Delphi4LED - From Measurements to Standardized Multi-Domain **Compact Models of LEDs**

A Report on the Thermal Modeling Aspects

By Genevieve Martin, Phillips Lighting

The rise of LED technology is changing the ecosystem of the lighting industry. With the commoditization of LED, Delphi4LED, a European Union consortium, is providing a solution to this dynamic market. It is providing the EU LED Lighting industry with a set of methodologies and standards to enable the design and production of more reliable, cost effective and market-leading LED-based lighting solutions.

Although LEDs are very efficient, and therefore dissipate much less heat than conventional light sources such as incandescent, halogen or high-intensity discharge lamps, their efficiency is dependent on the LED temperature. This temperature depends on how effectively the LED dissipates its power to the surrounding environment, the amount of heat dissipated by the device and the effectiveness of the heat transfer paths inside the LED component. Thermal-optical-electrical parameters are inter-related but incomplete or even erroneous in datasheets of LED suppliers.

At luminaire developers, this results in considerable reverse engineering effort to get the proper product information about packaged LED. Ways to do this include material analysis, cross-section analysis, computer simulation and measurements. All these reverse engineering techniques combined lead to reasonable results but require long development time and cost a lot of money. For example the exact package dimensions and materials properties – specific features and parameters of the LED chip and phosphors – are unfortunately proprietary information of LED suppliers and cannot be expected to be publicly shared.

The Delphi4LED consortium includes 15 partners from seven countries and seeks to identify and exercise methods to extract and use multi-domain compact models of LEDs. A modular approach to such compact models [1], [2], [3], [4] would then be employed to enable lighting designers to meet both thermal reliability and optical design goals (Figure 1).

Such models take forward current as an input, and calculate emitted optical properties such as luminous flux as well as operating junction temperature for each LED in a design. The temperature dependence of the conversion of electrons to photons is considered, which impacts the resulting thermal power dissipation which in turn affects the temperature etc. It is this electro-optical-thermal coupling that necessitates all three domains to be considered concurrently in a single multi-domain modular compact model.

From the thermal perspective, although methods such as DELPHI exist to extract compact thermal models (CTMs) of monolithic single heat source IC packages, LEDs can have multiple heat sources. This is the case for White LEDs where additional heat is dissipated in phosphor layers due to Stokes shift light conversion losses. In addition LED packages may have multiple LED chips within them as is the case for Chip on Board (CoB). Temperature prediction at each chip junction, in each phosphor layer and also at solder points is required to ensure reliability in operation.

This article was originally published in Engineering Edge Vol. 7 Iss. 1

Dimming behavior and operation under AC conditions also necessitates that these CTMs are capable of dynamic prediction, i.e. dynamic compact thermal models (DCTMs).

To extract such DCTMs, Delphi4LED is determining a methodology that starts with a physical LED sample, performs a transient thermal measurement, uses that to calibrate a 3D detailed thermal model and from that a DCTM with an assumed nodal topology may be extracted (Figure 2).

T3Ster and TeraLED are used to perform the transient thermal response measurement in compliance with the latest JEDEC LED testing standards and recommendations of CIE, such as JESD51-51, JESD51-52 and CIE 225:2017 [5], [6], [7]. The total emitted optical power is measured by the TeraLED integrating sphere, the resulting thermal power dissipation (the difference between the electrical supplied power and the optically emitted power) is used to correct the resulting Zth profiles ((Tj-Ta)/thermal dissipated power) vs. time. An important aspect of these combined thermal and optical measurements is that the LEDs' junction temperature is kept at known, constant value as also recommended by the CIE 225:2017 technical report. As a side product of such a test procedure, the temperature dependence of the light output properties of the LEDs can also be measured.

A FloTHERM model of an LED package is then constructed of the same configuration used for the T3Ster+TeraLED measurement (Figure 3).

FloTHERM's calibration feature is then used to fine tune material properties along the heat flow path until such time as simulated Zth responses (and corresponding structure function profiles) match the measurement. This entails nomination of those materials properties that are both most unknown and contribute most to the overall thermal resistance. In this case the chip submount, bottom die attach and FR4 thermal conductivities. Upper and lower bounds of those parameters are defined, a (computational) design of experiments set and solved then a gradient based optimization used to determine which parameter values result in the smallest deviation between measured and simulated transient thermal response curves (Figure 4).

