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Cylindrical Shape Slug Heat Conduction Numerical Analysis using Copper Material

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ABSTRACT

High power light emitting diodes have the edge over the conventional lighting system in terms of efficiency, low energy consumption and long operational lifetime. Nevertheless, the heat dissipation issue of the high power LED bottlenecks the fulfilment of the potential possessed by the LED. The heat dissipation of LED is evaluated in terms of junction temperature. In this work, simulation was carried out to evaluate the heat dissipation of a single chip LED attached to a copper based cylindrical heat slug. The junction temperature and the stress of the LED chip were scrutinized under natural convection condition with applied input power of 0.1 W and 1 W. Ansys version 11 was utilized for the simulation. For input power of 1 W, the maximum junction temperature and Von Mises of 117.44°C and 229.21MPa was exhibited by the GaN based chip.

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INTRODUCTION

High power light emitting diode (LED) is acknowledged as the latest lighting technology due to its supremacy in terms of efficiency, low energy consumption and long life time [1]. The appliance of the LED include lighting source in streets, theme park, workplace, automobile, smart phones and many more. However, the heat dissipation problem faced by the high power LED bottlenecks the fulfillment of the vast advantage and the potential that the LED possesses. [2]. Hence, thermal management of high power LED is noteworthy as the execution in terms of performance and reliability is influenced by the heat produced within the high power LED package. The heat dissipation of high power LED is evaluated in terms of junction temperature [1-8]. Comprehensive endeavor are demonstrated by various researches to address the heat dissipation issue faced by the high power LED. The thermal operations of high power LED modules with two varied circuit boards were compared by Juntunen *et al*. [3]where an innovative substrate based on insulated aluminum material systems (IAMSs) technology was compared with the customary metal core printed circuit boards (MCPCBs). Heat dissipation of high power light emitting diode packages with varied die attach materials was reported by Liou, Chen, Horng, Chiang and Wuu [4] where three types of die attach materials; silver paste, Sn–3 wt.% Ag–0.5 wt.% Cu (SAC305) solder, and SAC305 solder added with a small amount of carbon nanotubes (CNTs) were compared and scrutinized.An innovative method to improve the heat transfer of a LED package with the utilization of aluminum nitride (AlN) was demonstrated by Heo *et al*. [5] where the thermal performance of the AlN ceramic film was evaluated with the existing expoxy based metal PCB and PCB with thermal vias. Ye *et al*. [6] demonstrated a two phase change cooling technique for high power light emitting diode based on microlectromechanical (MEMS) technology. The analysis was carried out on a miniaturized evaporator which was fabricated by wet etching and wafer bonding. Fengze, Daoguo, Zhang, and Dongjing [7] presented an innovative thermal management method for high power light emitting diodes where a vapor chamber printed circuit board was coupled with sunflower heat sink. S. Liu, *et al*. [8] demonstrated optimization of the microjet cooling systems to enhance the heat dissipation high power LED where three types of microjet structures were scrutinized through numerical analysis to evaluate the best possible structure among the three structures.Thus, the assessment of LED junction temperature is important as the performance and life time of LED is prejudiced with

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the junction temperature of the LED. Nevertheless, the junction temperature of an LED are assessed through measurement done by thermocouples which are placed in the along and round the boundary of the packaged chip [2-6,8]. This is due to complexity of direct measurement of the heat dissipated from the LED chip which possesses a small scaled structure. In addition, any evaluation of the junction temperature subsequent to internal structure and component improvisation is costly and time consuming. Therefore, simulations are opted as cost effective and time saving method to implement and test various improvements antecedent to developing the absolute product [7,9]. Hence, in this work simulation was used to assess the heat dissipation of a single chip high power LED package. The evaluation of LED was done in terms of junction temperature and stress endured by the chip during operation mode. The simulation was done using Ansys version 11[10] under natural convection condition. The GaN chip was powered with input power of 0.1 W and 1 W where the junction temperature and the Von Mises stress of the LED chip were evaluated. The LED package under scrutiny consisted of GaN chip attached to a copper based cylindrical heat slug

Methodology:

