HIGH POWER LED THERMAL DISSIPATION ANALYSIS VIA SLUG AND HEAT SINK

by

RAJENDARAN A/L VAIRAVAN

(1130110623)

A thesis submitted in fulfillment of the requirements for the degree of Master of Science (Microelectronic Engineering)

School of Microelectronic Engineering
UNIVERSITI MALAYSIA PERLIS

2013

GRADUATE SCHOOL

UNIVERSITI MALAYSIA PERLIS

PERMISSION TO USE

In presenting this thesis in fulfillment of a post graduate degree from Universiti Malaysia Perlis, I agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by my supervisor or, in their absence, by Dean of the Graduate School. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my supervisor's written permission. It is also understood that due recognition shall be given to me and to Universiti Malaysia Perlis for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or make other use of material in whole or in part of this thesis are to be addressed to:

Dean of Centre for Graduate Studies

Universiti Malaysia Perlis

No. 112 & 114, Tingkat 1,Blok A, Taman Pertiwi Indah

Jalan Kangar-Alor Setar, Seriab

01000 Kangar

Perlis Indera Kayangan

Malaysia

ACKNOWLEDGEMENTS

Looking back over my Master's study, it was not only the time to pursue an academic degree but also a growth process for me. These valuable experiences will be cherished for the rest of my life. It could not have been possible to complete this degree without guidance, encouragement and support from the wonderful people around me. First of all, I would like to express my heartfelt gratitude and appreciation to my supervisor Major Assoc Prof Dr. Zaliman Sauli and my co-supervisor Captain Dr. Vithyacharan Retnasamy. I am deeply indebted to them for their precious time, patience, guidance throughout the course of this project and in various aspects of my life. Their suggestions and insightful comments have assisted me in completing the project. Words are not enough to express my sincere appreciation for everything they have done for me.

I am also very grateful to my mentors Mr. Steven Taniselass, Mr. Wan Mokhdzani, Mr. Hafiz, Mr. Ruhaizi and Mrs. Hafizah for their valuable input and moral support throughout the course of my studies.

Thank you to the Dean and all the staffs from School of Microelectronic Engineering for their unconditional support and facility. Thank you to the Vice Chancellor of UniMAP and the Research and Development Unit of UniMAP for their financial support of my postgraduate study. Thank you to Mrs. Rozila and Mrs. Suhana of R&D UniMAP for their invaluable assistance. Thank you to Mrs. Intan, Mrs. Zehan, Mr. Muzamir, Mr. Shaifful and all the staffs from the Centre of Graduate Studies of UniMAP for their valuable assistance and management during the course of my postgraduate study.

I am indebted to my colleagues and friends. The time spend together will never be forgotten. In no particular order, thanks are deserved to Moganraj, Ong Tee Say, Shakirina, Aaron, They Yee Chin, Khor Kang Nan, Lim Wei Jer, Izatul, my fellow SHARKZ and others for their support in the various stages of the study. Thank you to dear Ghirubaagiri for her pillar of strength and support throughout my postgraduate study.

Finally, the dearest and greatest thanks however belong to my parents: Mr. Vairavan Ramanathan and Mrs. Premalatha Subbiah, and my dearest brother, Kumeresen Vairavan who has supported and encouraged me through all these years at University Malaysia Perlis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

LED	Light Emitting Diode
GaN	Galium Nitrate
Al	Aluminum
Cu	Copper
Cu/Dia	Copper Diamond
MCPCB	Metal Core Printed Circuit Board
TIM	Thermal Interface Material
Al_2O_3	Sapphire
3D	Three dimensional
R1	Rectangular heat slug with size of l = 1 mm, w = 1 mm, h = 1 mm
R2	Rectangular heat slug with size of l = 2 mm, w = 2 mm, h = 1 mm
R3	Rectangular heat slug with size of l = 3 mm, w = 3 mm, h = 1 mm
R4	Rectangular heat slug with size of l = 4 mm, w = 4 mm, h = 1 mm
R5	Rectangular heat slug with size of l = 5 mm, w = 5 mm, h = 1 mm
C1	Cylindrical heat slug with diameter, d = 1 mm, h = 1 mm
C2	Cylindrical heat slug with diameter, d = 2 mm, h = 1 mm
C3	Cylindrical heat slug with diameter, d = 3 mm, h = 1 mm
C4	Cylindrical heat slug with diameter, d = 4 mm, h = 1 mm
C5	Cylindrical heat slug with diameter, d = 5 mm, h = 1 mm

