Characterization of heat-sinks of socketable LED modules using thermal transient testing

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Abstract

As socketable LED modules are being developed the need for thermal characterization of heat-sinks aimed at cooling such modules has also arisen. The natural approach from manufacturers is to apply the component level LED thermal testing standards to characterize complete LED module and heat-sink systems. In order to obtain the real thermal resistance of such a complete assembly needs the consideration of the radiant power of the LEDs when calculating the thermal resistance of the complete assembly. Also, the contribution of the LED module, the thermal interface between the module and the heat-sink and the thermal resistance of the heat-sink need to be separated. For the latter problem thermal transient measurements followed by structure function analysis is a solution. To eliminate the need for the measurement of radiant flux of the LED module we suggest building a thermal dummy of the module in question which mechanically is compatible with the module but the heat source is a conventional silicon device instead of LEDs. The paper provides details how such a thermal dummy was created and used in characterizing different heat-sinks aimed at a particular LED module family.

1 Introduction

As standards for socketable LED modules are getting published (such as the Zhaga books [1], [2]) the interest has arisen for standard methods to characterize heat-sinks designed for such products. There have been attempts in the past to characterize heat-sinks mainly for simulation purposes. Our team introduced the concept of compact thermal modelling of semiconductor device packages as well as heat-sinks based on thermal transient measurements [3] of power transistors and CPUs, using structure functions. Though the method outlined in this early paper provided quantified results to describe heat-sinks, no standardized method was provided to separate the device package, the TIM and the heat-sink in the structure functions. A recent report discussed the design optimization of heat-sinks aimed at cooling of CoB LED arrays [4], but the results presented in this paper are based mostly on simulation and are characteristic to the entire LED array + heat-sink assembly; do not provide quantified characteristics for the heat-sinks separately, thus, are not suitable to characterize heat-sinks for socketable LED modules.

In the present work the goal was to provide a systematic method to achieve quantifiable thermal characteristics of heat-sinks of socketable LED lighting modules. Though the characterization method presented in this paper was developed for GE's Infusion family [5], it is a generic method and can be applied to any other similar LED product.

2 The measurement concept

As outlined in [3] already, thermal impedance of heat-sinks can be identified with thermal transient measurements of packaged semiconductor devices attached to the heat-sink.

In case of LED modules the measurement is complicated with the fact that substantial part of the input electrical power is converted to light therefore the emitted optical power also needs to be measured as recommended by the recent LED thermal testing guidelines of JEDEC [6], [7], [8]. The problem is that these JEDEC standards are aimed at component level testing requiring cold-plate as thermal boundary condition while for testing a complete LED assembly with a heat-sink attached needs a natural convection environment similar to a JEDEC standard 1ft^3 still-air chamber, though, such a chamber must be much bigger in size than 1ft^3, as also suggested in [4].

2.1 Application of a thermal dummy

The workaround to the problem is to use a so called *thermal dummy* of the LED module which completely replicates the mechanical properties of the original LED module, provides the same amount of heating power as the original LED module and at its thermal interface has a similar heat-flux distribution as the original LED module. Such a thermal dummy of GE Infusion LED modules was built in which the original LED was replaced with a power BJT on the MCPCB substrate of the module, providing the same thermal properties at its thermal interface as the original LED module. In Figure 1 the thermally relevant parts of the originally LED module, the power BJT attached to the MCPCB substrate used in the module and the complete thermal dummy are shown.

The advantage of replacing the LEDs of the module with a silicon power transistor is that the classical semiconductor component thermal testing standards could be used for the measurements – this way we could omit the light output measurements during the testing.

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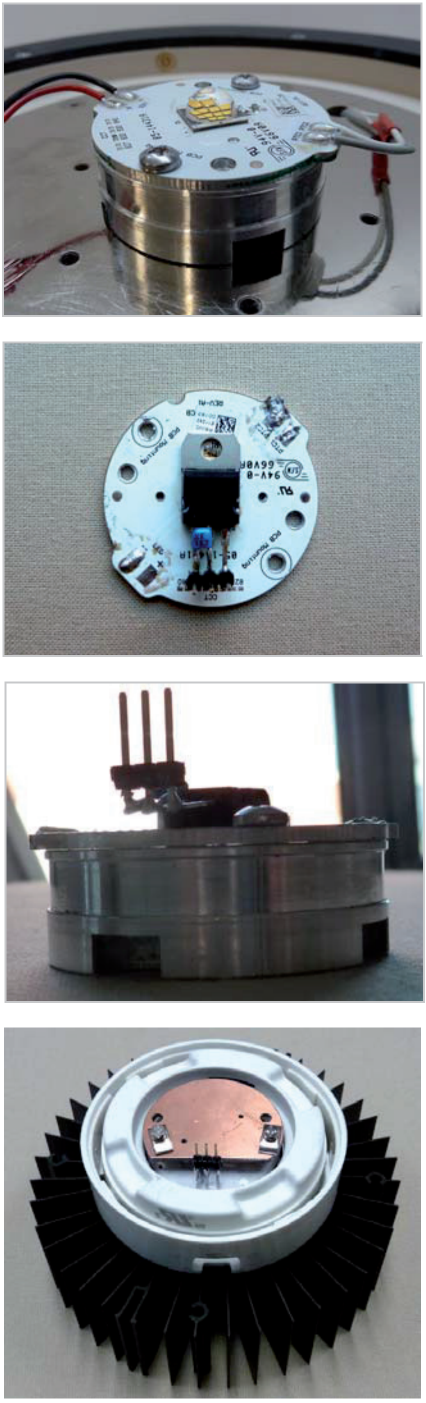

