THERMAL SIMULATION OF MULTIPLE CHIPS LED MODULE USING COMPUTATIONAL FLUID DYNAMIC SOFTWARE

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"THERMAL SIMULATION OF MULTIPLE CHIPS LED MODULE USING COMPUTATIONAL FLUID DYNAMIC SOFTWARE "** was prepared by **WONG YAU YUN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

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Date : _______________________

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ABSTRACT

In recent years, high luminous efficiency light emitting diode (LED) with low power consumption has become the trend in lightning system. However, LED module produces large amount of heat and the heat produced greatly reduced the life span and the performance of LED module. This makes thermal management a critical issue to be solved. Recently, a lot of researches were carried out to improve the heat dissipation performance of the LED module and reduce the junction temperature of the LED chip. In this paper, the author modelled multiple-chip LED module using computational fluid dynamic software and analysed the thermal performance of the module. In the first part of the research, various model parameter such as materials of LED chip, substrate and thermal interface material (TIM) were studied so as to find out the optimized design in relate to the best thermal performance of LED module. In addition, the optimal thermal and optical properties of LED were investigated through various arrangements, namely number of LED chips, distance between the LED chips and the orientation of LED chips. In present study, a simple multiple-chip LED module was developed for the prediction of thermal performance by employing different designs of heat sink. Parametric studies of heat sink design were then discussed based on the simulation results. Lastly, an optimized four LED-chips module that produces high luminosity light output with junction temperature lower than 90 ^{o}C was designed and analysed.

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LIST OF SYMBOLS / ABBREVIATIONS

$R_{j\text{-}a}$	total thermal resistance, K/W
K	thermal conductivity, W/mK
T_j	junction temperature, K
T_a	ambient temperature, K
T_b	board temperature, K
P_{th}	thermal power dissipated by the LED module, W
R_{die}	thermal resistance of LED chip, K/W
$R_{die\ attached}$	thermal resistance of die attached, K/W
R_{slug}	thermal resistance of slug, K/W
$R_{solder\ paste}$	thermal resistance of solder paste, K/W
$R_{substrate}$	thermal resistance of substrate, K/W
R_{TIM}	thermal resistance of TIM, K/W
$R_{heat\ sink}$	thermal resistance of heat sink, K/W
t_{die}	thickness of the LED chip, m
k_{die}	thermal conductivity of the LED chip, W/mK
A_{die}	cross section area of the LED chip, m^2
$T_{(x,y,z)}$	temperature of the LED chip at coordinate x,y,z, K
N	number of the LED chip
θ_i	total temperature excess of the module, K
Q	total heat dissipation power, W
P	density, kg/m^3
t	time, s
p	pressure, kPa
g	gravity, m/s^2
μ	viscosity, m^2/s
V_f	forward voltage of the LED module, V
I_f	current flow through the LED module, A

H	thermal coefficient (percentage of power converted to heat), %
CFD	computational fluid dynamic
LED	light emitting diode
COB	chips on board
TIM	thermal interface material
PCB	printed circuit board
MCPCB	metal core printed circuit board
DBC	direct bond copper
AlN	aluminium nitrate
GaN	gallium nitrate
GaAs	gallium arsenide
GaP	gallium phosphide

CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, the demand of LED (light emitting diode) has increased sharply owing to its advantages over the fluorescent light bulb and incandescent light bulb. LED is a power saving, long life time and environment friendly device. Besides, it is small in size and easy to control. Usually, a LED only need 3V of voltage to produce high luminous light output and the LED starts up quickly with low temperature and less noise. On the other hand, fluorescent light bulb requires a starter to start up the bulb and the starter consumes large amount of power (nearly 100 kW) during the start up process. It wastes a lot of energy and the life span is short if the fluorescent light bulb is switching on and off frequently. Therefore, LED is overriding traditional fluorescent light bulb in this past few years.

However, LED also has some disadvantages. The main disadvantage of LED as a light source is the low light lumen. Most of the researches showed that LED only converts 15% to 30% of the input power into light energy. In other word, it is about 80% of the input power been converted into heat energy. This high heat output reduces the light luminance and the life span of the LED sharply. The condition becomes worse when the LED was packaged into multiple-chips LED module which has smaller size and high packaging densities. The heat generated is unpredictable and module may be seriously damaged without efficient heat dissipation. Thermal management is thus important to keep the junction temperature of the LED low. It would indirectly enhance the light output quality and prolong life time of the LED module.

