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Heat Dissipation Analysis under Natural Convection Condition on High Power LED

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ABSTRACT

As the technology downscales with superior power and increased package density, the thermal effects of the high power LED are significant. Thus, the operating junction temperature of the high power light emitting diodes has to be reduced. In this paper, evaluation on single chip high power light emitting was done. The prime motive of this work was to assess the effect of heat slug size on the junction temperature and stress of LED chip under natural convection condition at ambient temperature of 25°C. Two sizes of rectangular heat slug were used. Simulation was carried out using Ansys version 11. Input power of 0.1W and 1W was applied to LED. Simulated results indicated that a larger slug size is favorable for a lower operating junction temperature and stress of the LED chip.

INTRODUCTION

Light emitting diode (LED) technology is vastly applied in diverse lighting systems. As the technology downscales with superior power and increased package density, the thermal effects of the LED have become more significant. Augmented chip temperature, variation in device parameters and reduction is device reliability is the key impact of the technology downscaling. Therefore, the most important aim of thermal management of high power light emitting diodes is to reduce the operating junction temperature of the high power light emitting diodes. With the improvement of the heat dissipation, the operating junction temperature can be reduced and the efficiency and the reliability of the LED can be enhanced [1]. Various methods and solution are demonstrated to overcome the thermal challenges faced by the high power LEDs. The feasibility for a LED cooling system for sequential based LED trigger was assessed by Song-Bor [2]. The thermal performance of the LED, heat sink base and fin structure was evaluated through simulation. The performance of high power LED with a novel form vapor chamber coupled fin heat sink was evaluated by Xiaobing et al.[3] and the performances was compared with a only fin heat sink based LED. The influence of printed circuit boards on the thermal performance of LED was evaluated by Nicolics, Langer, Lutschounig, Lang, and Huber [4]. Three types of printed circuit board were used for comparison in terms of thermal performances and temperature differences. The application of thermal interface materials as cooling interface in LEDs were scrutinized by Jun, Meilin,Shuzhi, Weiqiao, and Jianhua [5] where three types of thermal interface materials were used and the thermal performances were compared through thermal and optical-electro test.Therefore, as seen by the work demonstrated by other researches, it is acknowledged that the junction temperature of LED is a significant element which influences the performance and reliability of the LED. This is due to excess heat produced by at junction of the LED which will inflict reliability issues to the LED package[1-8]. Therefore, the heat needs to be dissipated out competently to the surroundings through a proper thermal path. The thermal conduction path in a packaged LED are influenced by several factors such as heat slug size, slug material, type of thermal interface material and heat sink designs [9]. Improving any of the factors stated would assist to enhance the heat dissipation of a packaged LED. However, to implement any improvement work directly and to test it is tedious, costly and timing consuming [1,9]. Therefore, simulation can be used to examine improvements as it enables to perform the testing without any limited number of run which is cost effective prior to implementing it in the real device itself [1,6-8].In this paper, a single chip high power LED package is designed to evaluate the heat dissipation characteristic through simulation. The prime motive of this work is to evaluate the effect of heat slug size on the junction temperature of LED chip under natural convection condition. Two sizes of rectangular heat slug were used and the junction temperature of LED package was evaluated. In addition, the stress of the LED chip with varied heat slug size was also scrutinized. Simulation was carried out using Ansys version 11[6-8]. The LED was power with input power of 0.1W and 1W at ambient temperature of 25°C.

Methodology:

The simulation was performed through Ansys version 11. Assumption were set to simplify the simulation process. First, the bonded wires and the encapsulant lens of the LED package were neglected. Second, each parameter of the material is temperature-independent from 25 °C to 150°C with perfect interface between all materials. Thrid, the thermal radiation effect was shunned .Fourth, the GaN chip was the only uniform plane of heat source and 80% of the input power is converted into heat and transferred is into the LED package. Two 3D LED package with varied heat slug size, R1 and R2 was developed for the investigation. The R1 and R2 abbreviation denotes size of the rectangular heat slug of l=1 mm, w=1 mm ,h= 1 mm and l=5 mm, w=5 mm ,h= 1 mm respectively. The 3D LED model includes a single GaN LED chip attached to sapphire substrate die attach, aluminum based rectangular heat slug with varied size, metal core printed circuit board, thermal interface material and four finned heat sink and the the dimension of the model is listed in Table 1 where l=length, w = width and h= height and d=diameter. Table 2 shows the material properties. Fig 1 illustrates the varied heat slug size (in green) of the 3D model.

