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# Numerical Study on the Effect of Thermal Pad on Thermal Management of Multi-Chip LED COB

Houda ELNOUINO
*Department of physics*
*Faculty of sciences Abdelmalek Essaadi university*
Tetouan, Morocco
houda.elnouino@etu.uae.ac.ma
0000-0002-1194-2998

Othmane Bendaou
*Department of Physics*
*Faculty of sciences Abdelmalek Essaadi university*
Tetouan, Morocco
o.bendaou@uae.ac.ma

*Abstract*—**Thermal interface materials (or TIMs) in the form of pads and sheets, characterized by low thermal resistance and substantial elasticity, are essential for the management of thermal energy. This research paper elucidates the impact of thermal pads on enhancing heat transfer in contact interfaces of a COB LED multi-chip package utilizing cold spray technology. Secondly, the effects of the thermal conductivity of TIMs and the convective heat transfer coefficient on the COB LED multi-chip package's thermal properties are analysed. The results show that the thermal pad's thermal conductivity greatly influences the junction temperature of the package by directly affecting heat transfer performance. However, the effectiveness of raising the convective heat transfer coefficient at the side of the heat sink to dissipate heat is limited. Furthermore, the results demonstrate that the gap between two adjacent LED chips has no effect on the thermal contact resistance, even when the material properties change. In summary, this research highlights the importance of thermal management in LED multi-chip packages and the critical role of thermal interface materials in enhancing heat transfer and dissipation.**

***Keywords—thermal pad; LED; gap; thermal analysis***

## I. INTRODUCTION

Light emitting diode (or LED) device technologies have become more and more widely used in lighting applications, including displays, LED backlight TVs, signage panels, street lighting, automobiles, and more, as a result of their promised qualities of being versatile and beneficial to the environment as in [1]. In order to preserve this technical progress, the decreasing size of electrical devices—particularly LEDs—has raised the need for extremely complex yet low-cost heat management technologies as in [2]–[3]. Nevertheless, LEDs continue to have a thermal issue that is mostly caused by a rise in junction temperature. The junction temperature rises significantly as a result of the fact that 85% of the power used is converted into heat as in [4]. In actuality, the LED lamp's lifetime, luminous flow, and energy efficiency all significantly decrease at high junction temperatures [5]. Thus, an essential factor in guaranteeing improved LED performance is the thermal management of the LED. The components of a standard COB (or chip-on-board) electronic chip packaging device are a chip, a metal substrate, a heat sink, and TIM. The most commonly accepted method for heat dissipation in chip packages is the application of a chip-TIM-metal substrate-TIM-heat sink configuration.

The primary challenges to efficient thermal management in the electronic heat dissipation process are the contact interfaces between chips and heat sinks [6]. This is because all material interfaces are naturally rough, and when two solid surfaces come into contact, the majority of the interface is filled with air. Due to the lower thermal conductivity of air compared to the mating solids, there arises an additional thermal resistance at the contact interface known as thermal contact resistance, or TCR as mentioned earlier [7]. TCR has a significant impact on the thermal management of LED packages, particularly in scenarios with high heat flow and the absence of conformal mating surfaces. However, TCR can also lead to increased energy consumption as mentioned earlier [8]. Thermal interface materials (TIMs) are utilized in semiconductor packaging to connect chips and heat sinks, eliminating air from interfaces and reducing TCR as in [9]. Common TIMs include phase change materials, thermal grease, thermal gel, and thermal pads. Among these, the thermal pad offers the advantage of preventing the "pump out" effect at the interface and is easy to disassemble and reassemble as in [10]. The primary obstacles to heat transfer from chips to heat sinks are three types of thermal resistance: bulk thermal resistance ($R_H$) of thermal pad, TCR between chip and thermal pad ($R_{chip/TP}$), and TCR between thermal pad and heat sink ($R_{TP/heatsink}$). Consequently, accurate prediction of these three thermal resistances is essential for the thermal management of LED packages and has garnered significant attention from researchers.