Besides thermal management, it is also important to predict the thermal performance of LED during the design phase. This would help the designer in designing LED modules which has high luminous light output and good heat dissipation ability. One of the most common methods used for the prediction of thermal performance is computational fluid dynamic (CFD) modeling and simulation. The simulation is fast and cost saving as designer can model their design in the software directly instead of building their prototype by hardware. This also allows the designer to examine their designed module under extreme condition by setting the junction temperature above the specified temperature that is typically limited by the manufacturers. Besides, CFD can map the temperature distribution and measure the junction, ambient and surface temperatures of the module accurately. Designers may also change their design directly based on the generated results in order to optimize the thermal performance of their design.

The CFD software named FLOTHERM would be used in this project. FLOTHERM is user friendly because it has a large library of predefined thermal models. Moreover, user can add in electronic and thermal components such as fans, heat sink, heat pipe and many others to simulate the thermal performance of the model. In addition, the simulation helps user to obtain the detailed graphical result such as temperature distribution of the module.

1.2 Problem statement

In this day and age, LED chips are mounted near each other directly on a substrate. This type of LED modules has improved the lightning system technology because it is smaller in size and provides higher intensity yet uniform light output. However, the small size, high packaging densities with high power output LED modules generate large amount of heat. If the heat generated is not able to dissipate well then it will damage the module seriously. Besides, large amount of energy is wasted in the form of heat energy and this reduces the energy efficiency of the module.

As a measure to the abovementioned disadvantages, various studies on thermal management of LED module have been carried out. The main objective of the thermal management studies is to remove the heat effectively. However, effectiveness of thermal management researches in real life relies on a number of technical problems which are not fully understood.

First, it is not easy to measure the junction temperature of real LED modules. Typically thermocouples and IR camera are used to measure the junction temperature. However, the results may not be accurate and precise due to the small size of the LED module. This is due to the fact that the thermocouple is placed next to the chip that covered by lens, whereas the IR camera can only record the surface temperature of the LED module. This would cause the variants in result from that taken on the actual heating point (Shi et al., 2015). Besides, the result could be affected by the external environment such as movement of air, humidity, intensity of light and many others. Moreover, the designer cannot observe the heat flow and heat spot of the module. Without the heat flow and heat spot parameters, the designer cannot modify his design because he does not know which part of the module has problems. This may prohibit the efficient removal of heat from the module.

It is a time consuming task for the designer to manufacture new LED modules each time he modified his design. Large amount of money is required to build the LED modules repeatedly. Besides, it is almost impossible to build two identical LED modules in real life. The quality of heat flow may change in the new developed module since it depends strongly on the quality of material used. Roughness of the material, air bubbles in the thermal grease layer, cracks in the die attached layer could change the result. Thus, the designer may not able to perform the comparison between two different modules. Moreover, designer cannot change the parameter of the LED module because variants may occur if the parameters of the design exceed the parameter set by the manufacturers. As a result, designer may miss to find out the factors that affect the thermal management of the module.

Thermal analysis and module design using FLOTHERM simulation is able to solve all the problems mentioned above. The junction temperature, ambient temperature and surface temperature of the module can be determined easily after the module was designed. The software also allows designer to zoom into any parts of the module to obtain the temperature. Furthermore, the result is more stable because it will not be affected by the external environment. Thermal distribution map and heat sport of the module can also be generated. Moreover, the designer can modify his design easily by changing the key parameters while keeping other parameters unchanged. This allows the module to function under extreme conditions so as to observe some possible effects that would occur.

1.3 Aim and Objectives

The objectives of the project are shown as follow:

i) To develop a detailed component level computational model of the multiple-chip LED package module using CFD software.

ii) To study the factors that affect the thermal resistance of the LED module such as thermal conductivity of material, LED chips arrangement and heat sink design.

iii) To model a multiple-chip LED module that has high luminous light output and good heat dissipation properties.

1.4 Outline

This report consists of five chapters and short summary for each chapter is discussed in this section.

Chapter 1 describes the background of the LED module and the FLOTHERM CFD software used in the present study. Besides, it reports the importance of using the FLOTHERM software in studying the thermal management of a LED module. This chapter also discusses the problem statement of the thermal analysis and the advantages of using the CFD software to solve the actual problem in real life thermal analysis. The objectives that provide directions for this project are stated in this chapter.