In this simulation work, Ansys version 11 was used as the computational software. A 3D LED package model which consisted of seven component was designed. The physical dimension of the 3D LED model is in term of (mm) where l=length, w = width and h= height and d=diameter and is stated in the following sequences. The component consist of GaN LED chip with dimension of l=1mm, w=1mm, h=0.25mm, sapphire substrate with dimension of l=1mm, w=1mm, h=0.25mm, die attach with dimension l=1mm, w=1mm, h=0.125mm, copper cylindrical heat slug with dimension of d= 1mm,h=1mm, metal core printed circuit board with dimension of l=8mm, w=6mm, h=0.25mm, thermal interface material with dimension of l=8mm, w=6mm, h=0.125mm and aluminum heat sink with dimension of l=20mm, w=20mm, h=10.625mm. The aluminum heat sink comprises of four fins with fin thickness of 2mm each. The 3D LED model is exemplified in Fig.1. The material properties of the 3D single chip LED model are listed in Table 1. Assumptions were used to simplfy the simulation. The assumption include neglecting the bonded wires and the encapsulant lens of the LED model for simplification in 3D modeling. Next, ideal interface exist between all the LED components. The GaN chip is assumed as the plane of heat source. The thermal radiation effect is neglected in this work. All the materials are assumed to be temperature-independent from 25 °C to 150°C.

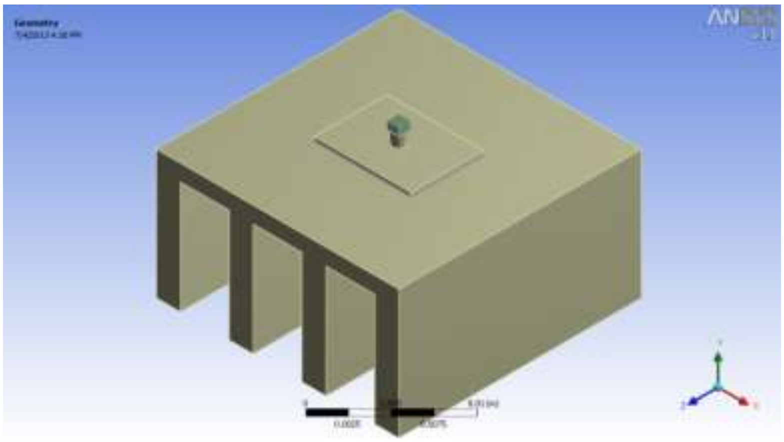

Fig. 1: Single Chip LED model.

Table 1: Material Properties.

Material	Thermal conductivity, k (W/m°C)
GaN	130
Sapphire	42
Au–20Sn (Die Attach)	57
Copper (Heat slug)	401
MCPCB	201
TIM	0.75
Aluminum(Heat sink)	237

For the thermal analysis, the LED model consisted of (SOLID 87) element. The contact regions in the 3D model were designated with (CONTA174) and (TARGE170) element [11]. The 3D LED model was meshed with 218400 tetrahedral elements with grid independence. The ambient tempature of the 3D model was set to 25°C with natural convection condition , h=5 W/m^{2}C occuring at the boundary of the 3D model. Input power of 0.1W and 1W was used in this analysis. As for the stress analysis, the LED model consisted of (SOLID 187) element. The contact regions in the 3D model was designated with (CONTA174) and (TARGE170) element [12].

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In this study, the stress of the LED chip is designated as Von Mises stress which was obtained based on the evaluated junction temperature from the thermal analysis which was used as an input for the LED chip stress analysis.

The junction thermal resistance of the LED was calculated using the following equation:[13]

$$R_{JA} = \left(\frac{T_J - T_A}{P}\right) \quad (1)$$

where R_{JA} signifies the thermal resistance, T_j signifies the junction temperature, T_a signifies the ambient temperature and P signifies the input power[13].