Despite years of extensive research, the heat transfer problem associated with TCR remains unresolved. Traditionally, two primary methods have been employed to evaluate TCR: numerical and experimental approaches. These methods have significantly benefited from advancements in technology, particularly in numerical simulation and experimental measurements. Gou et al. [11] adopted a more precise technique by examining surface topography under a microscope and generating rough surfaces using the acquired data for TCR prediction. Researches conducted in [12]–[13] corroborated the superior accuracy of generating rough surfaces with this approach [11] compared to assuming surface characteristics. However, a notable limitation in these studies [11–13] is the absence of consideration for the impact of thermal interface materials (TIMs) on TCR.

To assess the influence of a thermal pad on enhancing interfacial heat transfer for chip heat dissipation, we constructed a three-dimensional numerical model for this investigation [14]. The thermal conductivity of the thermal pad was incorporated into the model, and the thermal convection and radiation analysis results were obtained and evaluated. This approach allowed for a comprehensive examination of the thermal pad's impact on heat dissipation, taking into account the material's thermal conductivity properties.

## II. Numerical Model

### A. The Multi-chip LED Package

The multi-chip COB LED (or chip-on-board LED) is depicted in Fig. 1. The COB is an interconnected package made up of numerous LED chips and is constructed from a copper base COB array, heat sink, copper coat, and solder layers (as shown in Fig. 2). The heat sink is fabricated from an aluminum alloy, featuring thirty small holes with a 3 mm diameter to augment convective heat transmission. A 0.5 mm thick spray copper coat is applied to the heat sink's surface to facilitate soldering between the copper base and heat sink. The circuit layer and dielectric layer have a diameter of 10 mm and a thickness of 0.1 mm. On the copper substrate, there is a 3 × 3 array of gallium nitride semiconductors, each measuring 1 mm × 1 mm × 0.2 mm. The COB array's gap is 0.3 mm (as depicted in Fig. 3). This configuration allows for efficient heat dissipation and reliable operation of the LED chips [14].

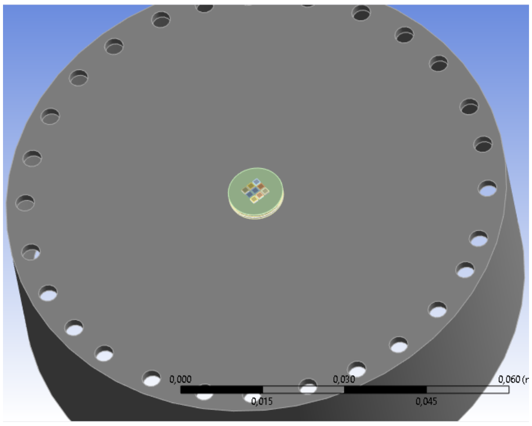



Figure 1. Structure of the multi-chip LED COB

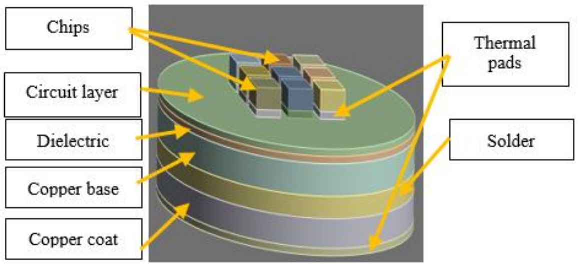



Figure 2. The soldering structure of chips and metal substrate arrays.

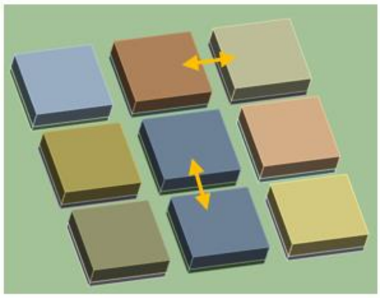


Figure 3. The gap of the chips

### B. Govering Equations

The model is employed to simulate the temperature distribution within the LED lamp. A finite-element ANSYS Workbench was utilized to create a 3D multi-LED chip package. The majority heat generated by the chips is dissipated from the substrate and the heat sink into the surrounding environment. The governing equation for heat transfer in a single component under steady-state conditions can be expressed as follows:

$$\frac{\partial}{\partial x}\left(\lambda_x \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_y \frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda_z \frac{\partial T}{\partial z}\right)+Q=0 \quad (1)$$