Chapter 2 discusses the literatures from various researchers. The review of the operation of LED, type of LED, thermal resistance, thermal conductivity of the material available and the effect of thermal conductivity on thermal management are summarized in this chapter. Moreover, the structure of the LED modules designed by other researchers and designers are discussed here.

Chapter 3 reports the methodology of this study. The software implementation of the CFD software is described, in terms of the steps to develop the detailed LED module in CFD software and the dimension and material of each layer of the LED module.

Chapter 4 analyses the results of the simulation. Discussion of the simulation results will be presented here too. The discussion includes the factor that affect the thermal management performance of the LED module, namely the thermal conductivity of the material, LED arrangement and heat sink design. The optimum parameters used in develop multiple-chip LED module that has high luminous light output and good heat dissipation properties are subsequenly suggested in this chapter.

Chapter 5 indicates the concluding remark and recommendation of the future work to improve the module design. The summary of the project also presented here.

CHAPTER 2

LITERATURE REVIEW

This chapter explains the main concept and theory used throughout the project. Besides, it also discusses some researches conducted by various researchers so as to give a clearer overview about this project. Their implementation methods and achievements are compared in this chapter.

2.1 Light Emitting Diode (LED)

LED is a semiconductor light source. The LED emits light in a way different from other light bulb because it does not have a filament. The LED produces light when the semiconductor crystal is excited by a suitable voltage supplied to it. This phenomenon is known as electroluminescence.

LED exhibits the electroluminescence phenomena as it is a p-n junction diode. The LED is built using the crystal (poor conductor) that is doped to reduce it conductivity. Doping is the process of adding impurities to a material and there are two kind of doping. N-type doping adds one more electron on the semiconductor and makes the semiconductor negatively charged, whereas P-type doping adds one extra hole on the semiconductor that makes the semiconductor positively charged. A LED is built by bonding a section of N-type material to a section of P-type material. This arrangement causes voltage to flow in one direction only. When no voltages apply to the LED, electron from the N-type material will fills the hole on P-type material.

This causes negative ion forms on the P-type material and positive ion forms on the N-type material. It creates a charge and forms the depletion region. The depletion region creates a large electric field that inhibits the flowing of electron to the P-type material. As a result, the semiconductor fails to conduct electricity. When forward bias voltage is applied to the semiconductor (negative terminal on the N-type material and positive terminal on the P-type material), the free electron at the N-type material is repelled by the negative charged of the electrode. The repletion force that stronger than the opposing electric field force of the depletion region pushes the electron to the hole on the P-type material causing current to flow again. To explain it in a simple method, a LED can light up when sufficient voltage is applied. This is because the electron from the N-type material is able to combine with the hole from P-type material at the P-N junction. This combination releases the energy in the form of photon and the energy is converted into light energy.

