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APPLICATION OF NANO MATERIALS IN THERMAL MANAGEMENT OF LEDs

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ABSTRACT

Objectives: With the worldwide drive to adopt LEDs as replacement for Incandescent and Fluorescent lamps, Thermal management has taken a central stage to meet the optical, lifetime reliability and cost requirements of the LEDs. Thermal Interface Materials (TIMs) play a crucial role in keeping the device temperature at a level that does not affect the over all performance of the LEDs. However, the TIMs widely used in general electronic industry fall short of the performance required to meet the challenges of High Power LEDs. So, development and application of Nano materials based TIMs has become a necessity and hot topic of research recently. Simulation tools have become unavoidable and necessary to evaluate various Nano materials that either exist or are being developed as TIMs to understand the Thermal performance of LEDs.

Material and Method: In the last decade, Nano materials and Nano composites have been researched and developed with a view to improving Thermal, Electrical Mechanical and Optical properties. While some of them are in production use, many others are at laboratory proof of concept level. In this paper, some of those materials have been highlighted for use in High Power LEDs at device, package and System levels. A simplified model of an LED package mounted on a substrate has been analyzed using commercial Computational Fluid Dynamics software tool FLOTHERM. Different TIM materials have been studied to evaluate thermal performance under Theta-JC (Junction to Case) thermal resistance testing condition. Three different Die attach materials, Two different Copper Die Attach pad materials and Two different Substrate materials have been studied. The details of the materials are explained under the Material and Methods section. Die Attach material properties were taken from [1] and the Copper Die Attach Pad properties were taken from [2].

Results: Results of the analysis of different material combinations show that Die Attach material as a TIM plays an important role because of its contact with the device. Even with the High Thermal conductivity Nano ceramic coated Aluminum substrate material[3], use of the standard Die Attach epoxy based die attach material was found to result in the Highest Device Temperature of 50.8 C under the conditions of analysis. Nano Silver die attach paste in combination with the same High thermal conductivity Nano Ceramic coated Aluminum substrate gave the lowest device temperature of 40.3 C. A comparison of standard Copper (Cu)Die Attach Pad and Copper Pad coated with Few Layer Graphene (Cu-FLG), keeping all other materials the same, showed only a slight improvement of 0.3 C under Theta-JC analysis conditions. The effect of Cu-FLG can be expected to be more at the thin device Interconnect level where the high electrical conductivity and in-plane thermal conductivity of graphene will help spread the heat and reduce hot spot effect.

Conclusion: Exploring, evaluating and applying Nano Materials has become essential and inevitable to meet the Thermal management challenges of High Brightness LEDs. Simulation tools are helpful to do the evaluation of relative performance of different possible materials. In the current study, simulation results pointed to Silver Nano particle based Die Attach and Nano Ceramic coated Aluminum substrate combination to yield the best results under the Theta-JC test simulation conditions. Similar type of simulations need to be done under other user end conditions to assess the over all performance of materials.

Key Words: LED, Nano Materials, Thermal management

INTRODUCTION

Compared to fluorescent lamps, LEDs are known to have longer life, higher light output, and higher energy efficiency. LEDs are also environmental friendly without the presence of harmful mercury. Despite all these advantages, conversion to LEDs by the users all over the world was slow due to high initial cost and lack of information about their long term benefits. However, in the past about 5 years, through out the world, due to the initiatives by various governments, through awareness programs and financial support, conversion to LEDs is moving at a faster pace.

In High Brightness LEDs, higher driving currents lead to heat dissipation levels that rival or even exceed the heat flux in typical microprocessors reaching 100W/cm^2 and beyond. In order to minimize the cost, LED devices are manufactured in smaller sizes in Flip Chip format. However, the smaller size of the Flip

Chip device and higher driving currents increase the heat flux generated. So, for the Thermal management, Nano materials based TIM solution need to be looked into.

This paper attempts to address a holistic approach to the use of Nano materials in the Thermal management of LEDs at every stage starting at device level and progressing down to package level involving Thermal Interface Materials (TIMs). Applicability of TIMs with nano metal particles using silver and copper, graphene, carbon nanotubes and boron nitride are discussed. Effective thermal management using dielectrics like Nano ceramics on metal substrates for device mounting are highlighted. Representative LED Thermal analysis results using FLOTHERM software at package level are presented.