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
Aluminum (Heat slug) R1 R2	 l=1, w=1, h=1 l=5, w=5, 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
Aluminum (Heat slug)	237
MCPCB	201
TIM	0.75
Aluminum(Heat sink)	237

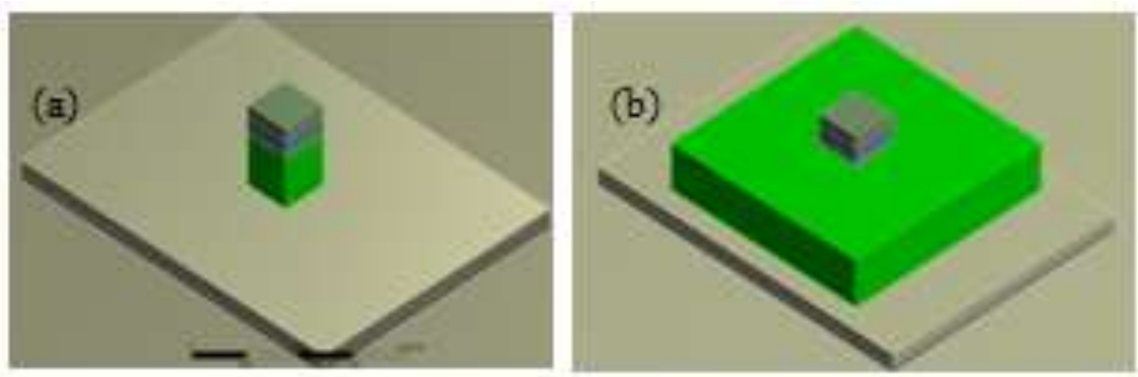

Fig. 1: 3D Single Chip LED model with varied heat slug (a) R1 (b) R2.

The simulation analysis has two parts, which are thermal analysis and stress analysis. For the thermal analysis, (SOLID 87)[6-8] element was used to develop the model. The contact regions of the model consisted with (CONTA174) and (TARGE170) element [6-8]. Next, the LED model with R1 heat slug was meshed 229302 tetrahedral elements with grid independence. As for the LED model with R2 heat slug was meshed with 220016 tetrahedral elements. Ambient temperature was set to 25°C with natural convection condition h= 5 W/m^2C. The LED chip was applied with input power of 0.1 W and 1W respectively. For the stress analysis, (SOLID 187) element was used to develop the 3D model [6-8]. The contact regions of the model consisted with (CONTA174) and (TARGE170) element [6-8].In addition, the equation 1 was utilized to compute junction thermal resistance of the LED:[9]

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

where R_{JA} defined as the thermal resistance, T_j defined as the junction temperature, T_a defined as the ambient temperature and P defined as the input power [9].The simulation was carried out based on the Fourier's law of heat conduction and Newton Law of cooling. The Fourier's law of heat conduction is stated as [11]:

$$Q_T = \frac{k_w}{y_w} A_T (T_1 - T_2) \tag{2}$$

where Q_t specifies the total quantity of heat transferred per unit time, k_w specifies the thermal conductivity of the wall material, y_w specifies the wall thickness,A_T specifies the total area of the wall and T_1 ,T_2 specifies the temperature of hot and cold surfaces of the wall respectively. On the other hand, the Newton Law of cooling is stated as[11]:

$$Q_{conv} = h\,A\,\Delta T \tag{3}$$

where Q_{conv} specifies the amount of heat transferred through convection (W); h specifies the heat transfer coefficient (W/m^2K); A specifies surface area (m^2);ΔT specifies temperature gradient across the material (°C) which is the difference between the surface temperature and ambient air temperature.

RESULT AND DISCUSSION

In this paper, a single chip high power LED package was designed to evaluate the heat dissipation characteristic through simulation. The effect of heat slug size on the junction temperature of LED chip under natural convection condition was investigated. Two types of rectangular heat slug size were used and the junction temperature of LED package was evaluated. In addition, the stress of the LED chip with varied heat slug size was also scrutinized. The simulation was carried out with input power of 0.1W to 1W at ambient temperature of 25°C. All the results presented here were computed by Ansys version 11. Fig. 2 illustartes the junction temperature curve of the LED package with varied heat slug size at input power of 0.1 W and 1W. The junction temperature of the LED package with R1 heat slug attained junction temperature of 34.44 °C and 119.43 °C at respective input power of 0.1 W and 1W which is represented by the blue solid line in Fig.2. On the other hand, the junction temperature of the LED package with R2 heat slug recorded the junction temperature of 33.79 °C and 112.91 °C at respective input power of 0.1 W and 1W and is represented as the red solid line in Fig.2.