Where T is temperature, and $\lambda_x$, $\lambda_y$, and $\lambda_z$ denote the material's thermal conductivity on x, y, and z directions and Q represents heat flow from the chips. Table I displays the thermal conductivity of the materials utilized in the simulation where $\lambda$ is the thermal conductivity. Through natural convection, heat from the heat sink disperses into the surrounding air. The convection heat flow $q_{convection}$ between the heat sink and air can be defined as the following equation:

$$q_{convection} = h(T_J - T_a) \quad (2)$$

Where $T_J$ represents the surface temperature, while $T_a$ denotes the ambient temperature and the thermal convection coefficient is represented by h.

TABLE I. Thermal Conductivities Of The LED Package Materials

| Components | Dielectric | Spray Cu | Cu | Thermal Pad | Solder | Aluminum |
|---|---|---|---|---|---|---|
| Thermal condictivity ($W.m^{-1}.k^{-1}$) | 1.1 | 160 | 398 | Assumed | 40 | 150 |

### C. Assumptions and Boundary Condition

The following lists the assumptions and boundary conditions applied in the simulation analysis:

- Each LED chip's top is assumed to receive a uniform heat flow of 10W, which is then evenly distributed within each LED chip, with an ambient temperature set at $T_a$= 20 °C.
- The materials considered in this study are all homogeneous, isotropic, and thermally neutral.
- Each material layer is devoid of any airspace.
- Thermal radiation dissipation is neglected, with heat primarily dissipating around the heat sink through convection heat transfer.
- The heat transfer coefficient for other surfaces exposed to the environment is fixed at 10 W/m².K due to natural convection.

Due to limitations in computer memory and simulation time, the number of elements that can be utilized is restricted, even though a finer mesh could enhance result accuracy. Employing local mesh refinement involves adaptive meshing. Once these steps are completed, the simulation result is displayed in Fig. 4, where the junction temperature is 97.329 °C.

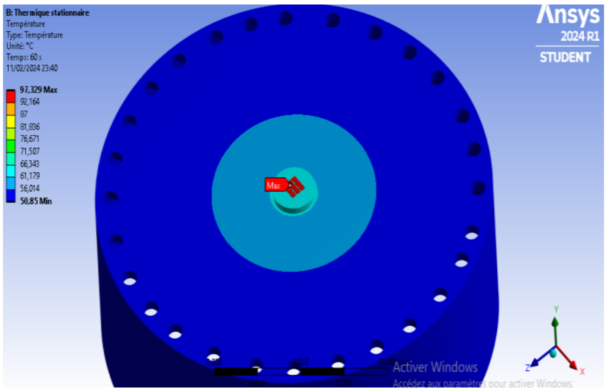



Figure 4. Thermal analysis of a multi-chip LED COB package

### D. Thermal Radiation Study of the LED Package

A numerical investigation is conducted to understand the influence of radiation. It is considered that the heat flow generated by the LED package by radiation and heat convection to the atmosphere comes only from the area surrounding the heat sink as in [15]. The radiation heat flow can be mathematically represented by (3):

$$q_{radiation} = \sigma\varepsilon(T_J^{\,4} - T_a^4) \tag{3}$$

The Stefan-Boltzmann law, denoted by $\sigma$ with a value of 5.67×10⁻⁸ W/m².K⁴, and $\varepsilon$ representing the emissivity of the aluminum heat sink surface at 0.85, are key parameters in (3), where $T_J$ signifies the junction temperature of the model. The ambient temperature $T_a$ is assumed to be 20°C.

