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TRANSIENT THERMAL ANALYSIS OF POWER LEDs AT PACKAGE & BOARD LEVEL

J. H. Yu¹, Gábor Farkas², Quint van Voorst Vader¹

¹Philips Lumileds Lighting B.V., Netherlands
e-mail: joan.yu@lumileds.com

²MicReD Ltd., Budapest XI, Etele ut 59-61, H-1119 Hungary,
e-mail: farkas@micred.com

ABSTRACT

Thermal transient analysis is a powerful tool for thermal characterisation of complex structures like LEDs [1][2]. It is especially suitable for R&D work and failure analysis. For online quality control measurements in manufacturing, the technique is less suitable because the measurements are too time consuming (several seconds). This paper shows that early transient analysis (10 to 50 ms) is a suitable tool for quality control of die attach. However, for analysis of board mounting, a full transient capture is needed.

This imposes the use of special techniques for power LED devices where accurate knowledge of coupled thermal and optical features is required to do thermal characterisations. The optical power is measured with a short time luminous flux measurement. It is shown that these correlate well with steady state measurements. Thus, the short and long optical measurements are complementary in the thermal transient analysis of similar length.

1. INTRODUCTION

At the characterisation of light sources in the last 100 years experience has shown that electrical, thermal and optical effects are influencing each other. At incandescent lamps electric current induced heating is the fundamental effect producing light energy. Ironically, these lamps are the least sensitive on ambient temperature, as their operating temperature is much above it. Fluorescent light sources show much stronger temperature dependence. At solid-state light emitting devices (LED) we experience that their light output, efficiency, spectral distribution all depend on the operating temperature (Fig. 1, Fig. 2) [3].

Besides the steady state values also the transient behaviour of high power LEDs is of major interest, as already published in a series of previous papers [1][2]. There, some measurement problems are reviewed and it is shown that the structure function approach ([5],[7]) is a

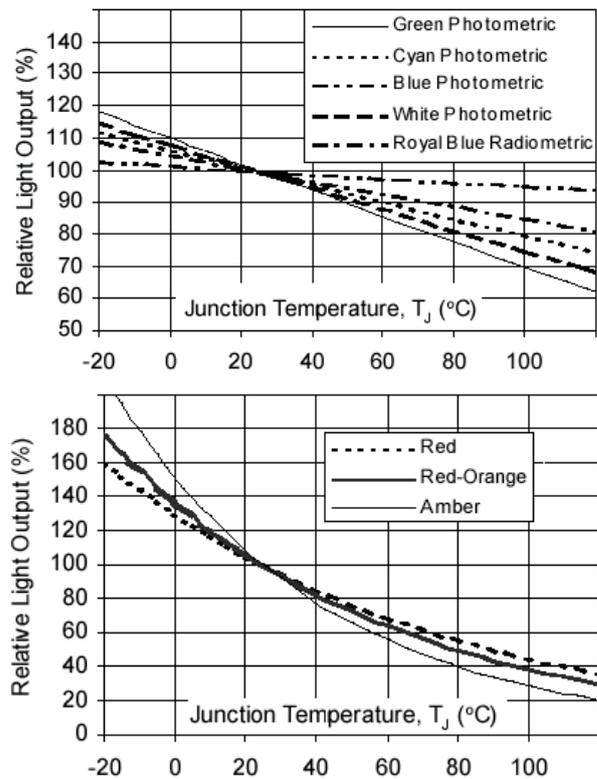


Fig. 1 Variation of relative light output of power LEDs on junction temperatures

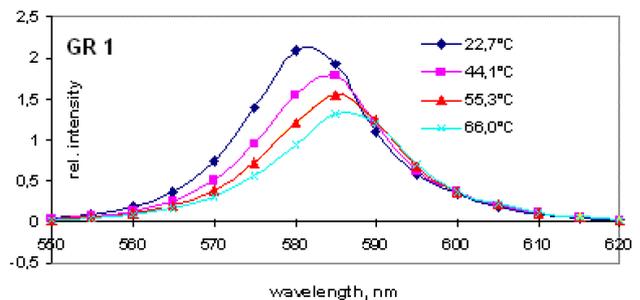


Fig. 2 Variation of the relative spectral distribution of a green LED

very powerful method for characterising the heat conduction path and calculating junction-to-case thermal resistances.