RESULT AND DISCUSSION

This work presents the heat dissipation assessment of a single GaN chip high power LED. The evaluation of LED was done in terms of junction temperature and stress endured by the chip during operation mode. The GaN chip is was attached to a copper based cylindrical heat slug. The characterization was carried out in natural convection condition The GaN chip was powered with input power of 0.1 W and 1 W where the junction temperature and the Von Mises stress of the LED chip were evaluated. All the computation was carried out using Ansys version 11. Fig.2 exemplifies the junction temperature curve of GaN chip at input power of 0.1 W. The curve exhibits an increasing trend with supplied input power and attains a saturation point after 5165s. At input power of 0.1 W, the maximum junction temperature of the GaN chip was 34.24°C. Fig.3 exhibits the junction temperature curve the GaN LED chip at input power of 1 W. The curve demonstrates a similar trend exhibited in Fig.2. The curve reached saturation point after 5165s. At input power of 1 W, the maximum junction temperature of the GaN chip was 117.44°C. Fig.4 illustrates the temperature contour of the GaN chip at input power of 1W. Concurrently under operational mode, stress is induced at the LED chip which correlates with the junction temperature. The Von Mises stress of the GaN chip at input power of 0.1 W is delineated in Fig.5. The stress curve shows an increasing trend with supplied input power and attains a saturation point after 5165s. The Von Mises stress of LED chip is 30.96 MPa at input power of 0.1 W.

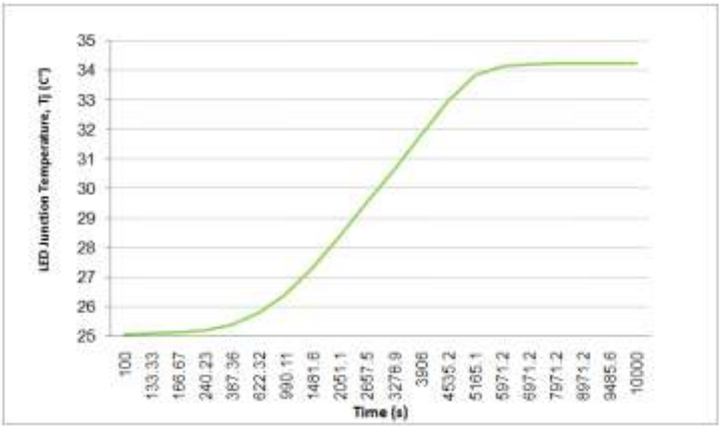

Fig. 2: LED junction temperature at input power of 0.1 W.

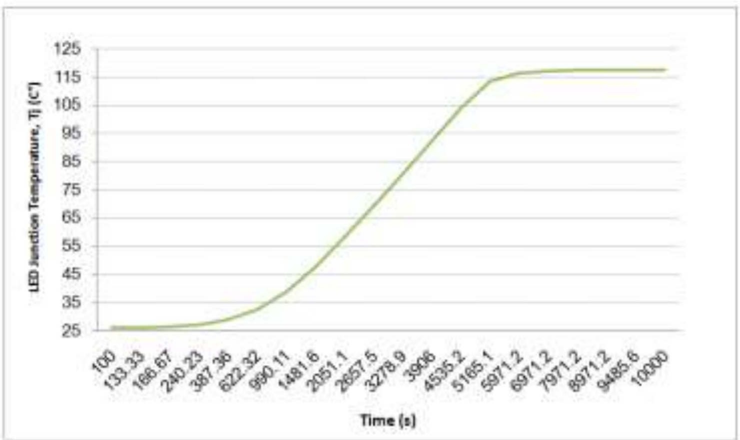

Fig. 3: LED junction temperature at input power of 1 W.

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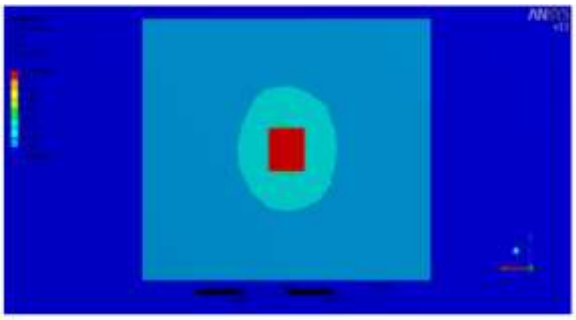

Fig. 4: Temperature contour (top view) of the LED package at input power of 1 W.

Fig.6 exhibits the Von Mises stress of GaN chip at input power of 1 W. A similiar trend of of increment in the Von Mises Stress curve is observed with steady state attained after 5165s.The GaN chip exhibited maximum Von Mises stress of 229.21MPa when powered with 1W. In addition, the thermal resistance of the GaN chip was calculated by utilizing equation (1). For both input power of 0.1 W and 1 W, the GaN chip exhibited a thermal resistance of 92.4 °C/W. Thus, in general, the evaluated result demonstrates that the junction temperature and the Von Mises stress of the GaN chip differ with the respect input power.