By comparing the values of radiative and convective heat flow, it is possible to determine the impact of radiative heat transfer since heat can be dissipated from chip surfaces by radiation and convection. Notably, the junction temperature of the package showed minimal variation with or without radiation, aligning with numerical predictions. The calculated convection heat flow, $q_{convection}$, amounts to 723.31 W/m², while the radiation heat flow, $q_{radiation}$, is 3.49 W/m².

Based on the previously acquired results, it becomes evident that due to the relatively low chip temperature, especially at lower chip power levels, the value of the radiation heat flow is assumed to be neglected in front of the value of the convection heat flow. Consequently, the consideration of radiation effects is considered to be avoided. For that reason, the heat dissipation of thermal radiation is ignored.

A parametric investigation is conducted to evaluate the impact of the Heat Sink's emissivity $\varepsilon$ on the thermal field of the package, further validating the above-mentioned assumption. Fig. 5 illustrates the temperature variation on chip surfaces with varying heat sink emissivity $\varepsilon$ values ranging from 0.1 to 0.9 as in [16]. By utilizing (3) to predict the radiation heat flow, the study explores how the thermal performance would vary if the heat sink's emissivity changed.

As expected, the results depicted in Fig. 5 indicate that the thermal behavior of the LED package remains unaffected by variations in the heat sink's emissivity $\varepsilon$. The changes were within the accuracy of the assumptions used in this assessment. The effect of radiation is still a negligible factor in improving the total thermal.

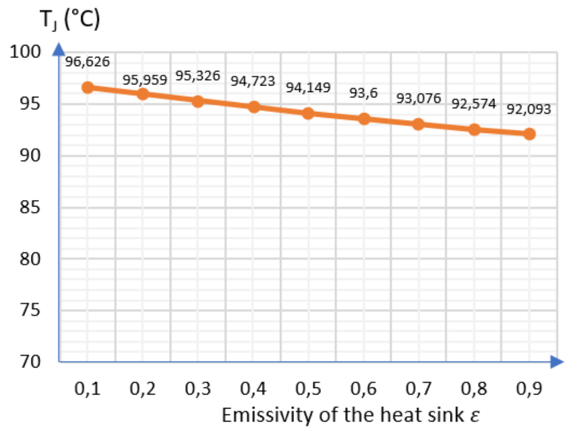



Figure 5. The junction temperature's variation of the LED package at different emissivity $\varepsilon$

### E. Validation

The numerical results of the temperature field derived from the current model are independently verified with both the experimental and numerical reesults of He et al. [14]. Fig. 4 illustrates the resultant temperature distribution of the LED module based on the specified boundary conditions and simulation parameters where the junction temperature $T_J$ is 97.329°C. Correspondingly, Table II presents a list of results obtained under same calculation conditions. Notably, when compared to the results in the literature by He et al. [14], the highest variation from the junction temperature is just 0.031%. These comparisons demonstrate a high level of agreement. Numerous articles corroborate the efficacy of numerical simulations in a similar way, as evidenced by studies conducted by Abdelmlek et al. [17], Mandal et al. [18], and Hu et al. [19].This collective research's articles reinforces the robustness and reliability of the numerical simulation approach employed in this study.

TABLE II. THE JUNCTION TEMPERATURE OF THE LED MODEL

| $T_J$ of our ANSYS model (°C) | $T_J$ of the reference model (°C) | Relative deviation (%) |
|---|---|---|
| 97.329 | 97.298 | 0.031 |

## III. RESULTS AND DISCUSSION

### A. *The Impact of Thermal Conductivity of Thermal Pad*

It is approved that the heat dissipation from the chip to the heat sink is depending upon the thermal conductivity of the thermal pad $\lambda_p$ .In order to perform a heat transfer study of the LED package, the temperature variation on chip surfaces with different thermal conductivities of the thermal pad is seen in Fig.6. Where the thermal conductivities of the thermal pad is adjusted from 1 to 10. The results of this investigation are presented in Fig. 6 and Fig. 7. As the thermal conductivity of the thermal pad increases, the junction temperature decreases as in [20]. It can be affirmed that the thermal pad significantly influences the thermal behavior of the package.