Figure 1: a) the original socketable LED module (without the LED driver circuitry) b) the power BJT attached to an MCPCB substrate to replace the LED of the original module, c) the complete dummy with the mechanical interface attached, d) the thermal dummy attached to a heat-sink .

Another advantage of using a power transistor is that its dissipation can be set in a wide range by choosing the proper value of its emitter current and collector-base voltage. With the thermal test equipment used for the measurements (Mentor Graphics MicReD T3Ster [9]) the dissipation of BJTs can be set to up to 100 W easily without the need for a booster device while for LED arrays with this level of power dissipation a booster device is definitely needed, not to mention the problem measuring the radiant power along with the junction temperature of the complete luminaire with the LED module and the heat-sink consistently, in a natural convection environment.

2.2 Matching the characteristic heat-flow path sections

As the MCPCB substrate and the mechanical interface of both of the thermal dummy and the real LED modules were the same it was expected that the heat transfer from the LED modules and from their thermal dummy was identical. To confirm this assumption thermal transient test results of the thermal dummy and that of the LED module were compared with thermal transient measurements. Both the thermal dummy and the LED modules were measured on a cold-plate with and without applying thermal interface material at the cold-plate.

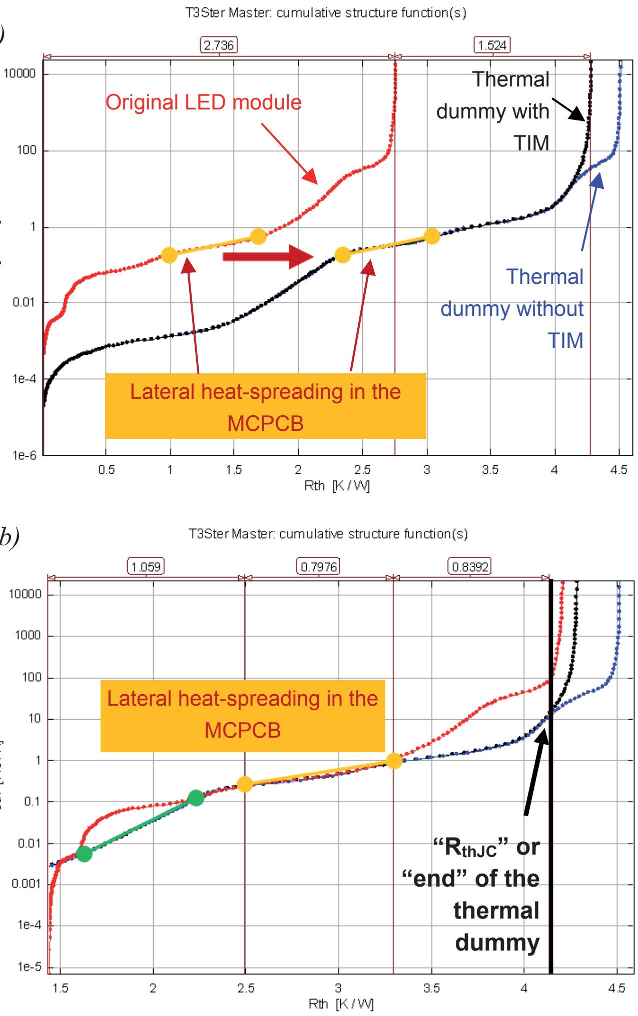

Figure 2: Cumulative structure functions of the original LED module and its thermal dummy: a) as measured, b) with a characteristic heat-flow path section matched.

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These tests resembled test procedure of the "transient dual interface method" described in the JEDEC JESD 51-14 standard [10] – this way the "end" of the thermal dummy (corresponding the "RthJC" concept of the standard) was identified – see Figure 2.

