Special Issue for International Conference of Advanced Materials Engineering and Technology (ICAMET 2013), 28-29 November 2013, Bandung Indonesia

Advances in Environmental Biology, 7(12) October Special Issue 2013, Pages: 3628-3633

High Power LED Heat Dissipation Analysis via Copper Diamond Slug

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ARTICLE INFO

Article history:
Received 11 September 2013
Received in revised form 21 November 2013
Accepted 25 November 2013
Available online 5 December 2013

Key words:
GaN LED; cylindrical copper diamond composite heat slug; junction temperature; ansys

ABSTRACT

The emergence of high power light emitting diode as a novel electronic based light source is due to its vast advantage in terms of optical efficacy, low power consumption and enhanced life time. However, the performances of the LEDs are dependent on the junction temperature as it is inherited high heat production. Hence, proper evaluation of the junction temperature is very significant. In this paper, the heat dissipation of single chip high power LED attached to copper diamond based cylindrical heat slug was scrutinized through simulation. The heat dissipation was characterized in terms of junction temperature. In addition, the stress of the LED chip is evaluated with varied input power. Ansys version 11 was used for the simulation. The simulated results reveal that at input power of 1 W, the max junction temperature of the LED is 114.69°C.

INTRODUCTION

Since its inception in 1920, the stature of the light emitting diode (LED) has evolved tremendously in the lighting industry [1].With the work function of direct transformation of electrical energy into light, the LED is a novel lighting source which is being utilized vastly in many areas such as traffic lights, car headlights, liquid crystal display (LCD) backlights and many more [2]. There are few benefits exhibited by the LED light source over the conventional light such as enhanced efficiency, low power consumption, protracted life time and eco-friendly [3]. Nevertheless, the lighting efficiency, quality and life time of the high power LEDs are significantly influenced by the excess heat produced by the LED chip which serves as thermal challenge to the LED industry [4]. Hence, by improving the heat dissipation competency of LED devices, the efficiency and life time of LED will be vastly protracted with added energy saving capability. Widespread efforts are placed by various teams of researchers to comprehend the thermal challenges of the high power LED. Xiang, Zhang, Jiang,Liu and Tang [5] scrutinized the relevance of phase change heat transfer technology for high power light emitting diodes package. In their work, an innovation phase change heat sink with improved boiling structure at the evaporation surface consisting of spiral and radial micro-grooves were developed. The heat spreading effect of chip on board (COB) LED array with power electronic substrate was analyzed by Ha and Graham [6] using an analytical thermal resistance model and simulation. The effect of two of power electronic substrates, insulated metal substrates (IMS) and direct bonded copper (DBC) on the junction temperature of LED array were scrutinized. The study of Tsai, Chen and Kang [7] (2012) was emphasized on the characterization of thermal effectiveness of COP package and module based on LED junction temperature via parametric analysis by computational code (ANSYS). Ming, Chun and Wan [8] performed an investigation on chip on plate (CoP) LED package to appraise the effect of phosphorus in terms of thermal resistance and reliability. The packages were subjected to wet and high temperature operation life (WHTOL) and thermal shock tests. Loop heat pipe cooling mechanism for high power LED was demonstrated by Lu, Hua, Liu and Cheng [9]. In their work, the heat dissipation of high power LED was enhanced by a loop heat pipe cooling system. Results of their study showed that the junction temperature of the LED was managed below 100°C with the aid of the loop heat pipe cooling system.Thus, from the previous work of various researches, it is understood that the heat dissipation of high power LED are assessed by junction temperature measurement. The appraisal of LED junction temperature is significant as the overall performance of an LED package is determined by it. If the LED package operates above its recommended junction temperature, the performance and the reliability of the LED will be effected drastically [5-9]. The junction temperature of LED package are measured by thermocouples which are placed in close proximity to the packaged chip[5-9]. However, direct measurement of the junction temperature is difficult due to the miniature structure of the LED chip and package. Moreover, performing a direct evaluation on the junction temperature succeeding various enhancement and variation to the internal structure and component of the LED package for an optimized heat dissipation is time consuming and costly as it requires a large number of testing [9]. Thus, all this work of improvisation and characterization can be done through simulation as it is cost effective and time saving approach to test the various enhancement before implementing it to the actual device self. In this paper, a simulation work is presented where the heat dissipation of single chip high power LED attached to copper diamond based cylindrical heat slug was scrutinized. The heat dissipation is characterized in terms of junction temperature. In addition, the stress of the LED chip is evaluated with applied input power. Ansys version 11 [10] was used for the simulation. Input power of 0.1 W and 1 W were applied. The simulation was carried at under natural convection condition with ambient temperature of 25°C.