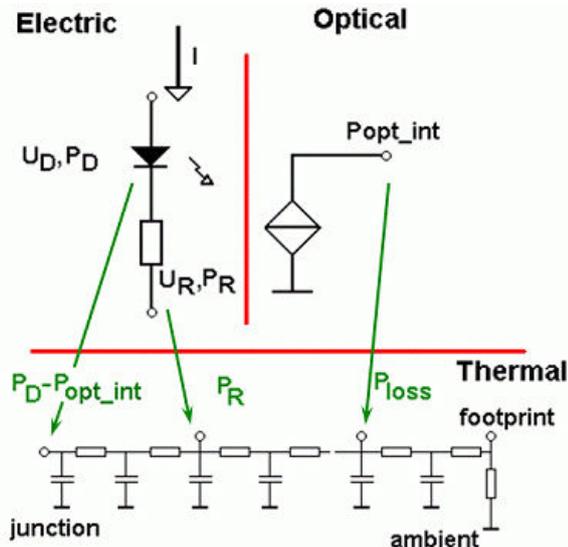


Fig. 3 Electric, optical and thermal domains of operation in a power LED

As Fig. 3 suggests, *electric changes* are influencing mostly the optical and thermal domains by changing the current levels, directly affecting the light output and quantum efficiency. After a time also the temperature changes due to the power variation. The time constants of these effects differ drastically: we can expect primary electric and light transients in the nanoseconds magnitude. Thermal changes – depending on packaging and attachment on boards or heat sinks – may last for minutes. In this longer time range we can measure thermally induced secondary voltage and light changes on the device.

2. SCOPE OF LED MEASUREMENTS

Purpose *Transient measurements* are carried out and subsequently evaluated for *serving multiple purposes*, such as:

- Characterising power LEDs’ thermal behaviour at package and board level
- Helping production engineers perform quality checks on packaging and die-attachment
- Giving feedback to designers of packages on the actual performance of constructions
- Helping the design engineers to evaluate thermal property of the (MC)PCB
- Yielding essential data to application engineers in format of data sheets or compact model libraries

As we can see some measurement tasks serve research and development (R&D), or can help to perform

structural failure analysis (FA) and production monitoring as part of the quality assurance (QA) program.

Time range At R&D and FA the time spent for each measurement doing transient analysis is not important. At these measurements we can completely capture the transients up to steady state level. This practice can also be followed at QA if we restrict investigations on a few selected samples.

When aiming a broader characterisation done on all manufactured samples the time per measurement is much more limited, i.e. we have to carry out short transients and search for correlations between short time and complete transient behaviours.

Manufacturing level Thermal characterisation can be done at different stages of manufacturing. In this paper we shall concentrate on measurements at single device level (Fig. 4) and board level (Fig. 5).



Fig. 4 Packaged high power LED devices

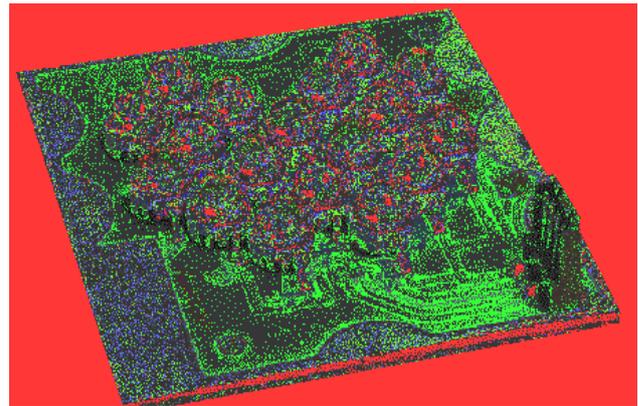


Fig. 5 Printed board populated with power LEDs

For characterisation at device level we have to capture and evaluate the temperature change of a single LED at highly repeatable boundary condition, i.e. we analyse a *thermal self-impedance*. At board level we are interested in a general response of the board when powering all LEDs by the same current, but also in *transfer effects*, i.e. in thermal transients of other devices than the one(s) powered.

3. MEASUREMENT RESULTS

Long term transient measurements were carried out for Luxeon high power InGaN green LEDs using MicReD’s T3Ster. Optical characterisation was done in the TERALED (MicReD optical sphere measurement system), which realises a long term steady state characterisa-

tion, and a Lumileds optical measurement system containing a CAS 140B from Instrument Systems. This optical measurement system (called CASFLUX) is according to the CIE standard [7] and measures the light output of the LED at short term pulse conditions (typically 20 ms).