3 Results

Three different heat-sinks with the thermal dummy attached were measured in a still-air environment resembling the JEDEC standard 1ft^3 test chamber. The heat-sinks were hanged in the middle of the test chamber. The heat-sinks were different in size and in the quality of the machining of the surface mating with the LED module. The three heat-sinks characterized in this study are shown in Figure 3.

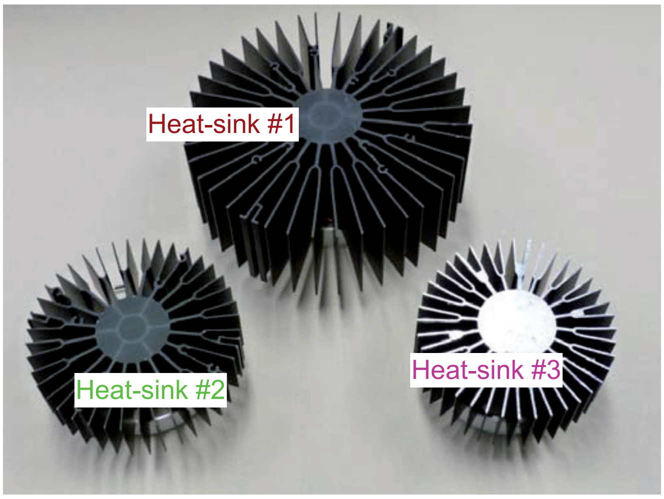

Figure 3: Three different heat-sinks characterized

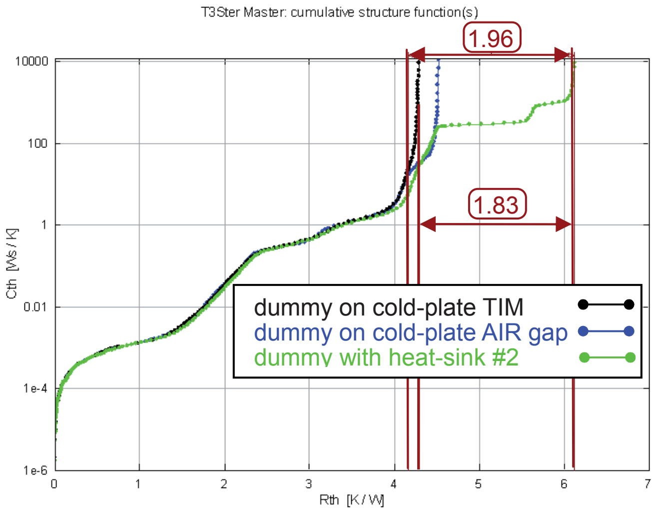

Figure 4: The thermal dummy measured with heat-sink #2 compared to the thermal dummy measured on cold-plate with and without applying TIM.

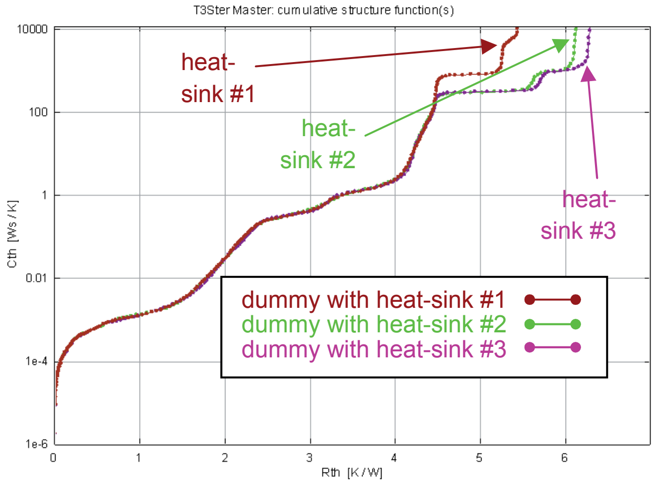

Figure 5: Structure functions of the thermal dummy measured with the all the three heat-sinks.

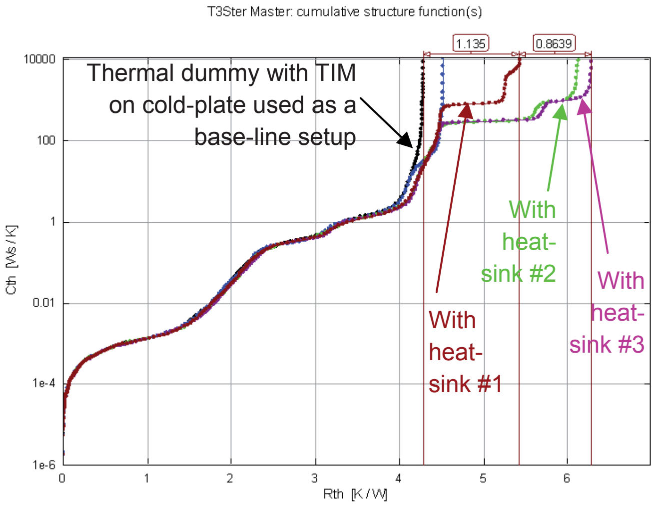

Figure 6: Structure functions of the thermal dummy (with and without TIM, measured on a cold-plate) and structure functions of the thermal dummy with the three different heat-sinks attached (measured in a natural convection environment).