The Von Mises stress of the LED chip with varied heat slug size at input power of 0.1 W and 1W is elucidated in Fig.3. The Von Mises stress of the LED package with R1 heat slug exhibited a stress of 36.13 MPa and 276.03MPa for respective input power of 0.1 W and 1W, and is represented by the blue solid line in Fig.3. Furthermore, the Von Mises stress of the LED package with R2 heat slug exhibited a stress of 35.42 MPa and 263.82 MPa for respective input power of 0.1 W and 1W, and is represented by the red solid line in Fig.3. The thermal resistance of the LED package with varied heat was calculated using equation (1). At both input power, the thermal resistance of the LED package with R1 heat slug was 94.4°C/W and 87.91°C/W for the LED package with R2 heat slug which is illustrated in Fig.4.

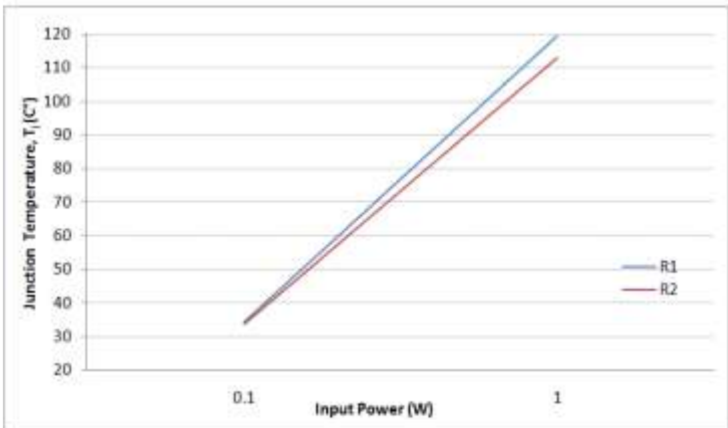

Fig. 2: Junction temperature of the LED package with varied heat slug size at input power of 0.1 W and 1W.

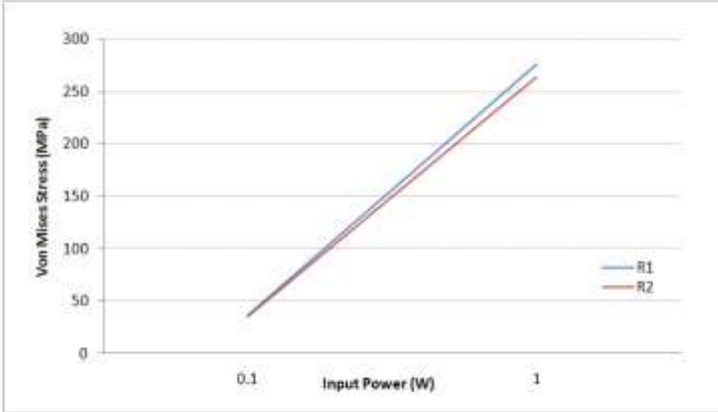

Fig. 3: The Von Mises stress of the LED chip with varied heat slug size at input power of 0.1 W and 1W.

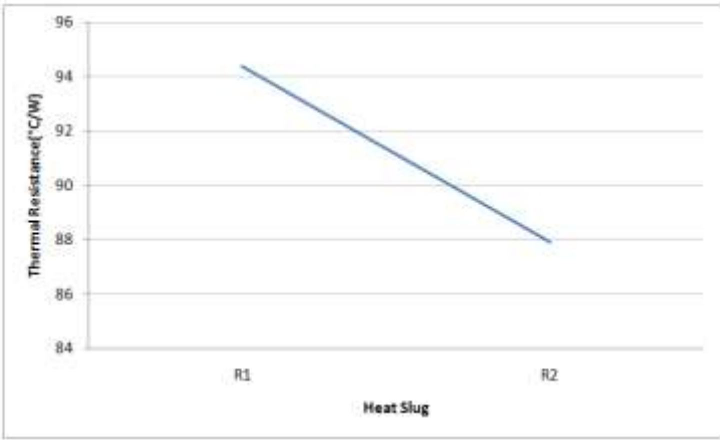

Fig. 4: The thermal resistance of the LED chip with varied heat slug size at input power of 0.1 W and 1W.