Methodology:

Ansys version 11 was utilized to execute the simulation. The simulation comprimizes of two parts. The first part is the thermal analysis. In this part, the LED model is developed with (SOLID 87) element. Next, the contact regions in the LED model were represented with (CONTA174) and (TARGE170) element [11]. Next, the LED model was meshed with 218400 tetrahedral elements with achieved grid independence. The simulation was carried out at ambient temperature of 25°C under natural convection condition h= 5 W/m2C. The LED model was applied with input power of 0.1 W and 1W. The second part of the analysis is the stress analysis. In this part, the LED model was developed with (SOLID 187) [12] element. Next, the contact regions in the LED model were represented with (CONTA174) and (TARGE170) element [11]. In this work, the evaluated junction temperature from the thermal analysis was used as an input to evaluate the stress of the LED chip is designated as Von Mises stress. The end time for both anaysis was set to 10000s.The LED model is divided into seven parts which are GaN LED chip, sapphire substrate, die attach, copper diamond based cylindrical heat slug, metal core printed circuit board, thermal interface material and heat sink. The dimension of the model is listed in Table I where l=length, w = width and h= height and d=diameter. The material properties are listed in Table 2.

Table 1: 3D Model Dimension.

LED Structure	Dimension (mm)
GaN	l=1, w=1, h=0.25
Sapphire	l=1, w=1, h=0.25
Au–20Sn (Die Attach)	l=1, w=1, h=0.125
Copper Diamond (Heat slug)	d= 1,h=1
MCPCB	l=8, w=6, h=0.25
TIM	l=8, w=6, h=0.125
Aluminum(Heat sink)	l=20, w=20, h=10.625

Table 2: Material Properties.

Material	Thermal conductivity,k (W/m°C)
GaN	130
Sapphire	42
Au–20Sn (Die Attach)	57
Copper Diamond (Heat slug)	650
MCPCB	201
TIM	0.75
Aluminum (Heat sink)	237

Assumptions were used for the simulation. They are, first, the only plane of heat source is the GaN chip. Second, the bonded wires and encapsulant lens of the LED model were neglected to simplify the 3D model process. Third,the thermal radiation effect is neglected. It was assumed that 80% of the input power is conveted into heat.The simulation was carried out based on few equation as demonstrated by previous work done by other researches.simulation [13,14]. First is the steady state heat tranfer equation is defined as equation 1[12]:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial T}{\partial z}\right)+\ Q=0 \tag{1}$$

where T and Q exemplifies the temperature and heat source from a chip. the thermal conductivity of the material is denoted by k_x, k_y, k_z[13].The convective heat transfer equation which was applied at the boundary of the model is defined as equation 2 [13]:

$$q = h(T_s - T_\infty) \quad (2)$$

where h specifies convection heat transfer coefficient. Whereas T_s specifies the surface temperature, and finally, T_∞ specifies the ambient temperature.In this work, the junction thermal resistance of the LED was calculated using the following equation 3:[14]

$$R_{JA} = \left(\frac{T_J - T_A}{P}\right) \quad (3)$$

where R_{JA} is the thermal resistance, T_j is the junction temperature, T_a the ambient temperature and P is the input power[14].