Unlike the measurement that was limited to only being capable of recording the

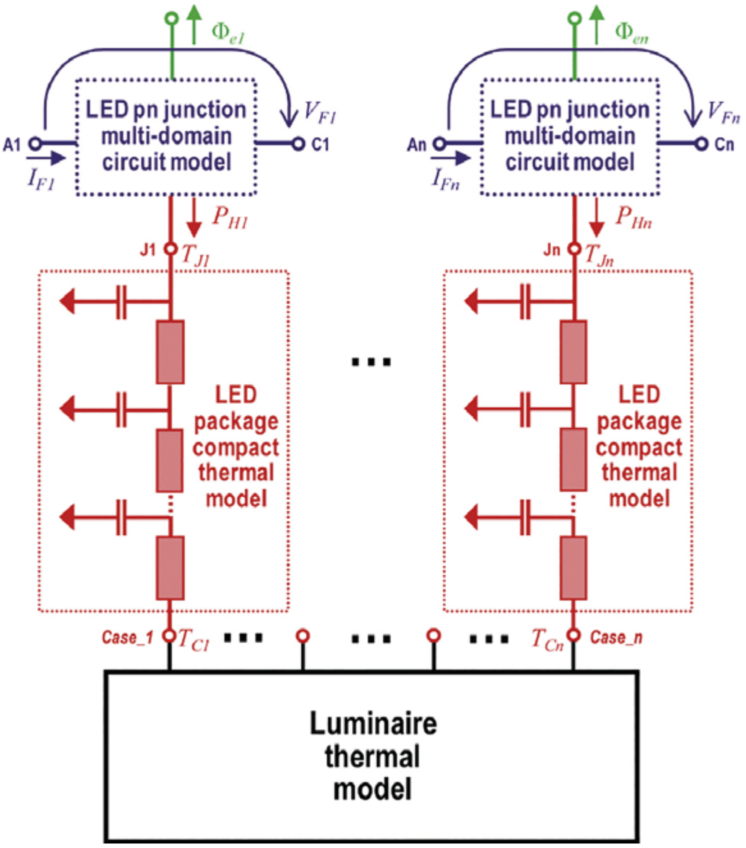

Figure 1. Multi-domain compact model of Multiple LEDs within their Operating Environment [3], [4]

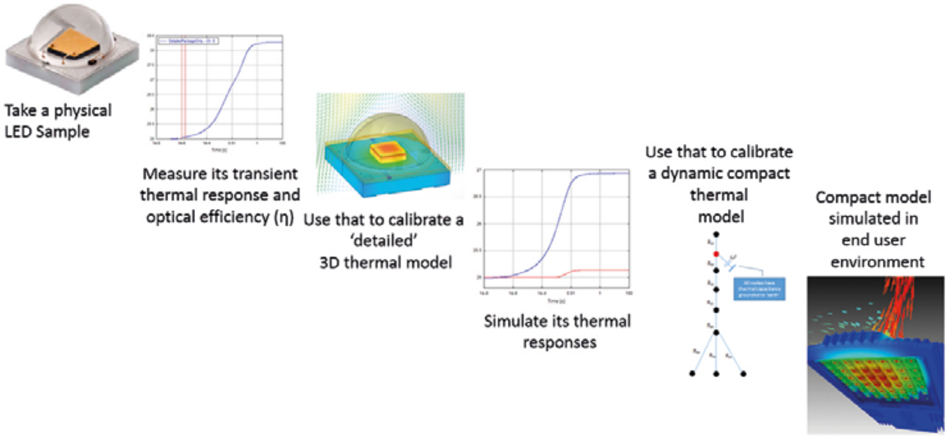

Figure 2. Dynamic compact thermal model extraction process

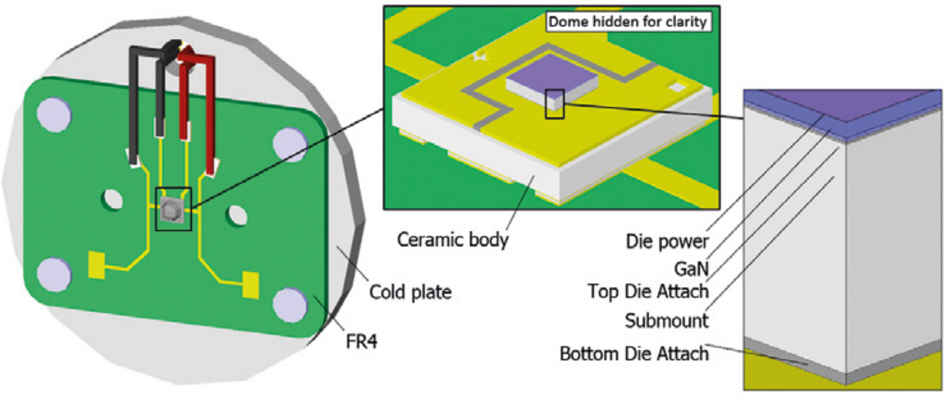

Figure 3. Cree XP-E2 Blue LED on FR4 on coldplate [8]

