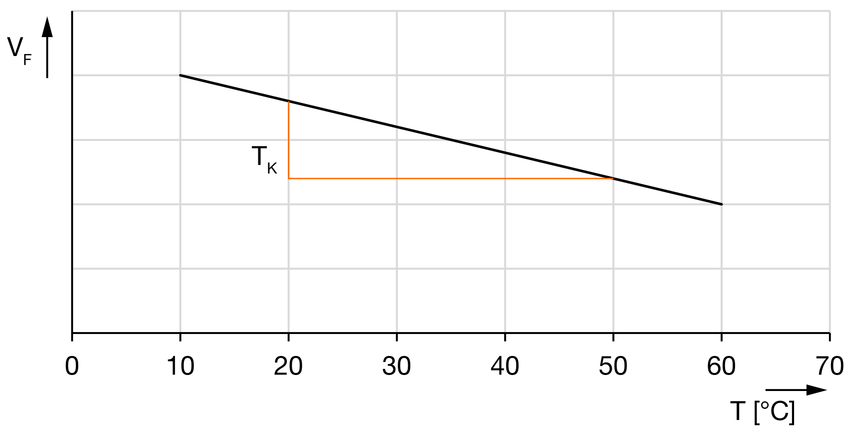


R_{th} measurement

To determine the thermal resistance, OSRAM Opto Semiconductors uses a thermal transient measurement methods which is referred to as the static thermal resistance test method according to JEDEC 51-51 [2] and 51-14 [6]. Since the thermal resistance of LEDs cannot be measured directly, the R_{th} is indirectly determined by the measurement of a temperature sensitive parameter (TSP), which depends on the junction temperature. The forward voltage $V_F(t)$ is chosen at the TSP at a (small) constant sensing current.

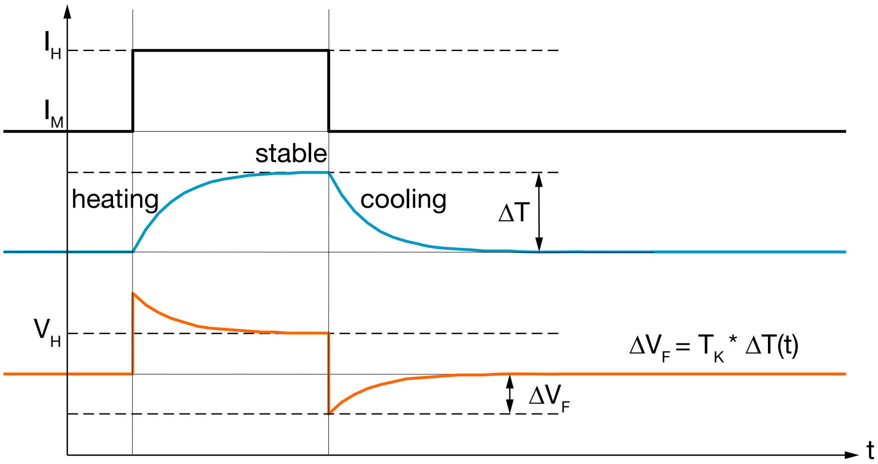
To determine the junction temperature, the temperature coefficient T_K of the respective device must first be measured. Therefore, the forward voltage V_F of the device is measured as a function of temperature for a small measurement current I_M. For small temperature changes the correlation between V_F and temperature is linear as an example in Figure 2. The slope of the straight line measured is the temperature coefficient T_k.

Figure 2: T_K calibration



Having determined T_K the sample is heated up with a current I_H to reach the temperature equilibrium, see Figure 3. Once the temperature equilibrium has been reached the current is switched off and the forward voltage change is recorded at the measurement current I_M. Together with the measured T_K the temperature changeover time can be evaluated.

Figure 3: Measurement procedure



The time-dependent thermal impedance Z_{th} (see equation below) can be derived from the measurement (see Figure 4). The Z_{th} curves show the total thermal behavior of the system from the heat source to the heat sinks. In order to determine the thermal resistance $R_{th,JS}$ from the junction to the solder point of the device, the device under test (DUT) has to be measured twice (similar to JEDEC 51-14).