IMPORTANCE OF THERMAL MANAGEMENT OF HIGH POWER LEDs

An increase in the junction temperature of the LED device can cause decrease in light output of up to 35% going from 25 C to 100 C. Higher LED operating temperature causes shift in emission wave lengths and a reduction in the lifetime of the device. A change in color temperature will result due to the wave length shift. Lumen output will be reduced when there is an increase in the phosphor temperature which reduces the quantum efficiency [4]. Higher operating temperature can also cause material interface delamination, higher stresses, increase in thermal resistance and change in properties. In view of the direct impact that higher device temperatures have on the light out put, color quality, interface stresses and on term reliability of LEDs, it is imperative to address Thermal issue at device, package and system levels.

MATERIAL AND METHODS

A general depiction of an Electronic device such as LED in a system is shown in (Figure-1). Different Thermal Interfaces are indicated as TIM1, TIM2 etc. Where ever there is an interface of materials, there exists an opportunity to reduce the thermal resistance across the interface with the choice of advanced Nano materials based TIMs that are consistent with the reliability requirements. Traditionally, Thermal management meant using big Heat sinks far away from the heat source device. Heat Sinks are placed either on the top device heat spreader side or the bottom Substrate side on which packaged LED is mounted. This is however changing with the need to take advantage of high thermal performance Nano materials based TIMs.

Materials for TIMs

At TIM1 level, where the LED Chip is attached to a metal pad called Die Attach pad or Lid Heat Spreader, material called Die Attach is used. The Die attach materials are typically Epoxy and eutectic solder materials. At TIM2 level, different types of thermal glues and films are used. With the advancements and research in Nano materials, apart from Nano metal particles based pastes, Carbon Nano Tubes (CNTs), Graphene and hexagonal-Boron Nitride are some of the candidates being explored to drastically improve the thermal performance.

Silver Nano particles of the size 40nm are used in nano silver paste which is used as Die attach material. Copper nano particles based pastes are also being developed. CNTs have high thermal conductivity and were initially explored for nano composites. However, Graphene with its better binding property with matrix has been a preferred material recently. Use of graphene varies from Single Layer Graphene (SLG), Few Layer Graphene (FLG), nano flakes fillers for die attach materials and nano flake based film. A thermally improved version of the graphene film has functionalized amino based and azide based silane molecules introduced [5]. Hexagonal Boron Nitride (h-BN) is another material which has high thermal conductivity with the added advantage of being an insulator unlike graphene which has very low electrical resistivity. Thermal adhesives based on Boron Nitride Nano particles have potential use in places where electrical isolation along with thermal performance is required.

Method: Thermal simulations were carried out on a simplified structure consisting of an LED die, Die Attach, Die Attach metal pad, Solder and Substrate. Figure-2 shows this stack up of materials. Three Die attach materials (Low, Medium and High conductivity materials), Two Die Attach Pad materials (One is Standard Copper and the Other is Few Layer Graphene coated Copper) and Two different Substrate materials (One is Standard Ceramic and the other is Nano Ceramic coated Aluminum) were simulated with different combinations. The GaN based LED die was assumed to be 2mm x 2mm x 0.5mm in size with a total power of 3 Watts. Summary of the six different cases analyzed and the Maximum Temperature are given in Table-1. The simulation was done assuming a Heat sink attached to the substrate kept at 35 C. Figre-3 shows the Temperature plots for the six cases analyzed.

RESULTS

The material combinations in Case 4 resulted in the Highest Temperature of 50.8 C which is about 26% higher than Case 3 material combination which resulted in the Minimum Temperature of 40.3 C. Also from Table-1, it is observed that the choice of Die Attach material has the greatest impact on Maximum temperature followed by the Substrate material. It is interesting to note from Case 1 and Case 2 that, using

Cu-FLG Die Attach instead of the standard Cu Die Attach pad, keeping other materials the same, is resulting in only 0.3 C in Maximum temperature.

DISCUSSION

Analysis results show the importance of removing heat from the immediate vicinity of the die as against resorting to bulky heat sinks at the system/module level. The present analysis focused only on Package level analysis. As graphene nano flakes based Die Attach materials and films mature to volume production, they will become candidates to consider. The in-plane conductivity dominance of materials like graphene along with the transparency and high electrical conductivity help address Thermal issue at device level serving as replacement alternatives for metal contacts. Away from the device where high through plane conductivity is required, a combination of graphene 2-D layers connected by CNTs are a choice. Cases where electrical isolation and High thermal conductivity are required Hexagonal Boron Nitride nano flakes based solutions will be useful.

CONCLUSION

Application of Nano materials has become inevitable to address the Thermal issues of high Thermal flux devices like High Brightness LEDs. A holistic approach to minimize the device temperature under continuous operating conditions by applying appropriate Nano material solutions at all levels , such as, device,TIM1,TIM2, Flip Chip underfill, Sub-mount and Substrate is essential and viable. Simulation tools such as FLOTHERM help assess the impact of choice of materials on Thermal performance which was demonstrated using the simplified model of an LED assembly. Further analysis of Thermally induced stresses based on the Thermal analysis is necessary to minimize areas of stress concentration which result in delamination of interfaces which increases the Thermal resistance and serve as moisture traps under humid conditions.