From the results, it is observed that the heat dissipation of the LED package with R2 heat slug is better as it exhibited a lower junction temperature compared to the LED package with R1 heat slug. The junction temperature difference between the two LED package with varied heat slug was 6.52°C for an input power of 1W. Also, the Von Mises stress of the LED chip with R2 heat slug is lower compared to the LED chip with R1 heat slug with the Von Mises stress difference of 12.21 MPa. Therefore, on the whole, the simulated results indicated that a larger slug size is favorable for better heat dissipation. In addition, when the surface area of the heat slug is increased, the Von Mises stress and the thermal resistance of the LED chip decreases.The surface area of the heat slug influences the junction temperature and the heat dissipation of the LED chip as described in the exclusive review done by Chang, Das, Varde and Pecht [10]. In their review paper, it was stated that a larger size heat slug would improve the heat dissipation of the LED package. Hence, when the surface area of the heat slug is increased, a decrease in junction temperature was observed. This is because each individual particle from the ambient acts on the surface of the LED package and it is drawn in in the heat conduction process. The heat slug with a wider area has more surface particles working to conduct and transfer heat. As such, the rate of heat transfer is directly proportional to the surface area through which the heat is being conducted, which lowers the junction temperature and the stress of the LED chip. This trend is justified by the Fourier's law of heat conduction equation (Equation 2) and Newton Law of cooling (Equation 3) . From equation 2 it can be seen that the total area, A_T of the heat slug is related with the heat conduction of the LED package. As total area of the heat slug is increased, the heat conduction of the LED package enhances and the junction temperature of the LED chip is reduced[11].

Conclusion:

In this paper, a single chip high power LED package was designed to evaluate the heat dissipation characteristic through simulation. The effect of heat slug size on the junction temperature of LED chip under natural convection condition was investigated. Two types of rectangular heat slug size were used and the junction temperature of LED package and the stress of the LED chip were evaluated. The simulated results indicated that a larger slug size is favorable for lower operating junction temperature and stress of the LED chip.

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REFERENCES

[1] Zahner, T., 2007. "Thermal management and thermal resistance of high power LEDs," in *Thermal Investigation of ICs and Systems, 2007. THERMINIC 2007. 13th International Workshop on*, pp: 195-195.

[2] Song-Bor, C., 2009. "The thermal analysis of sequential LED driven mode," in *Microsystems, Packaging, Assembly and Circuits Technology Conference, 2009. IMPACT 2009. 4th International*, pp: 203-206.

[3] Xiaobing, L., H. Run, G. Tinghui, Z. Xiaolei, C. Wen, M. Zhangming and L. Sheng, 2010. "Low thermal resistance LED light source with vapor chamber coupled fin heat sink," in *Electronic Components and Technology Conference (ECTC), 2010 Proceedings 60th*, pp: 1347-1352.

[4] Nicolics, J., G. Langer, F. Lutschounig, K.J. Lang and R. Huber, 2010. "Impact of printed circuit board technology on thermal performance of high-power LED assembly - experimental results," in *Electronic System-Integration Technology Conference (ESTC), 2010 3rd*, pp: 1-6.

[5] Jun, W., Z. Meilin, L. Shuzhi, Y. Weiqiao and Z. Jianhua, 2010. "Study on the application of thermal interface materials for integration of HP-LEDs," in *CPMT Symposium Japan, 2010 IEEE*, pp: 1-5.

[6] Sauli, Z., V. Retnasamy, R. Vairavan, W.M.W.N. Haimi, H. Kamarudin, Y. Neoh Fung and N. Khalid, 2013. "Solid State Lighting Stress and Junction Temperature Evaluation on Operating Power," in *Computer Modelling and Simulation (UKSim), 2013 UKSim 15th International Conference on*, pp: 290-293.

[7] Vairavan, R., Z. Sauli, V. Retnasamy, R.C. Ismail, N.I.M. Nor, N.S. Nadzri and H. Kamarudin, 2013. "High Power LED Thermal and Stress Simulation on Copper Slug," in *Computer Modelling and Simulation (UKSim), 2013 UKSim 15th International Conference on*, pp: 294-298.

[8] Sauli, Z., V. Retnasamy, R. Vairavan, R.C. Ismail, N. Khalid, M.F.C. Husin and H. Kamarudin, 2013. "Stress and Temperature Simulation Using Copper-Diamond Composite Slug," in *Computer Modelling and Simulation (UKSim), 2013 UKSim 15th International Conference on*, pp: 299-303.

[9] Shin, M.W. and S.H. Jang, 2012. "Thermal analysis of high power LED packages under the alternating current operation," Solid-State Electronics, 68: 48-50.

[10] Chang, M.H., D. Das, P.V. Varde and M. Pecht, 2012. "Light emitting diodes reliability review," *Microelectronics Reliability,* 52: 762-782.

[11] Butterworth, D., 1977. ”Introduction to heat transfer” (Vol. 18). Oxford University Press for the Design Council, the British Standards Institution and the Council of Engineering Institutions.