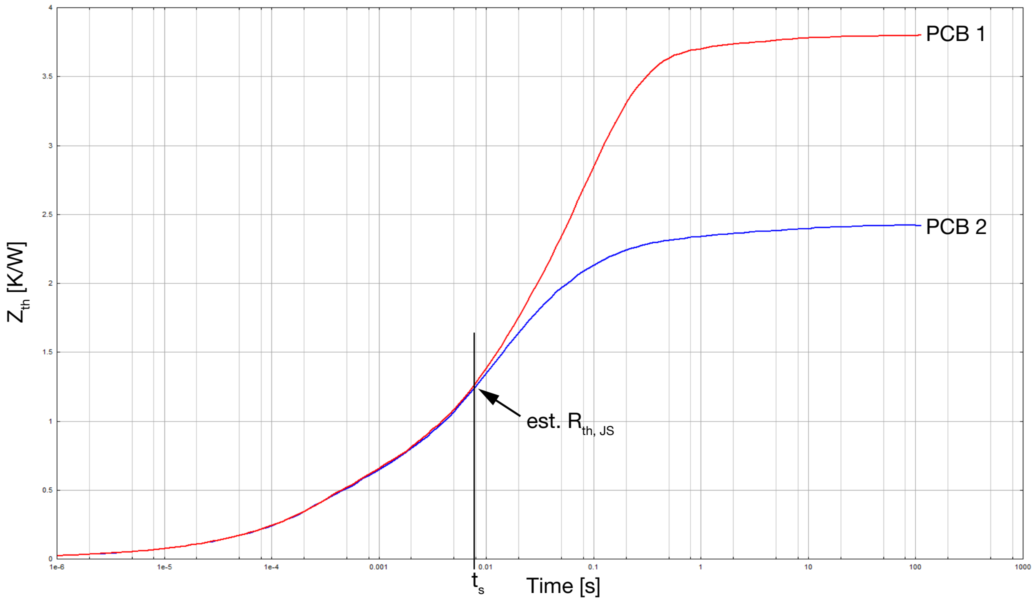
For SMD LEDs the DUT is measured on two different PCB materials. The transient thermal behavior of the device in this two-measurement setup is identical as long as the heat path is identical, and therefore as long as the heat propagates from the junction through the device. Upon arrival at the solder point the curves start to separate depending on the PCB material used. This change in condition indicates the end of the device. Therefore, the $R_{th,JS}$ value can be determined as the value $Z_{th}(t = t_s)$ at the point of time “t_s” when the two curves start to separate.

$$R_{th} \approx \frac{\Delta T}{P} = \frac{(\Delta V)/T_K}{P}$$

$$Z_{th}(t) \approx \frac{\Delta T(t)}{P} = \frac{(\Delta V(t))/T_K}{P}$$

$$R_{th} = Z_{th}(t_s)$$

Figure 4: Estimation of $R_{th\ JS,\ el}$



The accurate and reproducible measurement of the junction to the solder point, the thermal resistance $R_{th,JS}$ is far from trivial. For example, due to time resolution issues the first tens of microseconds after switching of the current, the change in V_F can not be measured and thus would lead to inaccuracy in the R_{th} determined. To overcome this inaccuracy, the measurement is corrected using a square root like fit, which is the so called “offset correction” [7].

Thermal resistance $R_{th,JS}$ in the data sheets

For OSRAM Opto Semiconductor LEDs the data sheets contain some or all of the following R_{th} values — determined by a statistical approach in order to be representative for all samples produced — depending on the device:

- the typical real thermal resistance (typ. $R_{th,JS\ real}$)
- the maximum real thermal resistance (max. $R_{th,JS\ real}$ = typ. $R_{th,JS\ real} + 6\ \sigma$)
- the typical electrical thermal resistance (typ. $R_{th,JS\ el}$) together with the typical optical efficiency (η_e) of the LED
- the maximum thermal resistance (max. $R_{th,JS\ el}$ = typ. $R_{th,JS\ el} + 6\ \sigma$) together with the typical optical efficiency (η_e) of the LED

These values are determined by means of measurements of a representative set of samples and entered into the data sheets as shown in Figure 5.

