Decomposition-based analysis of the multi-physical coupling structure in LED System-in-Package design

E.C.M. de Borst[1,2], L.F.P. Etman[1], A.W.J. Gielen[2],
A.T. Hofkamp[1], and J.E. Rooda[1]
[1] Eindhoven University of Technology, The Netherlands
[2] TNO Eindhoven, The Netherlands

Abstract

LED System-in-Package (LED SiP) is a novel lighting concept that aims to reduce the cost of the next generation LED lighting products. The LED SiP integrates LED chips with driver chips, sensors, radio-frequency interfaces and possibly other components into a single semiconductor solution. The integrated package reduces manufacturing costs. However, due to the integration, the design process becomes tightly coupled [1]. In this study we analyze the multi-physical coupling structure combining techniques from multidisciplinary design optimization and product architecture design.

The typical design decisions for the LED SiP are associated with, amongst others, the type, dimensions and mutual placement of the various components that make up the SiP, the routing of interconnects, and the encapsulation. The main design objectives are: performance, lifetime, and costs. The performance is described by the luminaire efficacy, i.e. the amount of light (lm) per amount of electrical energy (W), and the quality of the light output. The lifetime of the LED SiP is a function of failure due to lumen depreciation and catastrophic failure of components. The costs typically relate to material and manufacturing costs.

During the LED SiP design, mechanical, thermal, electrical and optical aspects have to be taken into account. In particular thermal management plays a key role, since the performance and lifetime of components is heavily affected by high temperatures within the package. For example, the light output of high brightness LEDs depends on the junction temperature in the LED. As temperature rises the light output decreases. Also the quality of the light deteriorates for increasing temperatures, since LEDs tend to shift wavelength at higher temperatures. On a longer time horizon, due to high temperatures and high electrical currents, driver and lenses tend to degrade resulting in lumen depreciation and color shift. The LED SiP can also fail catastrophically, when one of the components in the LED SiP instantly fails. Such catastrophic failures may be electrically or thermo-mechanically induced.

Our approach under investigation is as follows. We account for the contribution of the various physical responses in the coupling structure by incorporating the notion of responses in the functional dependency table [2] and design structure matrix descriptions [3]. We specify the functional relations between design parameters, responses, and objectives using the PSI language [4] and then automatically generate these matrices. Matrix partitioning is subsequently carried out to minimize a weighted criterion of partition sizes

and partition interactions. Graph partitioning algorithms such as Graclus are employed to this end. Also we seek to minimize feedback-coupling. The partitioning outcome serves as a means to analyze the SiP coupling structure from the product and design process perspective, and to reflect on the current practice to give electrical engineering the lead during SiP design.

We aim to validate the proposed approach on the basis a recently manufactured LED SiP prototype. Results for a first test case implementing the approach on a simplified version of the SiP prototype are available.

References

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