3.1 Package level analysis

A typical power LED structure (InGaN Luxeon Emitter) is shown in Fig. 6. A Si submount is attached to a copper slug. The bottom of the copper slug has a shape of a cutting edged circle with an area of 26 mm².

We measured several samples at highly repeatable boundary conditions, such as

- Device directly pushed to the cold plate, with thermal grease applied
- Using a ceramic sheet between the device and the cold plate

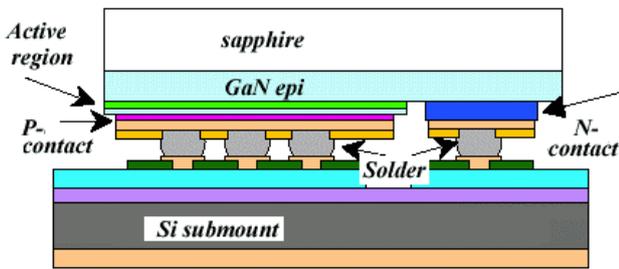


Fig. 6 Luxeon Emitter InGaN LED

These two boundaries helped to identify several structural elements in the structure functions derived later from the transients. Besides structure identification this experiment also helps to estimate the required transient time for board level measurements (next subsection) to forecast at which time variations in the glue quality can appear.

Three transient measurements (on samples G12, G13 and G14) are presented in Fig. 7.

We can convert the transients to structure functions (Fig. 8) [4] [7]. From former experience we suppose that we can hardly see the *chip area*, most likely because of the reverse mounted structure. The few dots until 1 K/W at low thermal capacitance represent most likely the small cross-sectional area of the *die interconnections*, bumps fixing the die to the silicon submount. At 1 K/W we see the steep increase in thermal capacitance, which can be identified as the *silicon submount*, of low thermal resistance thanks to high thermal conductivity. Then we see the die attach region and the copper slug. As shown in [6] at the highest curvature position after the slug we can read the junction-to-case thermal resistance (R_{thji} , see numeric data in Table I).

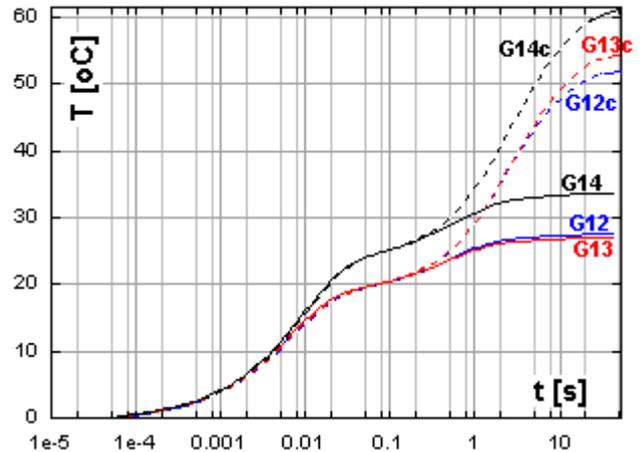


Fig. 7 Transient temperature measurements on three green LEDs. Solid lines: on cold plate. Dotted lines: ceramics inserted

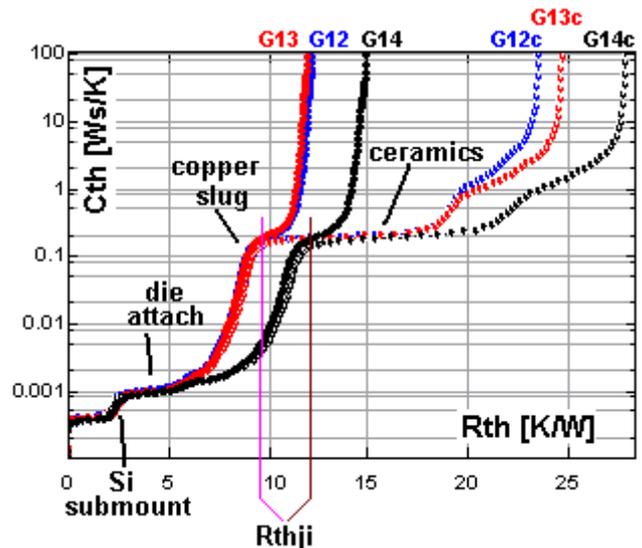


Fig. 8 Cumulative structure functions of the three green LEDs

Fast analysis can be based on the transient curves of Fig. 7. We see that the differences in heating develop in 10 ms if they are caused by the die attach. The figure also hints that if we glue these LEDs to the MCPCB, the glue differences can be seen at times larger than approx. 0.5 s as the ceramics is exactly put where otherwise the copper slug – glue interface appears.