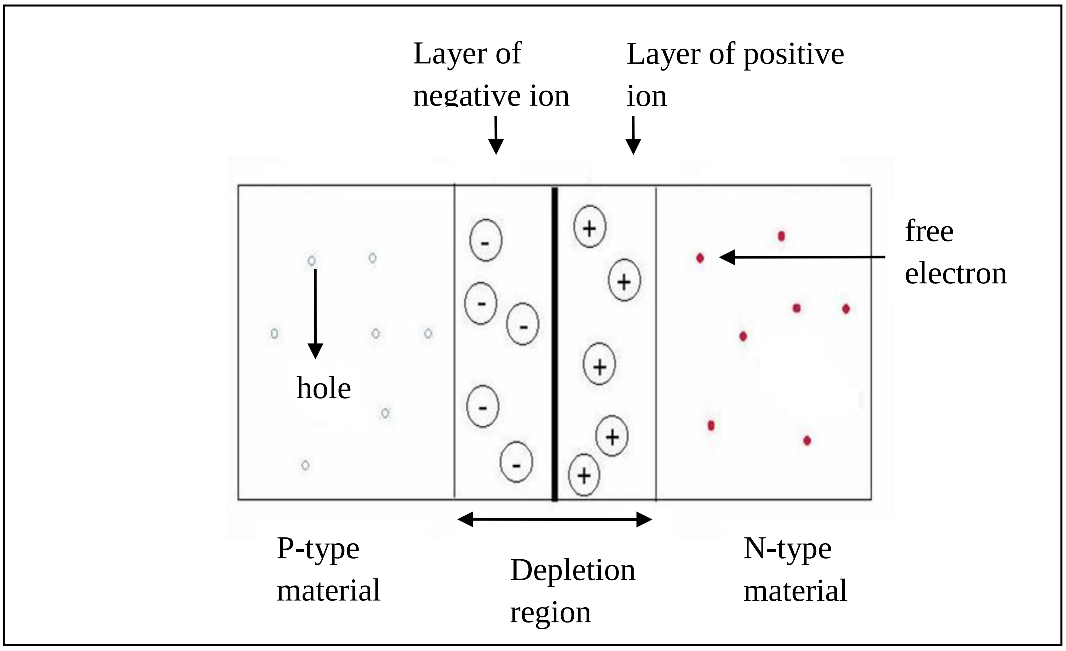


Figure 2.1: Unbiased P-N Junction

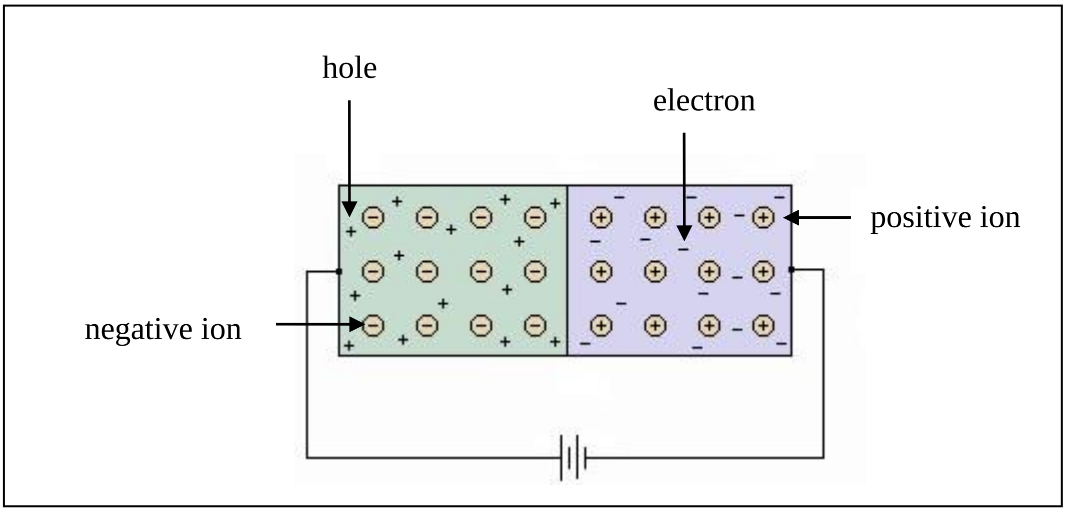
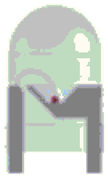
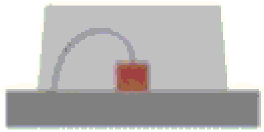
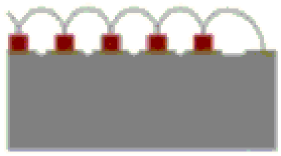
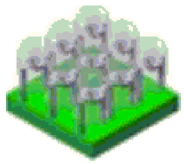
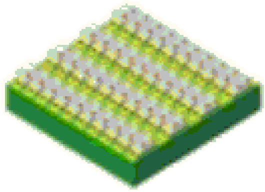
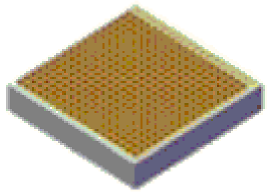


Figure 2.2: Forward Biased P-N Junction

2.2 Chips On Board Technology (COB)

Nowadays, the most popular and advance LED packaging method is chip on board (COB) technology. COB is done by mounting the LED chips directly on the substrate. This type of packaging has a lot of advantages compare to other packaging methods such as T-pack and Surface mount technology.

Table 2.1: Type of Packaging

LED type	T-Pack	Surface Mount	Chip on Board
Device image			
Package Array (10mm x 10mm)			
Density	9 LEDs	40 LEDs	342 LEDs
Array power	0.4 Watts	4 Watts	68 Watts

From the Table 2.1, we can see that the number of LEDs can be mounted on a 10mm x 10mm substrate (total 342 LEDs) using COB method is much higher than that of using the other two methods. Increases in number of LED built on the module will increase the light output of the module. This also implies that COB technology has ability to improve the operation of lighting system since COB LED module gives high luminous and uniform output with a smaller size.