LIST OF SYMBOLS

Q_t	Total quantity of heat transferred per unit time
k_w	Thermal conductivity of the wall material
y_w	Wall thickness
A_T	Total area of the wall
Q_{conv}	Amount of heat transferred through convection
h	Heat transfer coefficient
A	Surface area
ΔT	Temperature gradient across the material
Q_{rad}	Amount of heat transferred through radiation
ε	Emissivity of surface
σ	The Stefan-Boltzmann constant
T_s	Surface temperature of the material
T_f	Fluid temperature of the medium
T_{J0}	Ambient temperature
ΔT_J	Variation of junction temperature
R_{JA}	Thermal resistance
T_j	Junction temperature
T_a	Ambient temperature
P	Input power

Analisa Pelesapan Haba Diod Pancaran Cahaya Kuasa Tinggi Melalui Slug Dan Penenggelam Haba

ABSTRAK

Diod pancaran cahaya kuasa tinggi (LED), menarik perhatian pada masa kini kerana kesannya yang memberansangkan kepada industri lampu dari segi keberkesanan, penggunaan tenaga yang rendah, jangka hayat yang panjang dan saiz fizikal yang kecil. Walau bagaimanapun, suhu simpang diod pancaran cahaya yang tinggi terus menjadi isu utama dalam industri diod pancaran cahaya kerana ia ketara mempengaruhi kebolehpercayaan dan kecekapan diod pancaran cahaya tersebut. Dalam kajian ini, pelesapan haba pakej diod pancaran cahaya yang bercip tunggal dinilai dan dianalisis melalui simulasi. Tumpuan utama kajian ini diletakkan di atas slug haba pakej LED dan kesannya terhadap cip LED dari segi suhu simpang, tekanan Von Mises dan rintangan haba. Penilaian perubahan slug haba telah dilakukan dari segi saiz, bahan slug dan bentuk slug . Di samping itu, kesan reka bentuk penenggelam haba dari segi bilangan sirip dan pengaruh ke atas suhu simpang diod pancaran cahaya juga disiasat. Kajian ini telah dijalankan dengan menggunakan ANSYS versi 11. Untuk bahagian pertama kajian, analisa perubahan slug haba yang telah dilakukan. Cip tunggal pakej diod pancaran cahaya telah kuasakan dengan kuasa input dari 0.1 W hingga ke 1 W. Dua jenis bentuk slug haba; segi empat tepat dan silinder dengan dimensi yang berbeza-beza telah digunakan bagi analisi ini. Tiga jenis bahan slug haba, aluminium, tembaga dan tembaga berlian telah digunakan dan pelesapan haba telah dibandingkan. Simulasi telah dijalankan di bawah empat jenis keadaan pengaliran; keadaan olakan semulajadi, h = 5 W/m^{2}C dan tiga keadaan olakan paksa, h = 10 W/m^{2}C, 15 W/m^{2}C dan 20 W/m^{2}C. Dalam bahagian kedua kajian ini, analisa perubahan bilang sirip penenggelam haba telah dilakukan. Cip tunggal pakej diod pancaran cahaya telah diubah dengan penenggelam haba yang berbeza reka bentuk dari segi bilangan sirip yang terdiri daripada empat sirip hingga ke 20 sirip. Penemuan utama analisa perubahan slug haba dari segi bentuk slug haba, saiz dan jenis bahan slug haba pada kuasa input 1 W menunjukkan bahawa pakej LED dengan slug haba tembaga berlian berbentuk segiempat berukuran l = 5 mm, w = 5 mm, h = 1 mm, di bawah keadaan olakan paksa h = 20 W/m^{2}C mempamerkan prestasi terma yang terbaik dengan suhu simpang 56.01 °C dengan pengurangan ketara 53.10 % dari segi suhu simpang. Di samping itu, analisa perubahan bilang sirip penenggelam haba menunjukkan bahawa pakej LED dengan slug haba tembaga berlian berbentuk segiempat berukuran l = 5 mm, w = 5 mm, h = 1 mm, di bawah keadaan olakan paksa, h = 20 W/m^{2}C dengan penenggelam haba bersirip 20 mempamerkan prestasi terma yang terbaik dengan suhu simpang 44.84 °C dengan pengurangan ketara 19.94 % dari segi suhu simpang.