As failures in the solid copper slug are unlikely, it suggests that at mass thermal measurements capturing the 10 μ s - 50 ms range at high resolution gives some general measure on the die attach quality of single devices. At boards we need several seconds for a similar screening. However, we have to capture full-length transients for detailed structure analysis.

3.2. Board level analysis

Fig. 9 shows the Luxeon emitter package glued on metal core PCB (MCPCB) with the layer structure of 35 μm copper, 127 μm dielectric layer (1.3W/mK) and 1.5 mm aluminium. It is known that the copper patterns (coverage area, trace direction, location etc.), heat source dimensions and location on the board influence on the board thermal behaviour due to lateral heat transfers. We simulated a 38mm x 15mm MCPCB with an LED powering area of 1 mm² die using ANSYS. It is assumed that the MCPCB has an isothermal boundary at the bottom due to heat sinking, isoflux applied on the copper slug top area (7 mm²). Convective and radiation boundary conditions on the top and side walls of the board can be neglected.

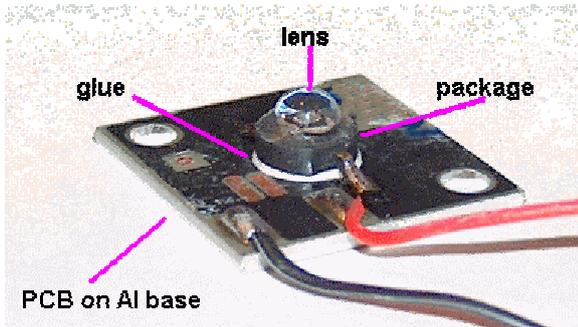


Fig. 9 Luxeon emitter glued on MCPCB

Changing the size of the copper area under the LED heat source we show the calculated results of the variations of the board thermal resistance in Fig. 10. The relative area factor of the copper area over the source area is plotted in axis x. It is shown that the thermal resistance stabilises at 2.3 K/W for ratios larger than 10.

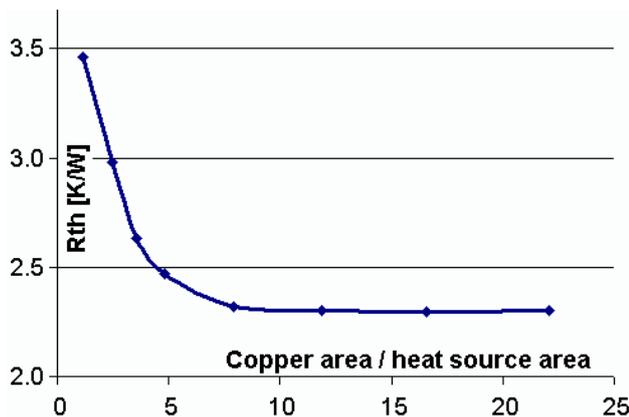


Fig. 10 Thermal resistance vs. copper area on MCPCB

The thermal resistance measured was 2.57 K/W (Fig. 11) for the similar board (ratios above factor 10). By correcting the optical power loss of the LED as a heat source, it becomes to 2.7 K/W. Doing the analysis on large sample numbers very consistent data were found for the MCPCB board resistance. The discrepancy suggests that

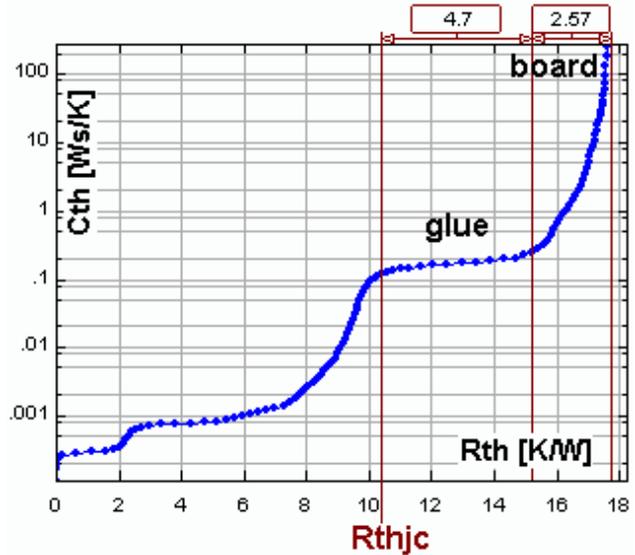


Fig. 11 Structure analysis: green LED on MCPCB

the thermal conductivity of Epoxy FR4 is less than the 1.3 W/mK which is assumed in the model. Variation in the board layer thickness is a more unlikely failure.

