Experimental Characterization of a MCPCB Replacement Using 500 W/mK Natural Graphite For Cooling High Power LEDs

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Abstract

Discrete power sources, such as light emitting diodes (LEDs), are often mounted on a metal core printed circuit board (MCPCB) in an effort to manage the heat output of these power sources. The metal core, typically aluminum or copper, dissipates heat from the power sources by functioning as a heat spreader. With the increasing heat fluxes from LEDs, a metal core with a higher thermal conductivity will be required to cool future heat fluxes. This paper will introduce a replacement for the MCPCB that utilizes the superior thermal spreading of 500 W/mK natural graphite in conjunction with a unique assembly design using standard FR4 printed circuit boards or flex-circuits. The MCPCB replacement has a ~ 22% reduction in weight when compared to the aluminum MCPCB. The natural graphite solution was shown to reduce the overall thermal resistance by ~ 1.7°C/W, mitigate "hot-spots" and improve temperature uniformity. Both experimental measurements and numerical models were used to analyze the aluminum and natural graphite configurations.

Introduction

The continuing increase in electronics power density, specifically in discrete heat generating electronic components such as LEDs, ASICs, CPUs, GPUs and solid state relays, has required the industry to redesign circuit boards for optimum thermal performance. Today, the metal core printed circuit board provides improved thermal performance over standard FR4 circuit boards, even with thermal vias [1]. The MCPCB commonly consists of a metal core layer (typically aluminum or copper), a continuous dielectric layer and a copper circuit layer. The metal core provides a means for heat spreading as a result of its high thermal conductivity. The increase in the LED junction temperature has been known to have many detrimental effects including the reduction in lifetime, reliability and lumen output [2].

One emerging material in many consumer electronic applications is natural graphite. Natural graphite, with its light weight, formability and high in-plane conductivity of 500+ W/mK, has emerged as a superior heat spreading solution in many consumer electronic applications including cell phones, laptops and plasma display panels (PDPs)[3], [4]. In this work, experiments were performed to compare the thermal performance of a LED mounted on a commercially-available MCPCB compared to a natural graphite replacement.

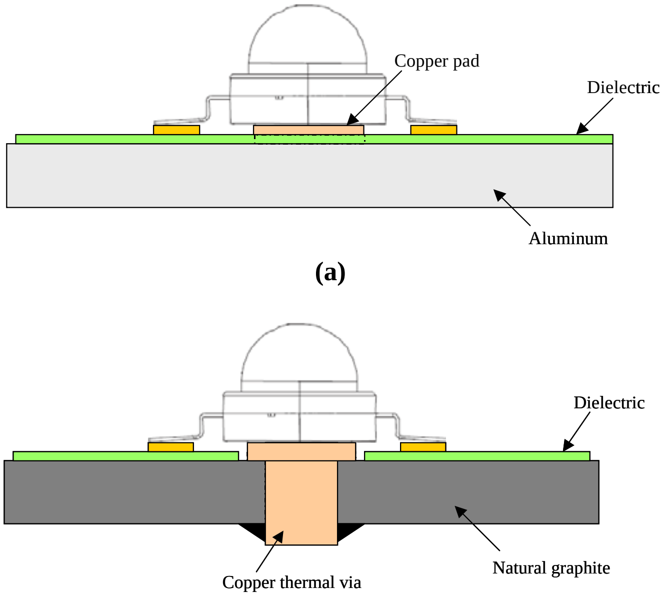
Board Configurations and Setup

Figure 1 shows a Lumileds Luxeon LED mounted on two different board configurations. Figure 1(a) is a schematic of the LED mounted on a commercially available MCPCB with a 1.5 mm aluminum metal core of thermal conductivity 200 W/mK. Figure 1(b) shows a schematic of the LED mounted on a natural graphite heat spreader with an embedded copper thermal via. The tested natural graphite in-plane conductivity was 540 W/mK and the copper thermal via of conductivity 388 W/mK served to conduct heat effectively in the thru-thickness direction. This material is both patented and patent pending and is only available from GrafTech International under the eGRAF® and zSPREADER™ tradenames [5].