High Power LED Thermal Dissipation Analysis Via Slug And Heat Sink

ABSTRACT

High power light emitting diode (LED), are captivating attention in recent times due to its cogent impacts on lighting industry in terms of efficacy, low power consumption, long lifetime and miniature physical size. However, the high junction temperature of the high power light emitting diodes continues to be a key issue in the LED industry as it significantly influences the reliability and efficiency of the LED. In this research, the thermal dissipation of a single chip high power light emitting diode package were evaluated and analyzed through simulation. The prime focus of this research is placed on the heat slug of the LED package and its effect on the LED chip in terms of junction temperature, Von Mises stress and thermal resistances. The variation of the heat slug was done in terms of size, slug material and shape. In addition, the effect of heat sink design in terms of fin numbers and its influence on the junction temperature of the LED was also investigated. The research was carried out using Ansys version 11. For the first part of the research, the heat slug variation analysis was done. The single chip LED package was powered with input power ranging from 0.1W to 1W. Two types of heat slug shape; rectangular and cylindrical with varied dimension were used .Three types of heat slug material, aluminum, copper and copper diamond was used and the heat dissipation was compared. The simulation was carried out under four types of conduction condition; natural convection condition, h = 5 W/m^{2}C and three forced convection condition,h = 10 W/m^{2}C, 15 W/m^{2}C and 20 W/m^{2}C respectively. In the second part of this research, heat sink fin number variation analysis was done. The single chip LED package was varied by different heat sink design in terms of fin numbers ranging from four fins to 20 fins. The key findings of heat slug variation analysis in terms of heat slug shape, size and material at input power of 1 W showed that the LED package with l = 5 mm, w = 5 mm, h = 1 mm rectangular copper diamond composite heat slug, under forced convection condition of h = 20 W/m^{2}C exhibited the best thermal performance with junction temperature of 56.01 °C with significant reduction of 53.10 % in terms of junction temperature. In addition, the heat sink fin number analysis showed that the LED package with l = 5 mm, w = 5 mm, h = 1 mm rectangular copper diamond composite heat slug, under forced convection condition, h = 20 W/m^{2}C with 20 fin heat sink exhibited the best thermal performance with junction temperature of 44.84 °C with significant reduction of 19.94 % in terms of junction temperature.

CHAPTER 1

INTRODUCTION

1.1 Overview of LEDs

Light Emitting Diode (LED) is an innovation which utilizes semiconductor materials to emit light. The discovery of light emitting semiconductor materials dates back to the last century. Silicon Carbide (SiC) was synthesized by Jon Jacob Berzelius in 1824 (Heathcote, 2011). The first observation of electroluminescene was reported by Henry Joseph Round in 1907 where evaluation of Carborundum and its application as crystal detector radios was done. Round noticed that SiC crystalline emitted light when applied with input current of 10 volts and 100 volts (Round, 1907). In 1928, a detailed inquisition on luminescence phenomenon was reported by Oleg Vladimirovich Lossev. SiC rectifiers were used by (Lossev, 1928) and a series of experiment were done. Lossev found that luminescence occurred and it could be switched on and off rapidly, making it suitable application as light relay and hence, the very first LED was born and ever since then, the LEDs have undergone tremendous evolution and its journey is summarized in Table 1.1 (Schubert, 2006).

There are two types of LEDs, namely low power LED package (indicator) and high power LED package (illuminator) which is illustrated in Figure 1.1. The low power package is identified as 5mm LEDs (Schubert, 2006). The structure of the low power LED package comprises of a die which is bonded to a reflector cup in the cathode lead wire. The LED top contact is connected to the anode lead wire through a bond wire and is covered with hemispherical shaped

Table 1.1: Historical summary of light emitting diodes (Schubert, 2006)