RESULT AND DISCUSSION

In this paper, a simulation work is presented where the heat dissipation of single chip high power LED attached to copper diamond based cylindrical heat slug was scrutinized The heat dissipation is characterized in terms of junction temperature. In addition, the stress of the LED chip is evaluated with applied input power under natural convection condition at ambient temperature of 25°C. All the results presented here were computed through Ansys version 11. The junction temperature curve of the LED package input power of 0.1 W is elucidated in Fig.1. It is observed that an increasing trend is exhibited by the temperature curve with supplied input power. The curve reaches a saturation point after 5200s. For an input power of 0.1 W, the maximum junction temperature of the LED package was 33.96°C. On the other hand, the junction temperature curve of LED chip at input power of 1 W is illustrated in Fig.2. The junction temperature increase initially and reaches a saturation point after 5200s. For an input power of 1 W, the maximum junction temperature of the LED package was 114.69°C. It is observed that chip of the LED has the maximum temperature compared to the other part of the LED package .Concomitantly, stress is induced at the LED chip under operational mode and it exhibits a correlation with the junction temperature. Fig.3 delineates the Von Mises stress of the LED chip at input power of 0.1 W. The stress curve exhibits a similar trend to the junction temperature curve and it reaches a saturation point after 5200s. For an input power of 0.1 W, the Von Mises stress induced at by the LED chip is 14.24MPa. Fig .4 elucidates the Von Mises stress of LED chip for an input power of 1 W. The Von Mises Stress curve increases initially and reaches steady state after 5200s. For an input power of 0.1 W, the Von Mises stress induced at by the LED chip is 105.04MPa. Equation 3 was utilized to calculate the thermal resistance of the LED chip. The thermal resistance of the LED chip at both input power of 0.1 W and 1 W were the GaN chip exhibited a thermal resistance of 89.6 °C/W. As a whole, it was observed that the junction temperature and the Von Mises stress of the LED varies with respect to the input power. Fig. 5 illustrates the temperature contour of the LED package. From Fig.5 it is observed that the maximum temperature occurs from the LED chip as indicated by the red region.

Furthermore at both input powers of 0.1 W and 1 W, it was observed that the junction temperature curve of the LED augments from the initial temperature of 25°C with respect to time and reaches a saturation point after 5200s as shown respectively in Fig 1 and Fig 2. This similar trend was also exhibited by the stress curve as well which is elucidated in Fig.3 and Fig.4. When the input power is applied to the LED chip, forward bias emerges at the p-n junction of the LED. This enables the electrons and holes from the p and n section migrate to the p-n junction which triggers the recombination and emission of photons at the p-n jucntion and it is corresponding to the respective band gap energy of the p-n material. The emission of photons releases light and simultaneously heat is produced as only 20% of the input power is converted to light and the rest is converted to heat and it is directly transfer from the LED chip into the the LED package [1-9,13,14]. This whole process repeat itself until a steady state is achieved. Consequently, the maximum junction temperature and the Von Mises stress of the LED chip is evaluated after the steady state. In view of that, it explains the correlation the junction temperature and the stress of the LED chip.

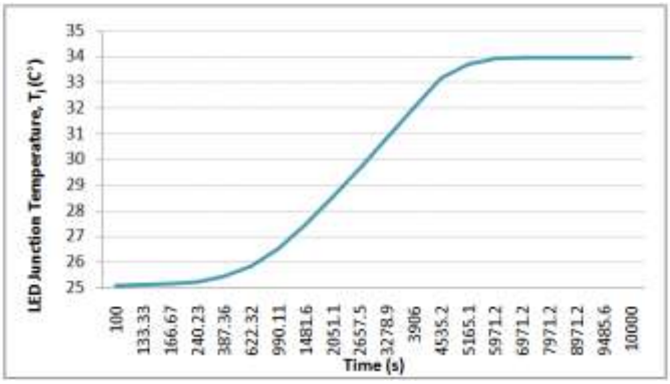

Fig. 1: LED junction temperature at input power of 0.1 W.

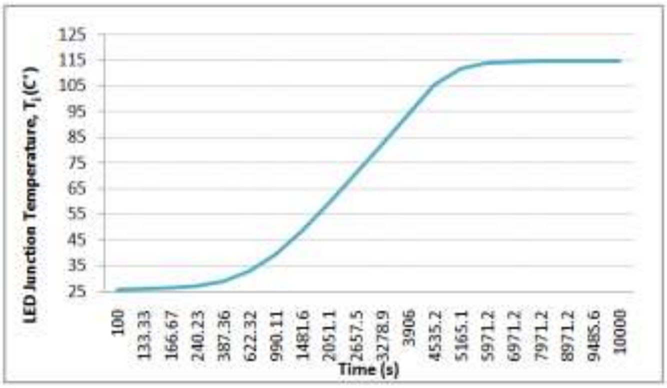

Fig. 2: LED junction temperature at input power of 1 W.