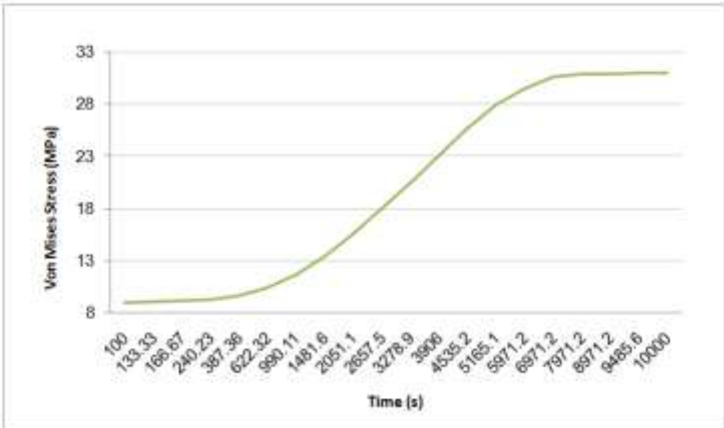

Fig. 5: Von Mises stress of LED at input power of 0.1 W.

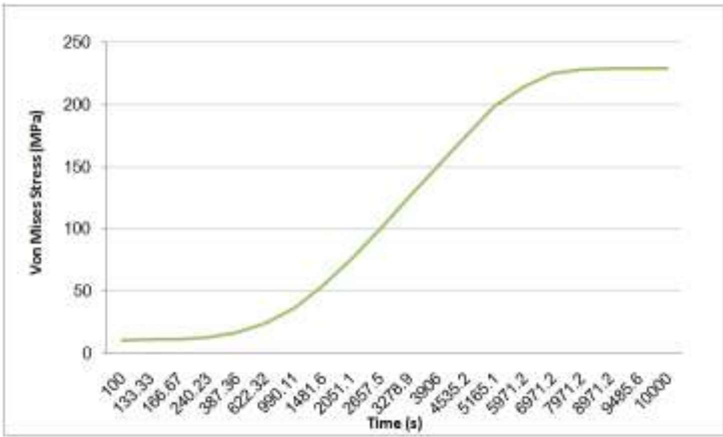

Fig. 6: Von Mises stress of LED at input power of 1 W.

On the other hand, it was observed that the LED junction temperature rises from the ambient temperature of 25°C with respect to time with attained steady state at 5165s for both input power of 0.1W and 1W as illustrated in Fig 2 and Fig 3. Furthermore, the Von Mises stress curve exhibited a similar trend to the junction temperature curve as shown in Fig.5 and Fig.6. This phenomenon takes place when the LED chip is powered, forward bias takes place at the p-n junction of the LED chip. During forward bias, the electrons and holes from the p and n region migrate to the p-n junction. At the p-n junction, recombination and emission of photons occurs analogous to the respective band gap energy of the p-n layer. Thus, during the emission of photons, light is released while heat is produced which is directly transfer from the LED chip and flows into the components of the LED package and out to the ambient atmosphere. This whole cycle will restate until a saturation point is reached. For this reason, the maximum junction temperature of the LED chip is obtained once it reaches steady state. In chorus, the heat produced at the p-n junction of the chip induces stress which influences the reliability of the LED package. Therefore, a correlation between the stress and the junction temperature of the LED chip exist as demonstrated by the evaluated results

Conclusion:

Simulation was carried out to scrutinize the heat dissipation of a single chip high power LED package in terms of junction temperature and Von Mises stress. The simulation was done under natural convection condition with applied input power of 0.1 W and 1 W respectively. The simulated results exhibited that, at input power of 0.1 W, a max junction temperature and Von Mises stress of 34.24°C and 30.96 MPa was eludicated by the GaN chip. On the other hand, at input power of 1 W, the max junction temperature and Von Mises stress of the chip were 117.44°C and 229.21MPa respectively. Hence, by the means of simulation, the characteristics of an LED package can be evaluated and further improvisation can be implemented .

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