Figure 2 shows the thermal resistance network of both board configurations from the LED junction temperature ($T_{junction}$) to the ambient temperature ($T_{ambient}$). The overall thermal resistance is simply the series summation of the individual conduction and convection resistances and can be defined as:

$$R_{overall} = \frac{T_{junction} - T_{ambient}}{q} \tag{1}$$

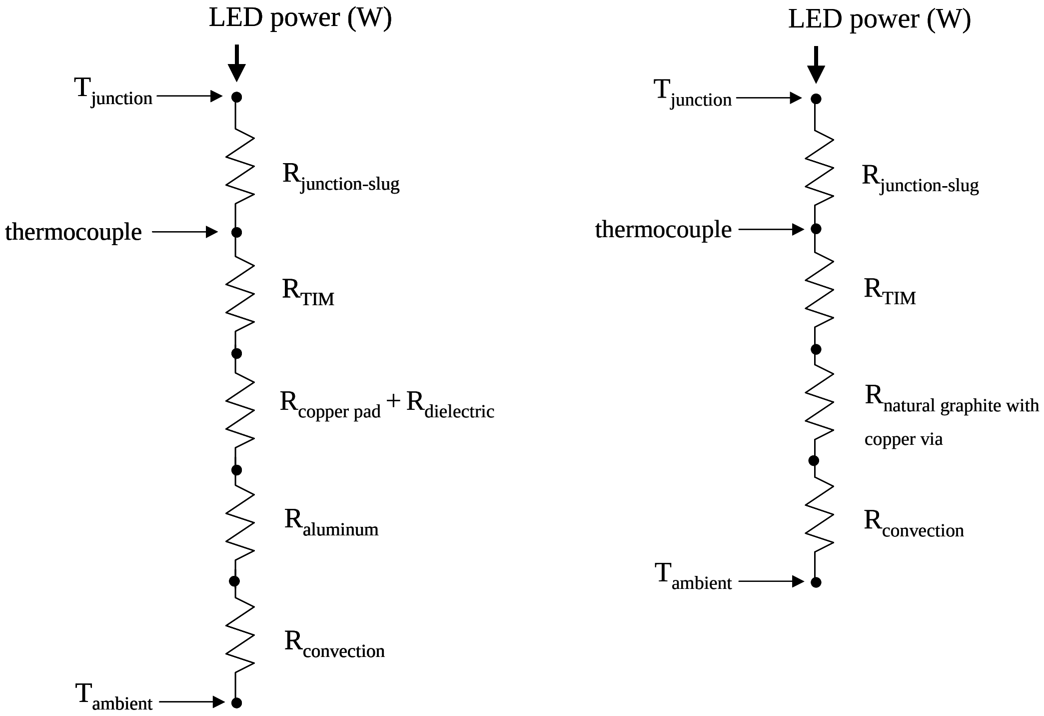
where q is the total power from the LED. The natural graphite board, in addition to its higher thermal conductivity, has the advantage of eliminating the copper pad and dielectric thermal resistances as indicated in the network diagram.



(a)

(b)

Figure 1 - Schematic of a LED mounted on (a) aluminum, (b) natural graphite with embedded copper via



(a) **(b)**

Figure 2 - Thermal resistance network for the (a) aluminum board, (b) natural graphite board

Another benefit includes a weight savings for the proposed replacement as presented in Table 1. The natural graphite solution combined with a flex-circuit results in a ~ 22% weight reduction. With FR4 as an alternative dielectric material, this weight savings will be reduced. Figure 3 shows the experimental test setup in which the board is oriented in the vertical direction. The vertical orientation was chosen because in application, LEDs are usually directed in this orientation. From a thermal standpoint, there is also improved natural convection due to buoyancy effects. A thermocouple of Type T was placed at the interface between the package slug and a thermal interface material (TIM). The location of the thermocouple relative to the overall thermal resistance network is displayed in Figure 2.

Table 1 - Weight savings of natural graphite replacement solution

Aluminum MCPCB	**TOTAL**	22.5 g
Natural Graphite Replacement	**TOTAL**	17.5 g
	Natural graphite + copper via	15.2 g
	LED	1 g
	Flex-circuit	1.3 g
	(FR4 circuit alternative)	(7.3 g)