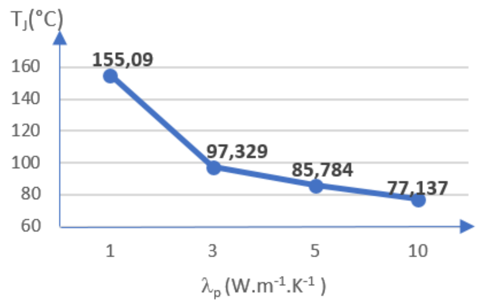
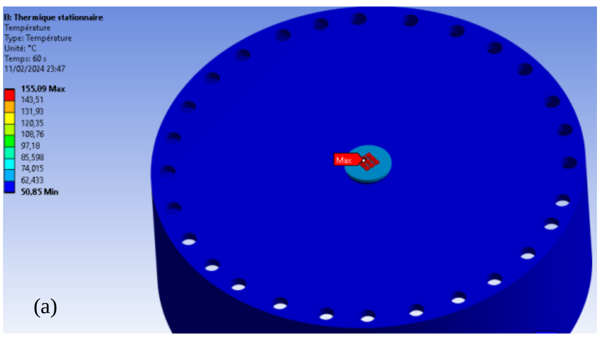



Figure 6. The Junction temperature of the package at different $\lambda_p$



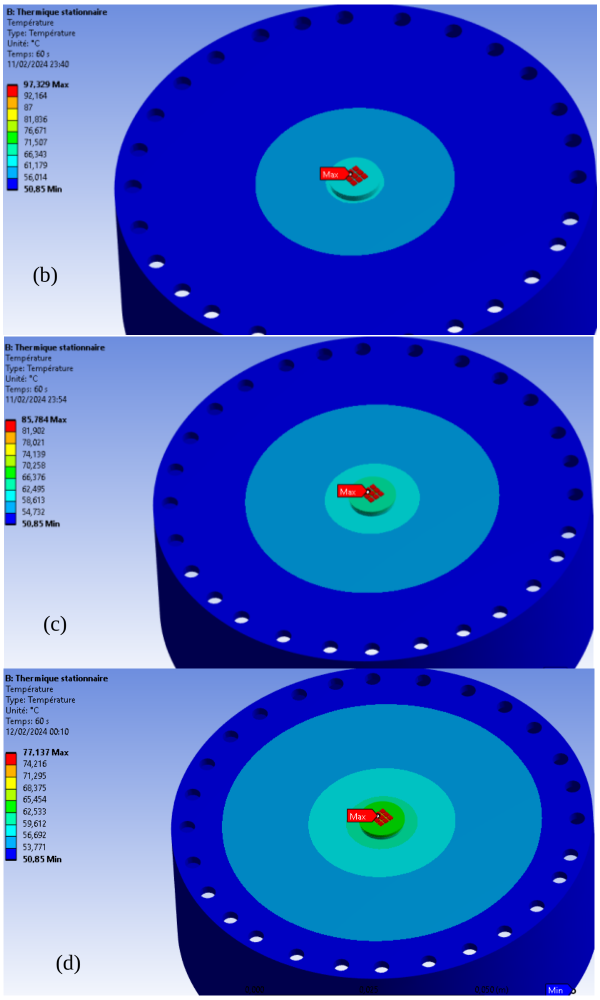




Figure 7. The Junction Temperature contours with thermal conductivity increasing. (a) λp = 1 W.m$^{-1}$.K$^{-1}$; (b) $\lambda_p$ = 3 W.m$^{-1}$.K$^{-1}$; (c) $\lambda_p$ = 5 W.m$^{-1}$.K$^{-1}$; (d) $\lambda_p$ = 10 W.m$^{-1}$.K$^{-1}$

### B. *The Impact of Convective Heat Transfer Coefficient of Heat sink*

Convective heat transfer serves to cool one side of a heat sink in certain engineering applications. Consequently, the convective heat transfer coefficient h a crucial factor in influencing the heat dissipation of the chip. Fig. 8 illustrates how h affects the chip's heat dissipation and the results confirm the hypothesis that an increased h will help the model dissipate heat. However, it is notable that the effect is limited, even as h increases from 6 W.m$^{-2}$.K$^{-1}$ to 18 W.m$^{-2}$.K$^{-1}$ when $\lambda_p$ = 3 W.m$^{-1}$.K$^{-1}$. This result implies that the interface is the principal heat transfer obstacle. Therefore, it can be affirmed that increasing $\lambda_p$ proves more effective than augmenting h.