ACKNOWLEDGEMENT

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Table 1: Analysis Results of 6 Cases with different Material Combinations

Component	Component Material	Thermal Conductivity K(W/mK)	CASE 1 Materials	CASE 2 Materials	CASE 3 Materials	CASE 4 Materials	CASE 5 Materials	CASE 6 Materials
LED Die	GaN	125	125	125	125	125	125	125
Die Attach	A) Epoxy	3.5				3.5		
	B) Eutectic	58	58	58			58	
	C) Nano Silver	240			240			240
Die Attach Pad	A) Standard Cu	313	313					
	B) Cu with Few Layer Graphene	376		376	376	376	376	376
Solder	SAC	60	60	60	60	60	60	60
Substrate	A) Ceramic	54	54	54				54
	B) Nano Ceramic coated Al	115			115	115	115	
Heat Sink	Copper	385	385	385	385	385	385	385
Max Temp .C			42.7 C	42.4 C	40.3 C	50.8 C	40.8 C	41.9 C

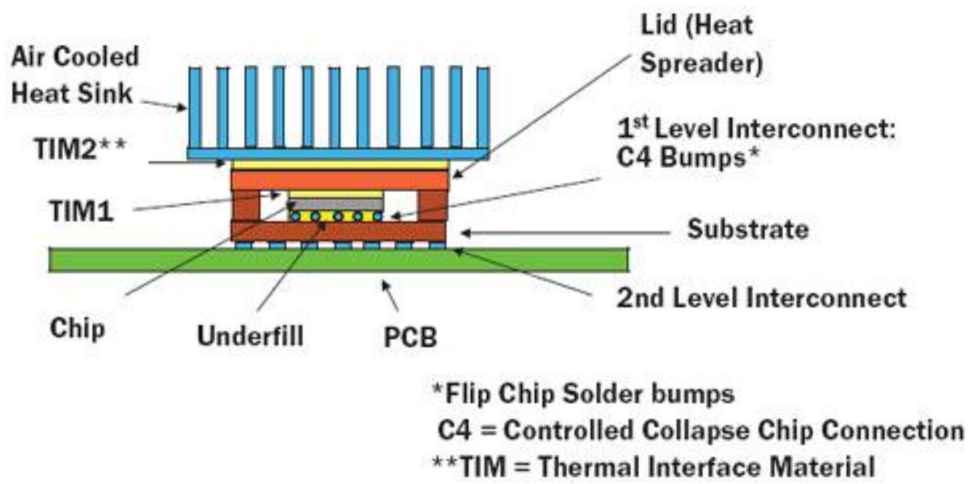


Figure 1: Flip Chip Device with different TIMs. TIM 1 is Die or Chip Attach Material. TIM2 is the material between Chip Heat Spreader and the Heat Sink. Note: Air Cooling may not be available in Lighting Systems.

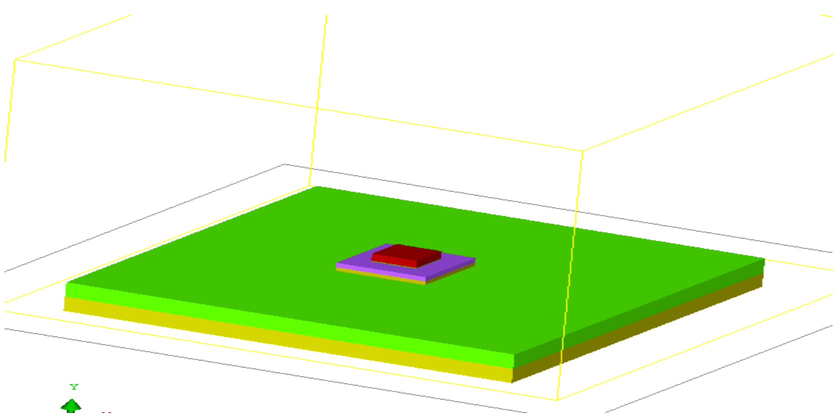
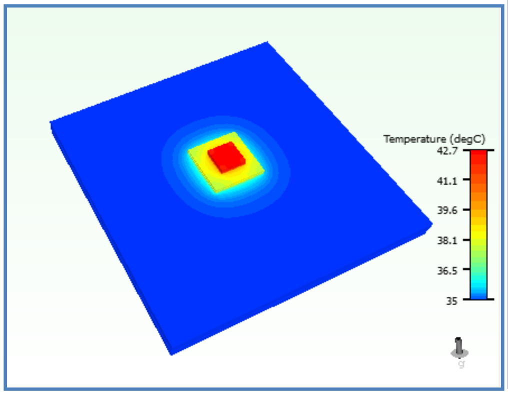
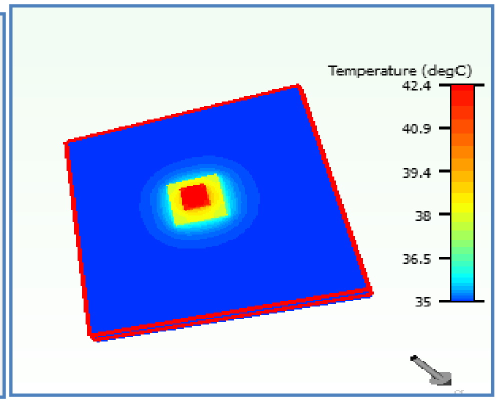