Measurement results showing the characteristics of the heat sinks are shown in Figures 4, 5, 6 and 7. In Figure 4 the contribution of the heat-sink #2 and its interfacial thermal resistance to the thermal resistance of the bare thermal dummy is shown. This value is equal to 1.96 K/W. Compared to the thermal dummy measured on cold plate the access thermal resistance is 1.83 K/W only. The ~0.13 K/W difference is attributed to the thermal resistance of the TIM layer. This resistance of the TIM layer depends on the type of the TIM and the clamping force applied between the thermal dummy and the heat-sink. In the tests presented here these conditions were not controlled, with the help of the structure functions the contribution of this layer to the total thermal resistance of the complete test set-up can be

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identified and can be considered when the thermal resistance of the heat-sinks under natural convection conditions is evaluated.

Figure 5 shows the test results obtained for the three heat-sinks. For the analysis for their performance the reference structure function of the thermal dummy measured on cold plate is used again, see Figure 6. The best performing heat-sink is the large one labelled #1. Its access thermal resistance with respect to the bare thermal dummy is 1.14 K/W. The largest overall thermal resistance is provided by the heat sink labelled #3. Its access thermal resistance with respect to the bare thermal dummy is about 2 K/W.

In Figure 6 the structure functions obtained from the thermal dummy measured with different thermal boundary conditions are seen. The curves obtained for the three heat-sinks are compared to the one obtained in the case when the thermal dummy was attached to a cold-plate with TIM applied.

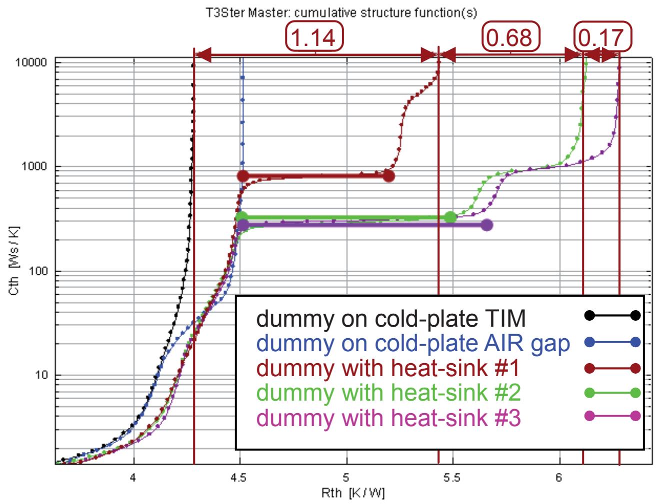

Figure 7: Close up view of the structure functions obtained for the thermal dummy measured on a cold-plate with and without TIM and the structure functions of the thermal dummy with three heat-sinks attached.

Figure 7 helps understand the performance differences of the heat-sinks. On one hand, as expected, larger overall fin area results in better heat transfer by natural convection, thus, results in smaller additional thermal resistance. On the other hand, the quality of the heat-sink surface mating with the LED module cooling surface also plays an important role. This is determined basically by the machining of the surface. In Figure 7 the horizontal indicator lines show the interfacial thermal resistances of these mating surfaces. As seen in Figure 7, the best thermal interface quality is provided by heat-sink #1. Heat-sink #2 provides the second best thermal interfacial resistance while the largest, thus the worst thermal interface was found at heat sink #3.

As one can see from these test results, heat-sink size is not the only contributor to the heat sink quality. In case of the investigated heat sink geometries the machining of the surface of the heat sink is almost as important as the heat sink size. Thus, heat sink size can be reduced if fine quality of the mating surface of the heat sink can be provided.

4 Conclusions

Application of a thermal dummy of socketable LED modules is suggested to measure the behaviour of their thermal environment when socketed. The thermal dummy used in our work was matched to the heat-spreading properties of the LED modules to be emulated from a thermal point of view. With the help of the “dual transient interface method” defined by the JEDEC JESD51-14 standard [9] we separated the contribution of the thermal dummy itself, the thermal interface between the thermal dummy and the heat-sink and the heat-sink to the total “junction-to-ambient” thermal resistance of the setup. This way quantifiable thermal characteristic of heat-sinks aimed at thermal management of socketable LED modules can be identified in a systematic, repeatable way without the need of measuring the emitted optical power of the LED module.

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