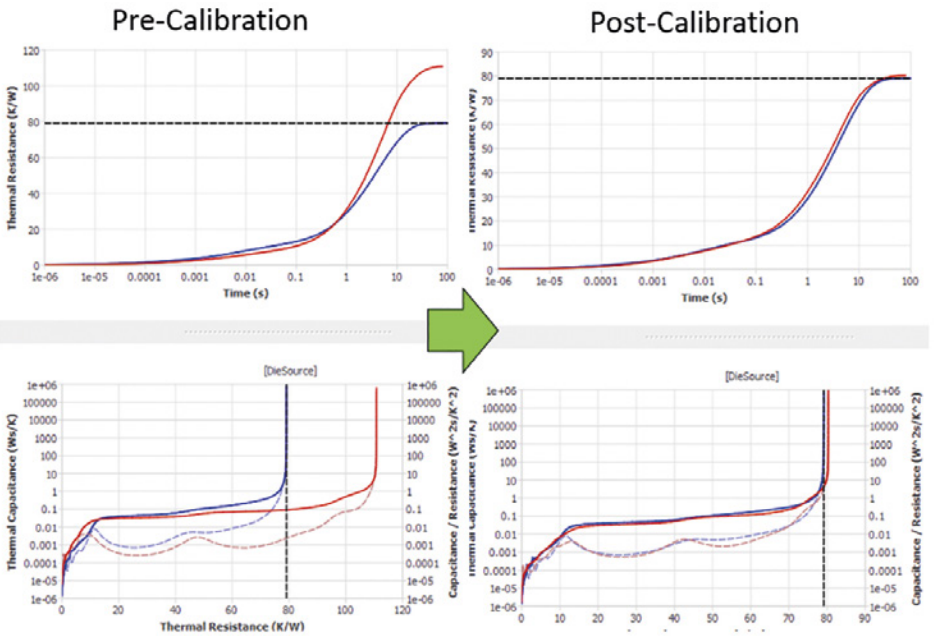

Figure 4. Pre- and post-calibration Zth (top) and Structure Function (bottom) comparisons. red = Simulated response. Blue = Measured response.

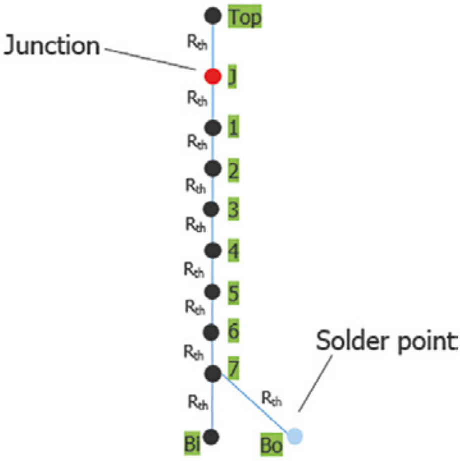

Figure 5. Nodal DCTM topology (thermal capacitance values at each node, not shown for clarity)

chip junction thermal response, the 3D FloTHERM model is capable of predicting temperature and 1000s of points. This additional simulated thermal response behavior is subsequently used to calibrate the thermal resistance and capacitance values at certain points in a nodal DCTM.

The topology of the DCTM has been determined having enough points so as to capture the dominant thermal time constants experienced along the heat flow path (Figure 5)

The heat flow path within the package, away from the package periphery, is boundary condition independent and can be represented with thermal resistance (R) and thermal capacitance (C) values taken directly from the measured structure function. The R and C values nearer the package periphery have to be determined so that the thermal response of the DCTM at both junction and solder point nodes match with the corresponding points of the 3D detailed model. The same calibration methodology is applied to achieve this, considering the DCTM in isolation with representative boundary heat transfer coefficients applied on top and bottom surfaces. In this case there are two pairs of curves that need to match, the driving point impedance at the junction as well as the transfer impedance of the solder point. The results of the DCTM calibration are shown in Figure 6.

