Investigation of Heat Dissipation Limits for High Power LEDs

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Abstract – From the point of view of energy consumption, LED technology is the most efficient lighting method at present. Thermal and electrical aspects as well as mechanical issues should be considered when designing a LED lighting system. Thermal requirements are usually linked with the mechanical design, meaning that the lighting unit heat sink represents the enclosure assembly. In an attempt to obtain the optimal solution, along with the mathematical approach, simulations are needed in order to validate as well as refine the solution. The paper performs a thorough analysis concerning heat distribution in an 18W chip-on-board LED by performing both simulations and laboratory measurements. Using computational methods, a virtual LED model has been designed having the material properties as input data for a thermal solver. Furthermore, laboratory measurements were made on the LED in order to compare the results with the simulation. This thermal study offers valuable information about the limits of heat evacuation in lighting systems that use high power LEDs.

Keywords- high power LED; thermal simulation; heat sink;

I. INTRODUCTION

Although LED lighting units have many advantages when compared to conventional lighting, an important amount of the absorbed supply power leads to heat generation which has to be properly managed. In order to reduce the heat generated when the LED is running, three aspects need to be considered. The first aspect takes into account the materials and fabrication constraints and the other two refer to proper management of the supply current and efficient thermal management.

The voltage across the LED, the color and the luminous flux are affected by the junction temperature. Consequently, the junction temperature is also a function of ambient temperature and dissipated power [1-10].

From the point of view of the luminous flux the LED as a single junction component is highly efficient; however in high power applications LED arrays are used.

In the LED arrays manufacturing process the final product consists of either high power LED packages electrically connected on the same assembly, which can be translated into a LED module, or of LED chips onto the same PCB resulting in a chip-on-board array (COB). The COB LED arrays are bonded to a substrate that can be integrated on a heat sink or other type of cooling assembly.

In order to achieve proper thermal management of a LED lighting unit not only the thermal behavior is of interest but also the interaction between the materials that are part of the mechanical assembly. The material’s behavior as heat conductor is also of interest for this approach.

II. EXPERIMENTAL APPROACH

The virtual model was designed based on a real 18W high power LED, as indicated in Fig. 1. Material properties were applied to the virtual model in order to use their defined coefficients as input data for the thermal solver.

In the modeling process, in order to simplify the simulation, the LED junction array was designed as a compact silicon area and the thermal influence of the junction proximity materials was neglected. For this approach it was considered that the materials used were homogenous and isotropic and their thermal conductivity was not influenced by the temperature. Moreover, only the convection heat transfer was taken into consideration for the simulation. The estimated value for the convective heat transfer coefficient is usually considered to be between 5 and 20 W/m²K. This convective coefficient can be influenced by the heat sink geometry: fin spacing and their orientation in regard to the gravitational force can both influence it.

In the case of the virtual LED model the solver was set up to calculate the heat evacuation through material in opposition with the LED lens. The model structure has two supply terminals and a thermal pad.
III. RESULTS

The initial conditions that were taken into consideration in order to obtain a solution for the thermal simulation were as follows: ambient temperature \( T_a \) - 21 °C, dissipated power \( P_d \) - 10W and the natural convective coefficient \( K \) - 10W/m²K.

From the thermal solver’s preliminary results it was determined that the LED cannot be used without a heat sink due to the high temperature values for the silicon area, which exceed the temperatures that are considered acceptable for the materials used (Fig. 2).

For this approach a virtual heat sink model was designed as indicated in Fig. 3.

Starting from this model, simulations were performed for two types of materials for the heat sink: aluminum and copper. Figures 4 and 5 indicate the results for aluminum and copper respectively.

The highest determined temperature was 83.88 °C for the aluminum heat sink and 81.97 °C for the copper heat sink.

In order to establish the LED’s limitations in the process of heat evacuation due to the small contact area, new simulation were performed using silver and gold for the heat sink (Fig. 6 and Fig. 7).

For the pure silver heat sink the highest temperature returned by the solver was 81.84 °C. For the gold heat sink the temperature reaches 82.5 °C.

Considering again the aluminum and copper heat sinks, slight modifications on the input data for the simulation were made, this time changing the convective transfer coefficient to 20W/m²K (Fig. 8, Fig. 9).
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Figure 8. Temperature distribution for the aluminum heat sink, \( T_a=21^\circ C, P_d=10W, K=20W/m^2K \)

Figure 11. Temperature distribution for the cooper heat sink, \( T_a=21^\circ C, P_d=10W, K=5W/m^2K \).

For the aluminum heat sink the maximum temperature is 98.35\(^\circ\)C and for copper heat sink the temperature reached 96.35\(^\circ\)C.