2.3 Measuring the Brightness of LED

The measurement of brightness for LED module is different from the fluorescent light. In fluorescent light bulb, we usually look on watts to determine the output brightness. Actually, the wattage is not use to measure the brightness but use to measure the amount of energy drawn by the bulb. However, it is still acceptable to compare the brightness of bulb with wattage for fluorescent light bulb but not for LED.

In LED, lumen is used to measure the brightness for LED. The higher the lumen, the brighter the output of the LED. The lumen (lm) is the SI unit for luminous flux. It is use to measure the total amount of light which are visible by human eye that emits from a light source. It is different from radiant flux which measures the total amount of wave emits, independent on human eye ability to receive it. Therefore, a good LED is LED which emit high lumen of light intensity with low power input.

Moreover, the brightness of the light may be also affected by the color of the light although they have same lumen. Light color is measured in Kelvin (K). A lower Kelvin temperature is called hot light because its spectrum has a lot of yellow and red color which look like a flame. The hot light appears yellow. It perceived as comfortable and suitable for general lighting in houses. On the other hand, higher Kelvin (more than 5000 °K) light is called cold light. Cold light appears white and it is brighter than hot light. It is suitable to use in kitchen and work space.

2.4 Thermal Management

High power LED module is commonly used as light source nowadays. Due to low luminous output for a single chip high power LED module, LED arrays with multiple-chip package are introduced for general illumination. However, these arrays generate large amount of heat. If the heat cannot dissipate well, the luminous and life span of the LED module will be greatly reduced. Therefore, thermal management is very important during the design process of LED module (Shi et al., 2015). Thermal management is the technique that uses different kind of temperature monitoring devices and cooling methods to control the overall temperature of the module. For LED module, the thermal management focuses on lowering the junction temperature. This is because high junction temperature of LED module will induce thermal activation of non radioactive electron-hole recombination and cause increases in defect responsible due to increase in non radioactive recombination. The increase in defect responsible will cause decrease in luminous and life span of the LED module (Chuang, et al., 1997). Thus, it is important to maintain the junction temperature of the LED module low during the operation period so as to prolong the life span and enhance the quality of the light output.

2.4.1 Thermal Resistance

Thermal resistance is the key factor that affects the junction temperature of the LED module. High thermal resistance leads to high junction temperature (Liu et al., 2014). In the past few years, various researches had been carried out by designers and thermal engineers in order to reduce the thermal resistance as well as the junction temperature of the LED module. Before the researches are discussed, it is important to understand some of technical terms that always appear in thermal management design. Thermal resistance is the rate of temperature increase due to increase in dissipated power. It is also measures the capability of the material to dissipated heat according to the article in 2011 by OSRAM. The higher the thermal resistance, the lower the capability of the material to dissipate heat. Thermal resistance in LED is caused by the temperature difference between the junction temperature and the ambient temperature. The temperature difference creates pressure in the junction and the pressure restricts the heat flows from LED chip to the surrounding. As a result, more and more heat accumulates at the junction and cause increase in the junction temperature. Thermal resistance is calculated based on the formula:

$$R_{j-a} = \frac{(T_j - T_a)}{P_{th}} \tag{2.1}$$

where

R_{j-a} = total thermal resistance, K/W

T_j = junction temperature, K

T_a = ambient temperature, K

P_{th} = thermal power dissipated by the LED module, W(Vakrilov, et al)

From the formula, thermal resistance changes proportional to temperature difference between junctions and ambient. Thus, lower thermal resistance decreases the temperature difference which also indirectly decreases the junction temperature.

Next, in order to predict the junction temperature of the LED chip before the module is designed, the total resistance between the LED chips and the ambient ($R_{j\text{-}a}$) must be calculated. Figure 2.3 shows the thermal resistance found in a LED module.