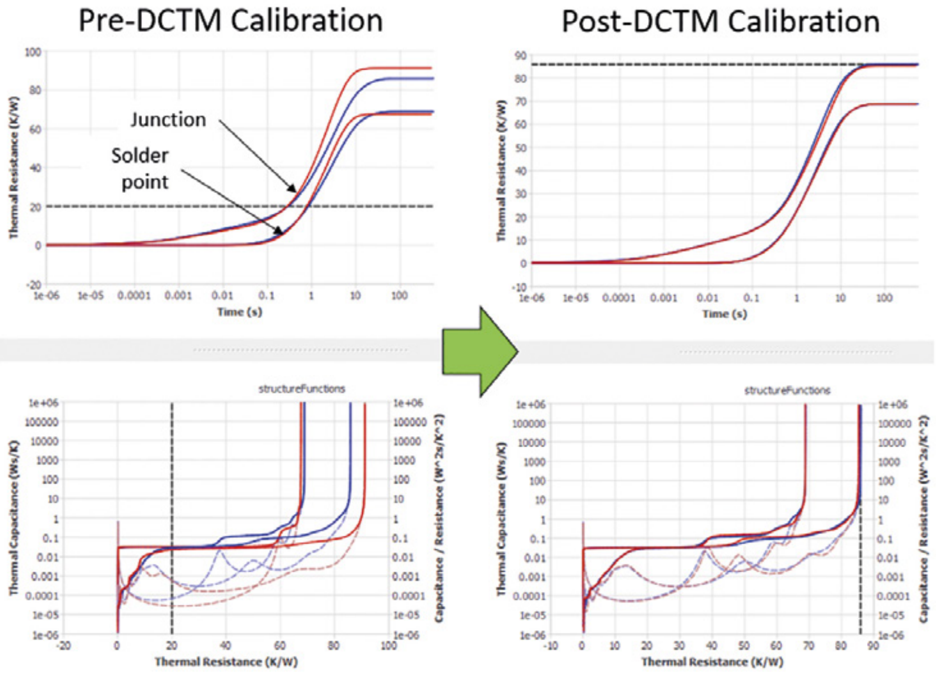

Figure 6. Pre- and post-DCTM calibration Zth (top) and Structure Function (bottom) comparisons. Red = DCTM response. Blue = 3D Detailed model response.

A verification of the accuracy of the DCTM can be ascertained by comparing the resulting thermal response when the DCTM is placed back into the full system level model representing the original T3Ster+TeraLED measurement (Figure 6)

A maximum error of 4.5% in dT prediction is noted, but only during 1-10s of the transient thermal response. Steady state temperature prediction is highly accurate.

The same methodology is being extended in the Delphi4LED project to extract boundary condition independent DCTMs by calibrating

This article was originally published in Engineering Edge Vol. 7 Iss. 1

R and C values so that all thermal response at all points of interest are accurate over a set of differing top and bottom heat transfer coefficient values. The number of points of interest may be extended to incorporate other dissipating nodes (i.e. nodes representing phosphor conversion) and additional solder point temperatures.

Coupled with a chip level model of LEDs (extracted directly from measurement) describing the temperature dependent electrical and optical characteristics, the DCTM forms part of the multi domain compact model. An accurate representation of the LED capable of providing thermal and optical information quickly and easily so that lighting designers may meet both functional and reliability product specifications.

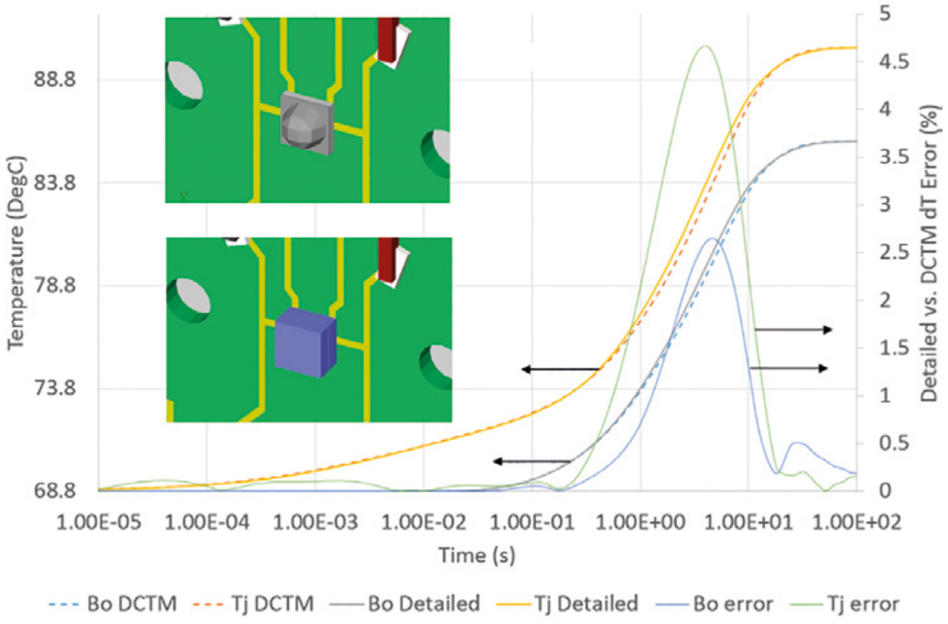

Figure 7. DCTM vs. 3D Detailed model comparisons

References:

