

HOT TOPIC FOR LEDs: STANDARDIZATION ISSUES OF THERMAL CHARACTERIZATION

András Poppe^{1,3} and Clemens J.M. Lasance²

¹*Mentor Graphics MicReD Division, Budapest, Hungary*

²*Philips Research Laboratories, High Tech Campus 4, 5656 AE,
Eindhoven, The Netherlands*

³*Budapest University of Technology (BME), Department of Electron Devices,
Budapest, Hungary*

1. Introduction

Nowadays the demand for thermal standards for power LEDs is increasing. On the one hand metrics for fair, comparison of competing products are needed; on the other hand, designers of power LED-based applications demand reliable and meaningful data for their daily work. Today's data sheet information does hardly meet any of these requirements. In earlier papers [1], [2] we compared the current situation in the LED world with the situation in the IC world over twenty years ago, observed that much can be learned from the progress achieved, and concluded with a proposal for action. This paper will address thermal issues that are specific to light emitting diodes, the drawbacks of the current situation with respect to the information in the data sheets, and emphasizes the need for electro-thermal-optical models.

1.1. Junction temperature of LEDs

Unlike two decades ago in the IC world, the junction temperature (T_J) of an LED is not just a performance indicator of the thermal design but also plays a major role in lighting design since many properties of the light output of an LED depend on the absolute junction temperature. This means that thermal management should be an integral part of the system design of an LED based lighting solution, resulting in changing roles of different engineering disciplines in the overall design process. Consequently, since T_J of LEDs is more widely used in the design process of LED-based lighting solutions, well-established definitions of standardized thermal metrics and models will be even more important than before, both for the LED manufacturers and the lighting system designers. Besides data sheets, another bridge between vendors and end-users of LEDs could be a well established, general multi-domain (electrical, thermal, optical) compact model of LEDs. A system designer wants to check if a junction temperature or a solder temperature stays within prescribed limits, or, alternatively, needs a temperature value for lifetime prediction. The equation that is most used is the following: $T_J = R_{th} J-ref \cdot PH + T_{ref}$ (1) where in daily practice R_{th} is a number that is supplied by the manufacturer, the power PH is provided by the electronic engineer, and T_{ref} is an often ambiguously specified reference temperature.

1.2. A few words about thermal resistance

The way how the EIA/JEDEC JESD51.1 standard [3] defines the thermal resistance is a re-arrangement of eq. (1): $R_{th} J-Ref = (T_J - T_{Ref})/PH$ (2) where T_{Ref} denotes the temperature of the reference point and PH denotes the power dissipated in the device. Note, that this definition of R_{th} is not as rigorous as discussed in [1] and [2]. Eq. (2) suggests building a spatial temperature difference in thermal equilibrium: heat up the junction and measure both the junction temperature and the temperature at a given

reference point. If the reference temperature is the ambient temperature (that we can control if measurements are performed e.g. on a cold plate), then in the un-heated device, in its initial thermal steady-state $T_{J0} = T_{Ref}$, i.e. the initial junction temperature and the reference point temperature are equal. After heating up the device and reaching the final thermal equilibrium of the hot junction, we shall reach the final T_J junction temperature, that is, after a transition from a cold steady state to a hot steady state (or vice versa). This procedure (also known as the static test method specified in [3]) suggests another reformulation of eq. (1). Suppose, in the initial steady-state a known $PH1$ heating power is applied, while in the final steady state another known heating power $PH2$ is applied. For both cases we can express the junction temperature based on the pattern of eq. (1): $T_{J1} = R_{th J-Ref} PH1 + T_{Ref}$ (3a) $T_{J2} = R_{th J-Ref} PH2 + T_{Ref}$ (3b) Subtracting (3a) from (3b) we obtain $T_{J2} - T_{J1} = R_{th J-Ref} (PH2 - PH1)$. (4) In eq. (4) we can also indicate that T_{J1} and T_{J2} junction temperatures occurred at different time instances: $T_{J1} = T_J(t1)$ and $T_{J2} = T_J(t2)$. Substituting these and rearranging (4) yields $R_{th J-Ref} = [T_J(t2) - T_J(t1)] / (PH2 - PH1)$ (5) or $R_{th J-Ref} = \Delta T_J(t) / \Delta PH$ (6) where $\Delta T_J(t) = T_J(t2) - T_J(t1) = T_{J2} - T_{J1}$ and $\Delta PH = PH2 - PH1$. In other words, instead of using a spatial temperature difference along the junction-to-reference heat-flow path, eq. (6) suggests that the 'thermal resistance' as a metric can be calculated from the difference of the initial and the final steady state value of the junction temperature, provided the change of the heating power at the junction is also known and the reference temperature is kept constant. A major advantage of the differential approach represented by eq. (6) is that inaccuracies in junction temperature measurement cancel out. The junction temperature and the junction-to-ref thermal resistance serve different purposes for both system designers and device manufacturers. The goal of component designers (manufacturers) is to achieve better thermal performance of the device and to establish figure-of-merit values for comparison with other vendors' products. Typically junction-to-ref thermal resistance values are used for such purposes. The junction-to-ref thermal resistance values are usually the only input data for (lighting) system designers who want to study what-if scenarios and want to obtain sufficiently accurate prediction of T_J through which other important properties of LEDs can be also predicted. Since LEDs are rather complex in their operation (as suggested by Figure 1), standardized multi-domain (thermal, electrical and optical) models would be required to predict operation of any vendors' LEDs. Outlines of such a model will be given in the final paper.