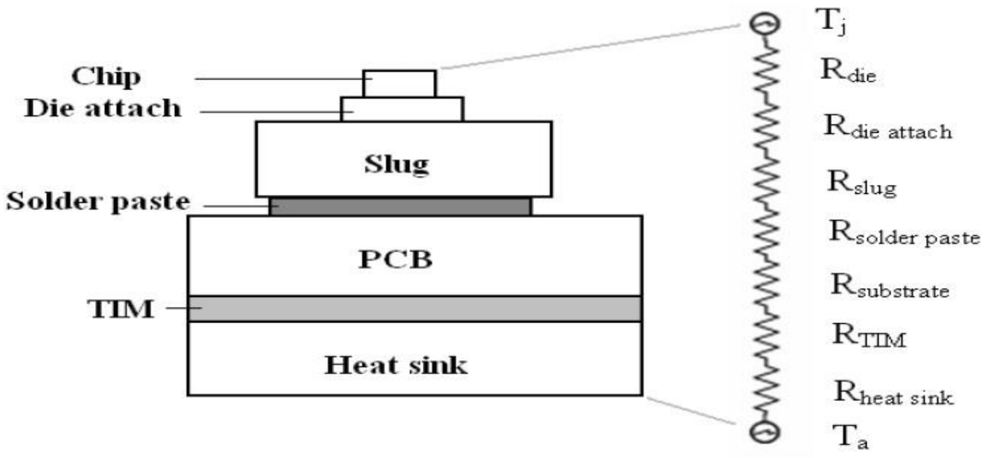


Figure 2.3: Thermal Resistance Found in a LED Module

From Figure 2.3, the total thermal resistance found in the single LED chip module can be expressed using the formula:

$$R_{j-a} = R_{die} + R_{die\ attach} + R_{slug} + R_{solder\ paste} + R_{substreate} + R_{TIM} + R_{heat\ sink} \tag{2.2}$$

Next, all the low conductivity materials such as die attach, solder paste and TIM is removed from the equation. The simplified total thermal resistance can be estimated as

$$R_{j-a} = R_{die} + R_{slug} + R_{substreate} + R_{heat\ sink} \tag{2.3}$$

By assuming uniform heat flux on the top of the chip, the thermal resistance of the LED chip can be described with one dimensional thermal resistance model for heat diffusion, which is

$$R_{die} = \frac{t_{die}}{k_{die}\, A_{die}} \tag{2.4}$$

where

R_{die} = thermal resistance of the LED chip,K/W

t_{die} = thickness of the LED chip,m

k_{die} = thermal conductivity of the LED chip, W/mK

A_{die} = cross section area of the LED chip,m^2

For thermal resistance of slug, substrate and heat sink, the formula used is same as the equation (2.4) but replacing all the parameter *t*, *k* and *A* with the parameter for the slug, substrate and heat sink.

To calculate the thermal resistance of the multiple-chip LED module, general analytic solution based on separation variable can be used. The solution for the temperature distribution of the heat sink which used to calculate the temperature of the multiple-chips LED module is

$$T_{(x,y,z)} - T_a = \nabla T = \sum_{i=1}^{N} \theta_i(x, y, z) \tag{2.5}$$

where

T_a = ambient temperature, K

$T_{(x,y,z)}$ = temperature of the LED chip at coordinate x,y,z, K

N = number of the LED chip

θ_i = total temperature excess of the module, K (Cheng et al., 2010)

The θ_i for the surface temperature distribution of the LED module at z=0 is

$$\theta_i(x, y, 0) = A_0^i + \sum_{m=1}^{\infty} A_m^i \cos(\lambda x) + \sum_{n=1}^{\infty} A_n^i \cos(\delta x) + \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} A_{mn}^i \cos(\lambda x) \cos(\delta x) \tag{2.6}$$

After solving the Fourier coefficient A_m, A_n, and A_{mn}, the total resistance of the $N \times N$ array multiple-chip LED module can be calculated using the formula

$$R_{j-a} = R_{die} + R_{slug} + R_{substreate} + N \times R_{heat\ sink} \tag{2.7}$$

The equation can be obtained by assuming the innermost gives the highest junction temperature

$$N \times R_{heat\ sink} = \frac{T_{(x,y,0)}}{NQ} \tag{2.8}$$

where Q is the total heat dissipation power measured in Watt (W).

2.4.2 Junction temperature, Board Temperature and Ambient Temperature

Difference between junction temperature, board temperature and ambient temperature must be firstly understood. Junction temperature is the highest temperature in the package of the device when the device is operating (Altera, 2012). Based on the article from electronic engineering journal, junction temperature is the internal temperature of the component itself (LED chip) which strongly affects its functionality and reliability. It can also refer as the hottest temperature on the LED module due to its power dissipation during operation. Thus, the most accurate way to measure the junction temperature is to measure the LED chip itself.