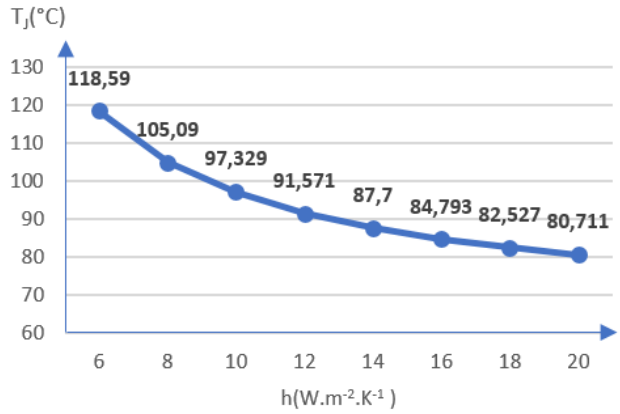



Figure 8. The impact of thermal convection coefficient when $\lambda_p$ = 3 W.m$^{-1}$.K$^{-1}$ on the junction temperture of the package

## C. *Different the chip gaps*

Modifying the chip gaps in multi-chip LED COB package will effect on the junction temperature. The chips, arranged in a 3 × 3 array, with the chip gap is 0.3 mm. The variation of the junction temperature of the package based on chip gap values of 0.1, 0.2, 0.4, 0.5, and 1 mm, are presented in Fig. 9.The graph reveals that the junction temperatures for various thermal pad conductivities remain relatively constant. This observation suggests that, within a certain range, changing the chip gaps does not modify the thermal resistance. Considering that increasing thermal conductivity can significantly decrease total thermal resistance, which is more effective for heat dissipation of the chip.

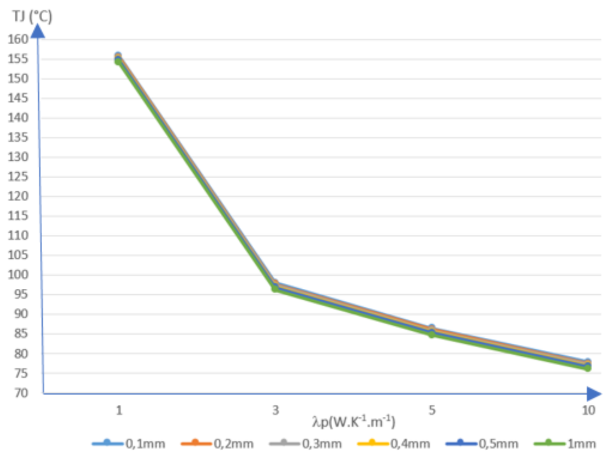



Figure 9. Junction temperature $T_J$ at different chip gaps and thermal conductivities of the thermal pad

# IV. CONCLUSION

In this work, we studied the thermal performance of a multi-chip LED COB package using a three-dimensional finite-element model. Chips, metal substrate, heat sink, and thermal pads are the structure of the model. Quantitative analysis is carried out on the impacts of the thermal pad's conductivity, convective heat transfer coefficient, and the chip's gap on thermal behavior of the package.

The following is a summary of the main conclusions:

- There is a limited impact of the heat sink's convective heat transfer coefficient on the thermal behavior of the model; the junction temperature decreases as thermal pad thermal conductivity increases.
- It has been demonstrated that the variation in the chip's gap is negligible when compared to the thermal pad's conductivity.
- The thermal analysis indicates a negative impact on the LED package's thermal performance when taking the heat transfer study's thermal radiation into consideration.
- It also demonstrates that the heat sink's emissivity changes is negligible.

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