One of the advantages to use thermal transient analysis would be detecting or eliminating contact thermal resistance from which most thermal analysis taking point-to-point measurement suffers.

4. OPTICAL MEASUREMENTS

Optical characterisation was done in TERALED measurements (TER), which measure a steady state full characterisation and also in the CASFLUX (CAS), measuring short term pulse excitation of the LED. Table I shows the measurement results on luminous flux, thermal resistance junction-to-case (slug) for both optical setups, comparing short term and steady state results.

The short optical transients and stabilised TERALED measurement are shown in Table I for R, G, B colour LEDs that were driven with approximately 1W electrical power for Luxeon red, at 2.3 W for Luxeon green and at 2.4 W for Luxeon blue. Spectral distribution and luminous flux is shown in Fig. 12. The luminous flux measured at short times is approx. 10% higher than at steady state condition. Partially this can be explained by the change in junction temperature at longer times.

Rth_el (junction-to-case) was directly measured by the MicReD T3Ster. By correcting optical power, we ended with the real thermal resistance junction-to-case (Rth_r), which is not sensitive to driving currents by ignoring the sensitivities of material to temperature. The Rth_r is related with Rth_el with:

$$R_{th_r} = R_{th_el} / \{1 - P_{op} / P_{el}\}$$

Small difference has been found for thermal resistance between steady-state measurement (R_{th_r} at TER) and short transient (R_{th_r} at CAS) measurement for all three colours.

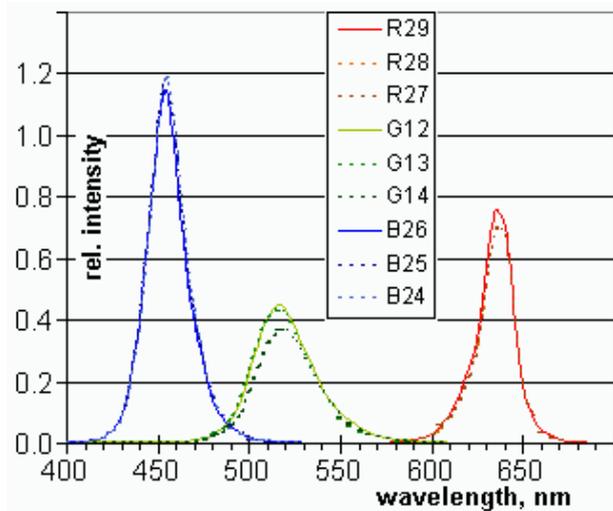


Fig. 12 Spectral distributions from stabilised measurements

Sample	Luminous flux [lm]		R_{th_el} [K/W]	R_{th_r} [K/W]	
	CAS	TER		CAS	TER
R27	43.26	38.43	8.0	10.8	10.4
R28	44.87	39.52	6.1	8.4	8.0
R29	43.52	41.13	5.8	7.9	7.7
G12	68.74	64.57	9.3	10.0	10.0
G13	68.18	61.10	9.1	9.8	9.7
G14	62.65	56.34	11.4	12.1	12.1
B24	12.31	11.35	8.3	9.4	9.3
B25	12.12	11.23	8.4	9.5	9.4
B26	11.42	10.79	8.6	9.7	9.6

Table I Measurement results from steady state measurements and short transients

5. CONCLUSIONS

Thermal transient analysis is a powerful tool for thermal characterisation of complete structures like LEDs. It is especially suitable for R&D work and failure analyses. For quality control measurements in manufacturing, the technique might be less suitable because the measurement time needed to discriminate is relative long (seconds).

Our experiments proved that short transients starting at 1 μ s and ending at 10 to 50 ms are suitable for die attach analysis. For board mounting approx. a second long transients reveal much of the thermal structure. However,

for a detailed picture on the thermal structure needed for QA & FA we need a full transient capture.

We have shown and investigated that luminous flux measurements at a short time transient and stabilised state are very well correlated. In such way these two flux measurements can be used as complementary tools to thermal transients of similar length. After doing the optical measurement we anyway switch off, the cooling transient can be used for thermal characterisation.

An accurate knowledge of thermal structure coupled with the optical performance is required to ensure a full LED thermal characterisation. It leads to use LED as heat sources for board thermal characterisations.

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