The simulation results are presented in Table 1.

<table>
<thead>
<tr>
<th>Material properties used for the heat sink model</th>
<th>Power dissipated as heat (W)</th>
<th>Convective coefficient (W/m(^2)K)</th>
<th>Maximum temperature ((^\circ)C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>10</td>
<td>5</td>
<td>98.35</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>98.35</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>75.99</td>
</tr>
<tr>
<td>Copper</td>
<td>10</td>
<td>5</td>
<td>96.35</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10</td>
<td>96.35</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>20</td>
<td>74.25</td>
</tr>
<tr>
<td>Gold</td>
<td>10</td>
<td>10</td>
<td>82.5</td>
</tr>
<tr>
<td>Silver</td>
<td>10</td>
<td>10</td>
<td>81.84</td>
</tr>
</tbody>
</table>

We can observe that as \( K \) increases, the maximum temperature decreases, regardless of the radiator used (aluminum or copper). For silver and gold the values obtained coincide with those for copper respectively aluminum for the same \( K \). Thus we can conclude that the use of precious metals is not justified.

For the last simulations the ambient temperature was set to 21\(^\circ\)C and the convective coefficient was set to 10W/m\(^2\)K according to the first simulation value. In this case the dissipated heat is 15W.

We can observe that as \( K \) increases, the maximum temperature decreases, regardless of the radiator used (aluminum or copper). For silver and gold the values obtained coincide with those for copper respectively aluminum for the same \( K \). Thus we can conclude that the use of precious metals is not justified.

For the last simulations the ambient temperature was set to 21\(^\circ\)C and the convective coefficient was set to 10W/m\(^2\)K according to the first simulation value. In this case the dissipated heat is 15W.

From this last simulation it was determined that for the aluminum heat sink the maximum temperature recorded was 75.99\(^\circ\)C and changing the heat sink to copper the solver returned 74.25\(^\circ\)C.

In order to draw some conclusions the model properties were changed again considering this time \( K=5W/m^2K \) (Fig.10, Fig. 11).

Figure 9. Temperature distribution for the cooper heat sink, \( T_a=21^\circ C, P_d=10W, K=20W/m^2K \).

Figure 10. Temperature distribution for the aluminum heat sink, \( T_a=21^\circ C, P_d=10W, K=5W/m^2K \).

Figure 12. Temperature distribution for the aluminum heat sink, \( T_a=21^\circ C, P_d=15W, K=10W/m^2K \).
conducted on the model with and without heat sink and using several metals. In order to validate the model, laboratory measurements were conducted with a thermal video camera on the real LED assembled onto a heat sink that was identical to the one used in the simulations. The simulation and measurement results were compared and it was determined that the difference between the two is 5.32 °C, this difference is due to the approximated values for the parameters used in the simulations. It was also determined that changing the convective coefficient values has a powerful impact on the results. Multiplying the convective coefficient by two will lead to a decrease of the maximum temperature with 8°C. Dividing the convective coefficient by two will determine the solver to display a 14°C increase of the maximum temperature, considering the reference value as 10 W/mK. Therefore, considering the results obtained with the LED-heat sink assembly, this passive cooling method may be a part of an improved lighting unit.

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REFERENCES

From figures 12 and 13, the maximum temperature was 115.6 °C for aluminum and 112.27 °C for the copper heat sink. In conclusion for \( P_r = 15\text{W} \) the heat sink should be redesigned since the temperatures reached are too high.

Laboratory measurement were conducted on the real LED for a 1010 mA supply current and at 12 V supply voltage. It has to be mentioned that the dissipated power is 10.3W if 85% from the supply power is converted to heat. The LED case was assembled onto a heat sink whose geometry is identical with the one used in the simulation process. It has been estimated that the value of the natural convective coefficient is 10 W/mK. The results obtained with the thermal video camera after 30 minutes are illustrated in Figure 14. The maximum temperature is 89.2 °C.

![Figure 13. Temperature distribution for the cooper heat sink, \( T_{\text{r}} = 21^\circ\text{C}, P_r = 15\text{W}, K = 10\text{W/m}^\circ\text{K}. \)](image)

We can observe that the measured value is 5.32 °C greater than the value obtained from the simulation. This is due to the approximations used in the model.

Thermal simulation of a lighting component offers an important contribution to the validation of the shape and dimensions that resulted from the calculations. Also, thermal simulation results will display a heat map of the model, without supplying or thermally affecting the real LED.

IV. CONCLUSIONS

The high power LED virtual model was designed using SolidWorks. Thermal simulations were