[1] R. Bornoff, V. Hildenbrand, S. Lugten, G. Martin, C. Marty, A. Poppe, M. Rencz, W. Schilders, J. Yu, Delphi4LED - From Measurements to Standardized Multi-Domain Compact Models of LEDs: a New European R&D Project for Predictive and Efficient Multi-domain Modeling and Simulation of LEDs at all Integration Levels Along the SSL Supply Chain, Therminic 2016, Budapest, Hungary

[2] www.delphi4LED.org

[3] A. Poppe, J. Hegedűs, A. Szalai, R. Bornoff, J. Dyson, "Creating multi-port thermal network models of LED luminaires for application in system level multi-domain simulation using SPICE-like solvers", In: Proc. of the 32nd IEEE SEMI-THERM Symp., 14-17 March 2016, San Jose, USA, pp. 44-49, DOI: 10.1109/SEMI-THERM.2016.7458444

[4] A. Poppe, "Simulation of LED Based Luminaires by Using Multi-Domain Compact Models of LEDs and Compact Thermal Models of their Thermal Environment", MICROELECTRONICS RELIABILITY 72:(5) pp. 65-74. (2017), http://dx.doi.org/10.1016/j.microrel.2017.03.039

[5] JEDEC JESD51-51 Standard "Implementation of the Electrical Test Method for the Measurement of Real Thermal Resistance and Impedance of Light-Emitting Diodes with Exposed Cooling" (2012), https://www.jedec.org/system/files/docs/JESD51-51.pdf

[6] JEDEC JESD51-52 Standard "Guidelines for Combining CIE 127:2007 Total Flux Measurements with Thermal Measurements of LEDs with Exposed Cooling Surface" (2012), https://www.jedec.org/system/files/docs/JESD51-52.pdf

[7] Y. Zong, P-T. Chou, P. Dekker, R. Distl, K. Godo, P. Hanselaer, G. Heidel, J. Hulett, K. Oshima, A. Poppe, G. Sauter, M. Schneider, H. Shen, M.M. Sisto, A. Sperling, R. Young, W. Zhao, "Optical Measurement of High- Power LEDs", CIE 225:2017 (Technical Report) ISBN 978-3-902842-12-1, DOI: 10.25039/TR.225.2017

[8] R. Bornoff, G. Farkas, L. Gaal, M. Rencz, A. Poppe, "LED 3D Thermal Model Calibration against Measurement", In: Proceedings of the 19th International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE'18), 15-18 April 2018, Toulouse, France

Mentor®
A Siemens Business

This article originally appeared in Engineering Edge Vol. 7 Iss. 1

ENGINEERING EDGE

Accelerate Innovation with CFD & Thermal Characterization

You might also be interested in...

Thermal Simulation of a SYN TRAC Powerpack
Edge Devices are Hot for IoT
Distributed Chilled Water Pumping AC System
Reliability Evaluation of Sintered Copper Die Bonding Materials
Virtual Reality and Modeling Tools
Ask the GSS Expert
Simulation of Hydraulic Servo Gimbal Control of a Space Launch Vehicle
How to… Convert CAD Geometry into a FloMASTER Sub-System
A Study of Aerothermal Loads
Development of a Turbocharger with FloEFD
Risk Prevention & Energy Saving in Ships
Interview: Takuya Shinoda, Denso Corporation
Three Thermal Simulation & Test Innovations for Electronics Equipment Design
Series Car Brake Cooling
Liquid Cooling Turned on its Side
Thermal Analysis of an ADAS Camera
Thermal Design Leading the Charge
Understanding Die Attach Thermal Performance
Rapid Beverage Cooling Analysis
Bitcoin Mining: A Thermal Perspective
Designing High Efficiency, Low-Cost Synchronous Reluctance Motors
A Cool Emulator
Achieving Precision in 1D Dynamic Models of Hydraulic Servo Valves
Using FloEFD as an Engineering Tool
Comparison between Experimental & Computational Results
Design of a High Speed Decoy UAV
Thermal Interface for Pluggable Optics Modules
Geek Hub: What do Engineers see in Coffee Grounds?