Figure 5: Thermal resistance in the data sheet

Characteristics

I_F = 700 mA; T_S = 25 °C

Parameter	Symbol		Values
Chromaticity Coordinate [3]	Cx Cy	typ. typ.	0.33 0.34
Viewing angle at 50 % I_V	2φ	typ.	120 °
Forward Voltage [4] I_F = 700 mA	V_F	min. typ. max.	2.75 V 3.13 V 3.50 V
Reverse voltage (ESD device)	$V_{R\ ESD}$	min.	45 V
Reverse voltage [2] I_R = 20 mA	V_R	max.	1.2 V
Real thermal resistance junction/solderpoint [5]	$R_{thJS\ real}$	typ. max.	5.7 K / W 7.3 K / W
Electrical thermal resistance junction/solderpoint [5] with efficiency η_e = 28 %	$R_{thJS\ elec.}$	typ. max.	4.1 K / W 5.3 K / W

Sample calculation

The junction temperature T_J can be calculated from the values derived $R_{th,JS}$ according to the equations shown above.

The previously mentioned OSLON® Compact CL, LUW CEUP.CE was selected as an example. The respective values for the calculation can be found in the data sheet.

I_F = 0.7 A, typ. V_F = 3.15 V, η_e = 28 %, $R_{th,JS\ el}$ = 4.1 K/W, $R_{th,JS\ real}$ = 5.7 K/W

T_S must be derived from a temperature measurement at the solder point (see application note "Temperature measurement with thermocouples". For the example calculations it is set to T_S = 25 °C.

Calculation of T_J from $R_{th,JS\ el}$ at 25 °C:

$$R_{th\ el} = \frac{T_J - T_S}{P_{el}}$$

$$T_J = T_S + (R_{th\ el} \cdot P_{el})$$

with $P_{el} = I_F * V_F$

$$T_J = 25\ °C + (4.1\ K/W \cdot 0.7\ A \cdot 3.15\ V)$$

$$T_J = 34.04\ °C$$

Calculation of T_J form $R_{th,JS\ real}$ at 25 °C:

$$R_{th\ real} = \frac{T_J - T_S}{P_{el} - P_{opt}}$$

$$R_{th\ real} = \frac{T_J - T_S}{P_{el} \cdot (1 - \eta_e)}$$

$$T_J = T_S + (R_{th\ real} \cdot P_{el} \cdot (1 - \eta_e))$$

$$T_J = 25\ °C + (5.7\ K/W \cdot 0.7\ A \cdot 3.15\ V \cdot (1 - 0.28))$$

$$T_J = 34.05\ °C$$

In conclusion, the junction temperature can be calculated correctly from both the electrical and the real thermal resistance, assuming that the parameters are chosen accordingly.

However, in the application the light extraction can change depending on the temperature and current. To take this variation into account the real thermal resistance must be used.

E. References

[1] JESD51-50, “Overview of Methodologies for the Thermal Measurement of Single- and Multi-Chip, Single- and Multi-PN-Junction Light-Emitting Diodes (LEDs)”, JEDEC Standard, April 2012.

[2] JESD51-51, “Implementation of the Electrical Test Method for the Measurement of Real Thermal Resistance and Impedance of Light-Emitting Diodes with Exposed Cooling”, JEDEC Standard, April 2012.

[3] JESD51-52, “Guidelines for Combining CIE 127-2007 Total Flux Measurement of LEDs with Exposed Cooling Surface”, JEDEC Standard, April 2012.

[4] JESD51-53, “Terms, Definitions and Units Glossary for LED Thermal Testing”, JEDEC Standard, May 2012.

[5] JESD51-1, “Integrated Circuit Thermal Measurement Method — Electrical Test Method”, JEDEC Standard, December 1995.

[6] JESD51-14, “Transient Dual Interface Test Method for the Measurement of the Thermal Resistance Junction to Case of Semiconductor Devices with Heat Flow Through a Single Path”, JEDEC Standard, November 2010.

[7] F. Daiminger, M. Gruber, C. Dendorfer, T. Zahner, Experimental investigation on the offset correction of transient cooling curves of light emitting diodes based on JESD51-14 and simple semi-empirical approximations, Microelectronics Journal, 46, 2015, 1208-1215.

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