Next, board temperature is the temperature adjacent to the LED chip. The measurement point of the board temperature should be less than 1 mm away from the centre of the LED chips. Figure 2.4 shows the ideal measuring point for the board temperature.

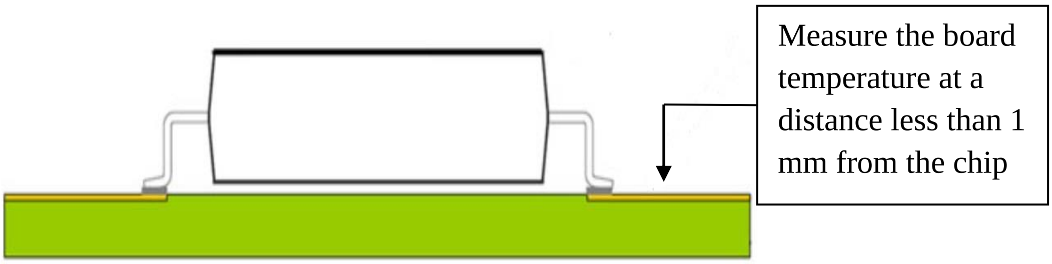


Figure 2.4:Ideal Measuring Point for Board Temperature

After the board temperature is measured, junction temperature can be calculated using the formula:

$$T_j = T_b + (\Psi_{jb} * P_{th}) \tag{2.9}$$

where

T_j = junction temperature, K

T_b = board temperature, K

Ψ_{jb} = Psi-jb, K/W

In equation (2.2), a new term is introduced which is Psi-jb. The Psi-jb is almost same as the Theta-jb (θ_{jb}, thermal resistance). When calculating Theta-jb, the heat is assumed to flow from the junction to the board. On the other hand, when calculating the Psi-jb, the heat is assumed to flow through top and side of the chip. Therefore, the value for Psi-jb is smaller than Theta-jb because the temperature difference is divided by the full power instead of the power from the source of the temperature difference (XILINX, 2013). Figures 2.5 and 2.6 show the simplified form of the difference between Theta and Psi.

Theta (θ)

$$\theta_{xy} = \frac{Tlocation\ x - \text{Tlocation}\ y}{\text{Power path}x - y}$$

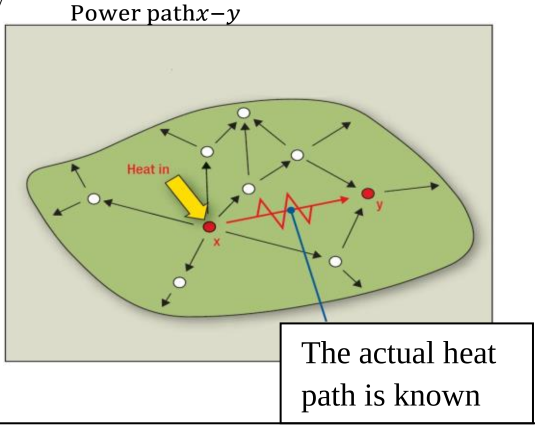


Figure 2.5: Formula and Method to Find Theta

Psi (Ψ)

$$\Psi_{xy} = \frac{Tlocation\ x - \text{Tlocation}\ y}{\text{Power toal device}}$$

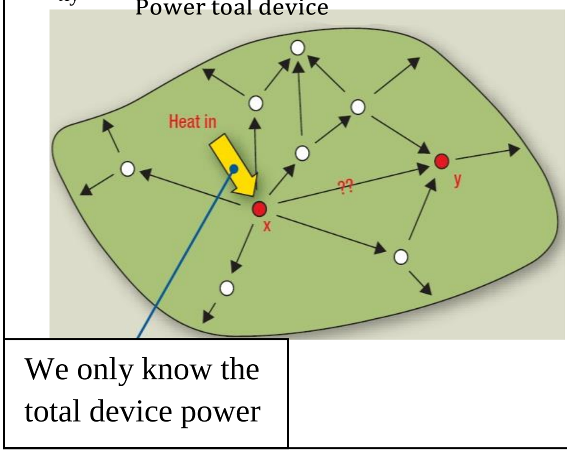
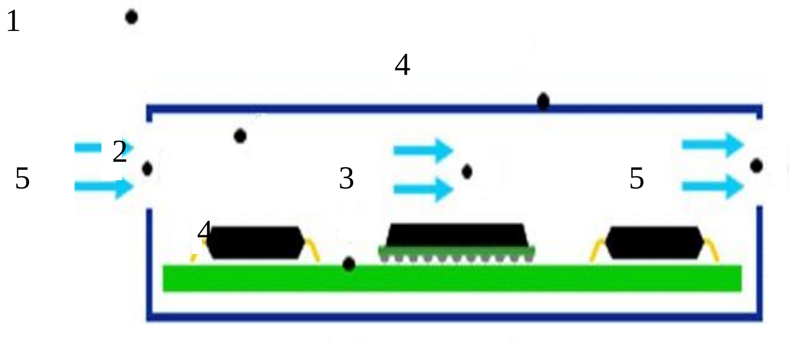