Year	Significant Discoveries
1824	Silicon Carbide (SiC) was synthesized by Jon Jacob Berzelius.
1907	First observation of electroluminescence through evaluation of Carborundum and application as crystal detector was reported by Henry Joseph Round.
1928	The first SiC LED was invented by Oleg Vladimirovich Lossev.
1957	The first infrared (870- 980 nm) LEDs based on gallium arsenide(GaAs) was reported by Radio Corporation of America.
1962	The first practical visible-spectrum LEDs based on GaAsP was developed by Nick Holonyak Jr.
1967	The first visible spectrum with red emission LEDs based on AlGaAs was invented by IBM.
1968	First mass production of low cost GaAsP LEDs was done by Monsanto Corporation.
1971	The emission of red, orange, yellow and green wavelength range based on GaAsP was developed by Monsanto Corporation.
1971	First observation of blue electroluminescence 475 nm based on GaN was reported by Radio Corporation of America.
1972	Blue and violet emission centered at 430 nm was reported by Radio Corporation of America.
1989	Initiation of the AlGaInP based LEDs development.
1992	First GaN p-n homojunction LED with ultraviolet (UV) and blue emission with efficiency of 1% was reported by Isamu Akasaki
1993	First blue and green GaInN double heterostructure LED was developed by Nichia Chemical Industries Corporation.
1997	Invention of blue laser diode was reported by Nakamura
2000	White LEDs based on phosphor wavelength converters was reported by Nakamura.

encapsulant (Schubert, 2006). The low power LED packages are generally utilized for low power application such as indicators in calculators, watches, traffic lights and signals. The amount of heat produced from these low power LEDs are very minimal (Arik, Petroski, & Weaver, 2002). On the other hand, the high power LED package has an Aluminum or Copper heat sink slug and the LED submount is soldered with a metal based solder. The chip of the high power LED package is encapsulated with silicone. Above that, the silicon encapsulant is covered with a lense made out of plastic. Finally, the chip is mounted directly on Si submount (Schubert, 2006). The advantages of the high power LED package is that it has direct thermal conductive path which initiates to the convectional fluorescent, incandescent lights and other traditional light sources (Lafont, Zeijl, & Zwaag, 2012). In general, the luminous efficacy of light source is measured in lumens per watt (1m/W) and this describes the efficacy of the light source. The theoretically achievable maximum efficacy at 555 nm is 683 lm/W with 100% input power conversion to light (Happek, 2009). At present the preeminent efficiency of high-power white LED is claimed by Cree Inc with a luminous efficacy of 200 lm/W at input power 1W and ambient temperature of 25°C (Cree Inc, 2012a).

1.2 Problem Statement

The LED structure generally consists of p-type and n-type semiconductor material which creates the existence of a p-n junction. When input power is applied to the LED, electroluminescence effect take place at the p-n junction and energy is released as light. This is known as light emission process. Nevertheless, the transition from low power LED package to high power LED package has also significantly increased the input power as well to augment the light output which simultaneously increases the heat generation within the package. In high power LEDs, only 20% of the input power is emitted as light and the remaining 80% is converted as heat (Cheng, Luo, Huang, & Liu, 2010). The heat generated by the high power LED chip is very large when compared with conventional light sources. The amount of heat generated by the chip is also influenced by the heat dissipation path within the LED package structure (Cheng, Luo, Huang, & Liu, 2010). Hence, the heat generated at the p-n junction of LEDs is termed as junction temperature. The junction temperature of LED is very significant as the performance characteristic such as overall life time and luminous efficacy is extremely influenced by it (Jayasinghe, Gu, & Narendran, 2006 ; Gao et al., 2008; Senawiratne, 2008). A high operating junction temperature results in augmentation of non-radiation recombination in LED and the quantum efficiency will reduce (Liu, Tam, Wong, & Filip, 2009). 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 (Lafont, Zeijl, & Zwaag, 2012). Figure 1.2 exhibits the relative flux versus junction temperature from the Cree XLamp XB-D LED data sheet (Cree Inc, 2012b). It is observed that the luminous flux of the LED decreases with augmentation of junction temperature.