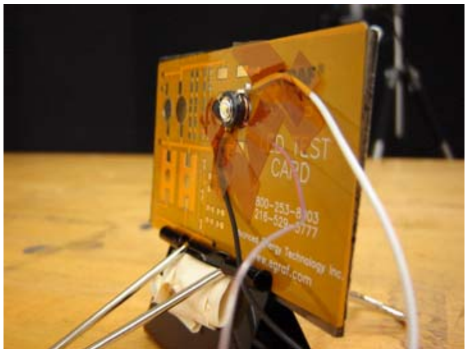


Figure 3 – Image of experimental setup with thermocouple attached

Results

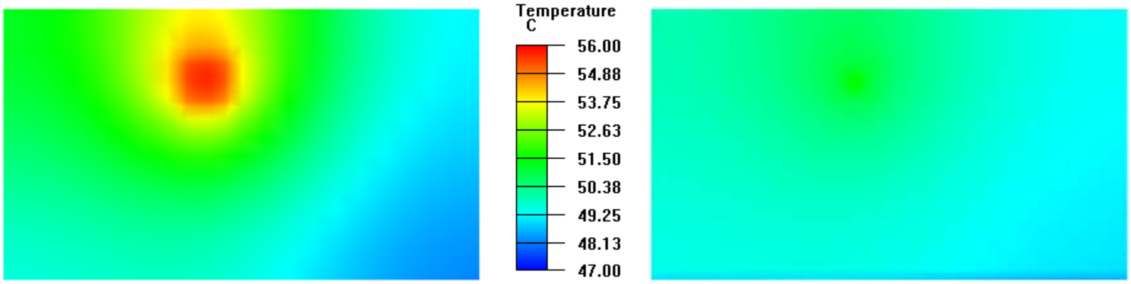
The experimental thermocouple readings for both board configurations are shown in Table 2. The natural graphite solution has a lower thermocouple temperature compared to the commercial aluminum MCPCB. But it is the LED junction temperature that is of interest. Since the LED is encased within a package, the junction temperature cannot readily be measured experimentally. Therefore a numerical model was created to extract the LED junction temperature. The commercially-available computational fluid dynamics (CFD) program, Icepak 4.1.16, was used to solve the mass, momentum and energy equations [6]. For both configurations, the LED package resistance ($R_{junction\text{-}slug}$), obtained from specifications, was set to 9.3°C/W and the material geometries and conductivities were set accordingly. The resulting LED junction temperatures are shown in Table 2. With LED temperatures approaching the threshold of junction failure in a typical application, a ~ 5°C improvement using the natural graphite solution is quite significant. Using Equation 1, the overall thermal resistance can be extracted and shows a ~ 1.7°C/W reduction with the natural graphite solution.

Table 2 - Experimental and numerical results of the two board configurations

	Experimental			**Numerical**
Case	**LED Power (W)**	**Ambient Temperature (°C)**	**Thermocouple at Slug/TIM interface (°C)**	**LED Junction Temperature (°C)**
Aluminum MCPCB	3.33	21	65.7	97.1
Natural Graphite Replacement	3.37	21	61.1	92.2

Negligible heat transfer occurs from the top of the package due to the low conductivity of the encapsulant materials used in packaging the LED. Therefore, it is the board-level thermal solution that becomes the primary path for heat dissipation. In actual application, the MCPCB may be attached to a larger heat spreader such as a chassis. In this case, the thermal resistance from the back of the board to the ambient will be much lower and the conduction resistance of the materials will be increasingly important in the overall thermal resistance.

Figure 4 shows the CFD temperature contours on the backside of the two board configurations where a clear “hot-spot” appears with the aluminum MCPCB. The replacement natural graphite solution, in Figure 4(b), has mitigated the “hot-spot” and improved temperature uniformity due to the high in-plane conductivity of natural graphite and the improved thru-thickness heat transfer using a copper thermal via.



(a) **(b)**

Figure 4 - CFD temperature contours on the backside of the (a) aluminum board, (b) natural graphite board

Conclusions

This paper presented a MCPCB replacement of a traditional aluminum board with a higher thermal conductivity natural graphite material. Experiments were performed using a high power LED mounted on both board solutions. The natural graphite solution reduced the LED junction temperature by ~ 5°C, mitigated “hot-spots”, improved temperature uniformity and had a weight savings of 22% compared to the commercially-available aluminum MCPCB.

References

[1] Stratford, J., Musters, A., “Insulated Metal Printed Circuits – A User-Friendly Revolution In Power Design”, http://www.electronics-cooling.com/html/2004_nov_a3.html, 2004.
[2] Arik, M., Becker, C. Weaver, S., Petroski, J., “Thermal Management of LEDs – Package to System”, 3rd International Conference on Solid State Lighting, Proceedings of SPIE Vol. 5187, 2004.
[3] Smalc, M., Shives, G., Chen, G., Guggari, S., Norley, J., Reynolds, A.R., “Thermal Performance of Natural Graphite Heat Spreaders”, ASME Interpack 2005, San Francisco, CA, 2005.
[4] Norley, J., Reynolds, A., Shives G., Smalc, M., “The Development of Natural Graphite Based Heat Spreaders for Reducing Temperature and Increasing Temperature Uniformity in Flat panel Displays,” SID 2005 International Symposium, P-73, Pgs 562-565, 2005.
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[6] Icepak 4.1.16 User’s Guide, Fluent Inc., 2000.