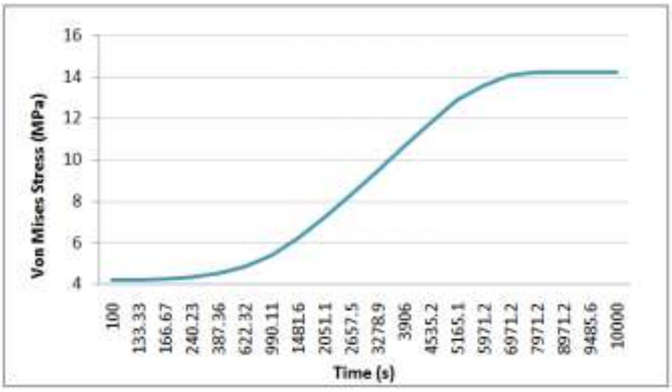

Fig. 3: Von Mises stress of LED at input power of 0.1 W.

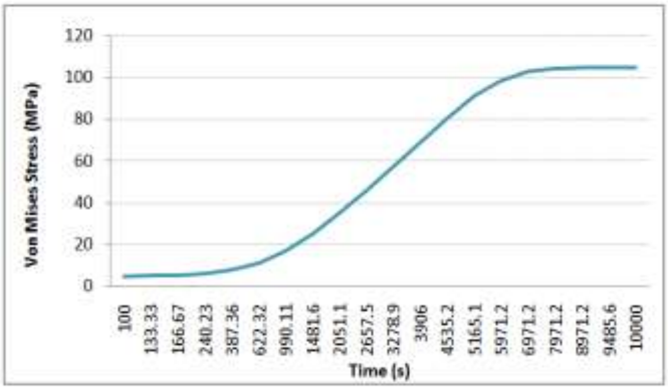

Fig. 4: Von Mises stress of LED at input power of 1 W.

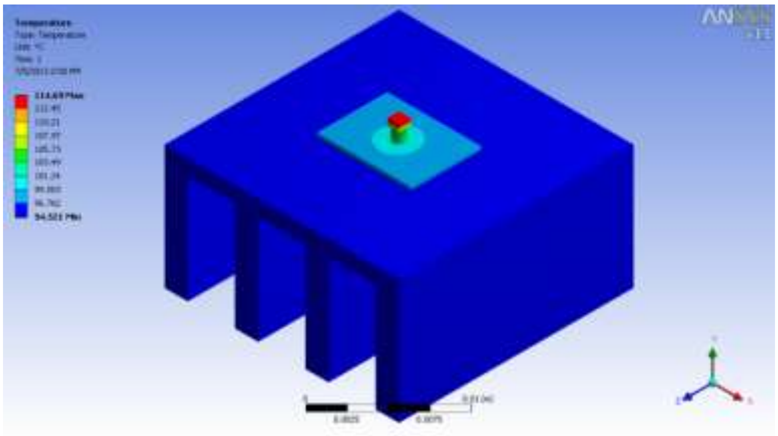

Fig. 5: Temperature contour of the LED package at input power of 1 W.

In addition, increase in junction temperature will result in lumen degradation, augmentation in parasitic series resistance, short circuit, decrease of the forward voltage, reduced light output, wavelength and color changes[14]. Therefore it is essential to evaluated the junction temperature of the LED as the overall reliability of the device is very dependent on it[1-9,13,14]. Hence, the excessive heat generated by high power LEDs directly affects the overall performances of the LED. Therefore, thermal management of LEDs is a main issue which needs to be address in order to fully utilize its potential as a prime lighting source in the near future[1-9,13,14].

Conclusion:

In this paper, a simulation work is presented where the heat dissipation of single chip high power LED attached to copper diamond based cylindrical heat slug under natural convection condition was scrutinized with varied input power. The findings of this work are summarized as below:

i) For input power of 0.1 W, the max junction temperature and Von Mises stress of the LED chip were 33.96°C and 14.24MPa respectively.

ii) For at input power of 1 W, the LED chip exhibited a max junction temperature and Von Mises stress of the chip were 114.69°C and 105.04MPa respectively.

iii) Maximum temperature occurs at the LED chip.

iv) Steady state of both of the junction temperature curve and Von Mises stress were reached after 5200s.

ACKNOWLEDGMENT

The authors would like to thank and acknowledge the School of Microelectronic Engineering,Universiti Malaysia Perlis for their support and facility. The authors appreciation are extended to the Ministry of Higher Education for the support given

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