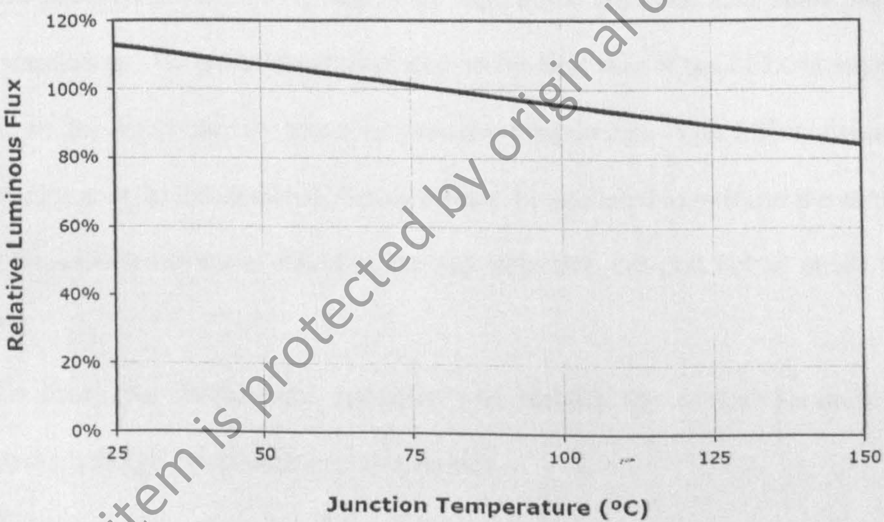

Figure 1.2: XLamp XB-D relative flux vs. steady-state junction temperature (Cree Inc, 2012b)

Furthermore, mechanical stress is induced within the LED packages due to the extensive junction temperature of the LED chip which reduces the reliability of the LED packages. The reliability of any LED is a direct function of junction temperature. The higher the junction temperature, the shorter will the lifetime of the LED is. Failures issue which are associated with high junction temperature and mechanical stress are electromigration, carbonization of encapsulant, encapsulant yellowing, phosphor thermal quenching, lens cracking ,delamination of layers within the LED structure and packaging (Lafont, Zeijl, & Zwaag, 2012). 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.

1.3 Research Objectives

The main objective of this project is to evaluate and characterize the heat dissipation and thermal stress of a single chip high power light emitting diode package through simulation. The prime focus is placed on the heat slug of the LED package and its effect on the LED chip in terms of junction temperature, Von Mises stress and thermal resistances. In this research, Ansys version 11 was used to perform the analysis. In order to achieve the main objective the sub objective detailed below needs to be addressed:

i) To study the fundamental operation and identify the critical parameters of packaged high power light emitting diodes.

ii) To design 3D model resembling a light emitting diode package with heat sink for the simulation analysis.

iii) To study the relationship between heat slug and its influence on the junction temperature of the LED.

iv) To assess additional way to reduce the operating junction temperature of the LED.

1.4 Research Scope

The scope of this research covers the subject of evaluation and characterization of the heat dissipation and thermal stress of a single chip high power light emitting diode package through simulation. The focus of this research is placed on the heat slug of the LED package and its effect on the junction temperature of LED package in terms of heat dissipation and thermal stress. The research was done accordingly as:

i) Rectangular and cylindrical shape heat slug were used to investigate the heat dissipation and thermal stress of the single chip LED package.

ii) The heat slug size was varied from 1 mm x 1 mm to 5 mm x 5 mm for rectangular slug with thickness of 1 mm. As for the cylindrial shape heat slug, the diameter was varied from 1 mm to 5 mm diameter with thickness of 1mm.

iii) Three types of heat slug material, Aluminum, Copper and Copper Diamond composite were used and results were compared.

iv) The input powers used for the single chip LED are from 0.1 W to 1 W with increment of 0.1 W for each simulation run.

v) The simulation was done under four types of convection condition: one natural convection condition and three forced convection condition.

vi) The evaluated junction temperature was used as an input to evaluate the thermal stress of LED die.

vii) For the first part of the simulation, the heat sink design was kept constant with four fins.

viii) After determining the best heat slug size for lower junction temperature thermal stress and low thermal resistance, the second part of the simulation was done with varied heat sink fins ranging from four fins to 20 fins heat sink with increment of two fins for each simulation run.

1.5 Research Approach - step by step

This research was initiated with a literature review on LEDs which is presented in chapter 2. This was done to understand the fundamental operation of LED and the thermal problem faced by high power light emitting diodes. Second, the review was done to identify which part is yet to be investigated by preceding studies and to author's best knowledge, a study on heat slug and its effect on the junction temperature of single chip LED package is yet to be reported. Hence this initiated the research and was investigated through simulation. Next, 3D model resembling a single chip LED package was developed based on details gathered from the literature review and the simulation analysis was performed using Ansys version 11. The parameters and simulation condition as stated in the project scope were set. Several assumptions were made to simplify the simulation. Grid independence analysis was done prior to the performing the overall simulation to evaluate the accuracy of the simulated results. The grid density was systematically increased until there is no appreciable variation in the output result. Finally, the simulation analysis was done according to the project scope and the results were gathered and analyzed.