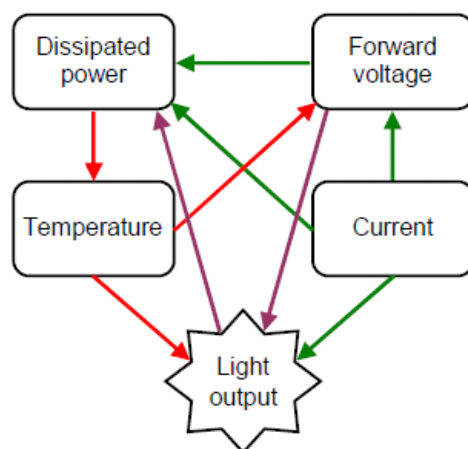


Figure 1: Light output depends on 'everything'

2. Examples of problems with current datasheets

The topic is discussed in detail in [4]. Here we give a shorter outline only. Although most LED vendors perform thermal testing according to the EIA/JEDEC JESD51-1 standard, they consider the PH power of eq. (2) in a sloppy way. For silicon diodes there is no doubt that $P_H = I_F \cdot V_F$ (the electrical power supplied to the diode) while in case of LEDs emitted light energy must be considered. In case of high power LEDs the current component associated with radiative recombination (giving rise to light output) represents a significant percentage of the total forward current I_F , consequently, the $I_F \cdot V_F$ product does not represent the heat dissipated in the device (at the junction): the portion of power associated with radiative recombination must be subtracted from the $I_F \cdot V_F$ product when calculating the heat dissipation of an LED. To highlight this, let us compare two simple cases to address the consequences, and let us define $R_{th\ el}$ as the thermal resistance based on the total supplied electrical power $P_{el} = I_F \cdot V_F$ only, and quantity $R_{th\ real}$ as the real thermal resistance of the LED package based on the real dissipation which is $P_H = P_{el} - P_{opt} = P_{el} \cdot (1 - WPE)$ where WPE stands for wall-plug efficiency and it is calculated as the ratio of the supplied electrical power and the emitted optical power of the LED: $WPE = P_{opt}/P_{el}$. The P_{opt} emitted optical power can be measured at well defined I_F forward current and T_{ref} reference temperature values as the total radiometric flux $J_e(I_F, T_{ref})$ of the LED, using the procedures recommended in the CIE 127 2007 document [5].

Case 1:

Efficiency $WPE=25\%$, supplied electrical power $P_{el}=10W$, junction temperature rise $\Delta T_J=50^\circ C$ Then we have for $R_{th\ el} = \Delta T_J / P_{el} = 50/10 = 5.00\ K/W$ for $R_{th\ real} = \Delta T_J / (P_{el} - P_{opt}) = \Delta T_J / [P_{el} \cdot (1 - WPE)] = 50/(10 \cdot 0.75) = 6.67\ K/W$

Case 2:

Efficiency $WPE=50\%$, supplied electrical power $P_{el}=10W$, junction temperature rise $\Delta T_J=50^\circ C$ Then we have for $R_{th\ el} = \Delta T_J / P_{el} = 50/10 = 5.00\ K/W$ for $R_{th\ real} = \Delta T_J / (P_{el} - P_{opt}) = \Delta T_J / [P_{el} \cdot (1 - WPE)] = 50/(10 \cdot 0.5) = 10\ K/W$ As widely known, the overall efficiency (denoted as WPE before) depends on temperature and current. This is the reason why any metric of an LED reported in a data sheet should also be reported together with the current and temperature at which the given metric was identified. Furthermore, to allow system level designers using data sheet values, it is not sufficient to present efficacy information only, but energy conversion efficiency should also be provided by LED vendors.

3. Some questions about LED thermal standardization

Apart from the problems with the current data sheets, many other thermal characterization issues also pose challenges. The topics listed below deserve a position on the standardization agenda:

- For all parties involved: what is needed in terms of standards and guidelines? It seems that at the device level the basic definitions of the most relevant measurement standards (EIA/JEDEC JESD51-1 [3], CIE 127-2007 [5]) are applicable to high power LEDs, with additional guidelines. For example, the wording of JESD51-1 about "power dissipated in the device" might be completed by guidelines providing a correct interpretation for LEDs. Guidelines regarding test conditions specific to LEDs might also be needed (e.g. definition of meaningful test environments).
- What do the manufacturers want as a fair and reliable thermal metric to compare products? During the panel discussion at the 14th THERMINIC Workshop in September



2008 in Rome there was an agreement among participants that the quantity denoted as R_{th} real in section 2 was acceptable.

- What do trained end-users want, and can this be realized by the manufacturers? The above panel discussion concluded the following:
- A component datasheet should contain sufficient and reliable data to be able to predict performance and reliability of the system.
- Datasheet values should have relevance for any application (such as compact thermal models for electronic devices).
- Not only thermal performance but also the thermal link to optical performance and reliability should be described, e.g. besides efficacy, efficiency should also be reported.

Further questions to be addressed in more detail:

- What are the pros and cons of steady-state vs. transient thermal measurements of LEDs?
- How to combine recommendations of JEDEC JESD51-1 and CIE 127-2007 in order to measure LEDs' 'thermal' power?
- How to measure the case temperature?
- How to deal with non-uniform and non-unique die temperatures? How to tackle multiple heat-sources?
- What about pulsed-type thermal measurements?
- How to relate the short-pulse LED test results to properties that can be measured under steady-state operating conditions?

4. Steps taken so far

Steps taken so far include forming a task group in JEDEC JC15.1 committee to deal with the topic. CIE has also formed two new technical committees dealing with thermal issues related to LED testing. By the time of presenting this paper we can inform the lighting community about the outcome of the March 2009 meeting of the JEDEC JC15.1 committee where thermal measurement standards regarding power LEDs will be dealt with in detail.

References

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