Figure 2: Stack up of Materials considered for Thermal Analysis. Top Red block is LED Chip.

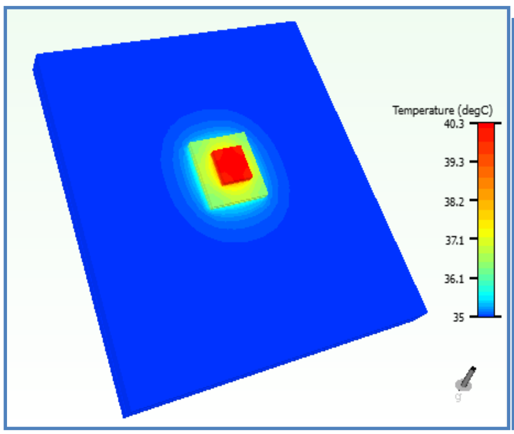
CASE 1: Temperature Plot. Maximum 42.7 C



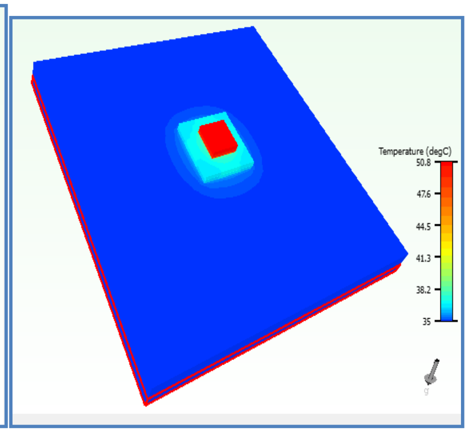
CASE 2: Temperature Plot. Maximum 42.4 C



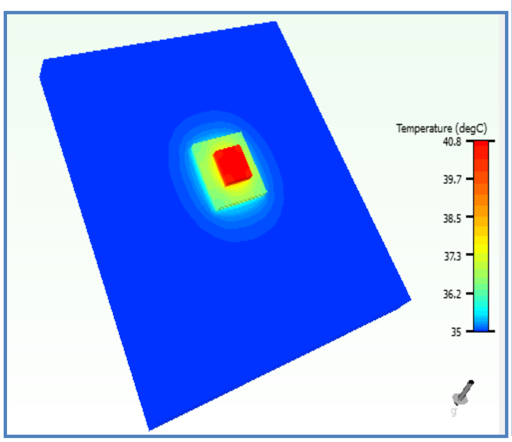
CASE 3: Temperature Plot. Maximum 40.3C



CASE 4: Temperature Plot. Maximum 50.8 C



CASE 5: Temperature Plot. Maximum 40.8C



CASE 6: Temperature Plot. Maximum 41.9 C

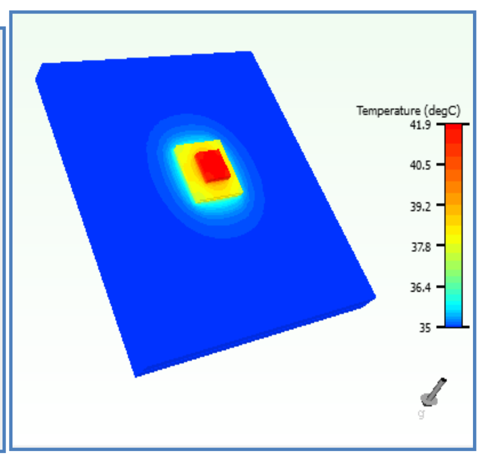


Figure 3: Temperature Plots for the Six Material Combination Cases Analyzed