Figure 2.6:Formula and Method to Find Psi

From the Figures 2.5 and 2.6, specific heat flow path must be determined before calculating the theta. On the other hand, the specific heat flow path is not important when calculating psi. This is because the total heat in the system is used to calculate the Psi (Stout, 2008).

Moreover, ambient temperature is the temperature that distant away from the LED chip, hence it is not affected by the component heat contribution. As for example, if the LED is packaged in housing, the ambient temperature is the temperature outside the housing. From the example and explanation, ambient temperature can refer to the air temperature inside or outside the LED module. Figure 2.7 shows some of the measuring point for the ambient temperature.



Final System (Airflow optional)

System testing on bench or in oven

Figure 2.7: Eight Different Measuring Points for Ambient Temperature

There are eight potentially different ambient temperature measuring points (Romig, 2010). The ambient temperature is different when the ambient temperature is measured at different measuring points. Therefore, calculating the junction temperature using the ambient temperature is less accurate and shall not be used.

2.4.3 Thermal Conductivity and Thermal Management Product

Thermal conductivity is the ability of a material to conduct heat. The higher the thermal conductivity of the material, the easier the material conducts heat. Thermal management consists of three categories namely package level, board level and system level. In package and board level, selection of the material for die structure, die bonding and substrate is very important (Yang et al., 2013) Ideally, to have a good thermal management performance, materials which have high thermal conductivity was chosen when building the module. In this session, some researches that involve the application of thermal conductivity of material of to improve the thermal management performance of the LED module are discussed. Besides, some improvements have been done by researchers to enhance the thermal management performance of LED module without increasing the cost and size of the LED module.

The first research discussed is about thermal conductive substrate. Based on an article on lighting technology, Rich Wessel and Kurt Roberts found that thermal conductive substrate is the key factor in improving the thermal management performance of LED. They have carried out the research to determine the suitable material to make the circuit board. They replaced the traditionally used aluminum based FR-4 boards circuit board with metal core laminated board (MCB) such as DuPont™ CooLam™ thermal substrate. DuPont has the polyimide content which is commonly applied to many industries field. It is due to the fact that it can maintain the good physical, electrical and mechanical properties over a wide range of temperature. Due to the advantage of the polyimide layer in the DuPont™ CooLam™ thermal substrate, they are used as good insulated metal substrate for high power LED module. Moreover, the thin polyimide layer has very low thermal resistance together with thin dielectric layer that allow heat to dissipate in a small package LED module. At the end of their research, they found that thermal management performance of the LED modules with MCB substrate is better that LED modules with FR-4 substrate due to thin dielectric insulating layer according to the article in 2012 written by DuPont™ CooLam™.

Next, metal core printed circuit board (MCPCB) is also used as a substrate because it provides high thermal management performance. MCPCB board has aluminum or copper metal core and insulating layer on top. The metal core is used to provide mechanical support and help in heat dissipation. However, the thermal performance of MCPCB is lower than MCB due to the high thermal resistance of the insulating layer. In the research of Eveliina Juntunen, copper core MCPCB with thermal vias is introduced. The copper core MCPCB consists of microvias through the FR4 insulating layer. Juntunen found the microvias provide an effective path for the heat from the LED chip to be dissipated through high thermal resistance insulating layer. Based on the result of the research, the thermal management performance of the MCPCB with microvias is better than the thermal management performance of aluminum MCPCB. Figures 2.8 and 2.9 show the structure of the MCPCB with microvias and a typical MCPCB (Juntunen et.al, 2014).

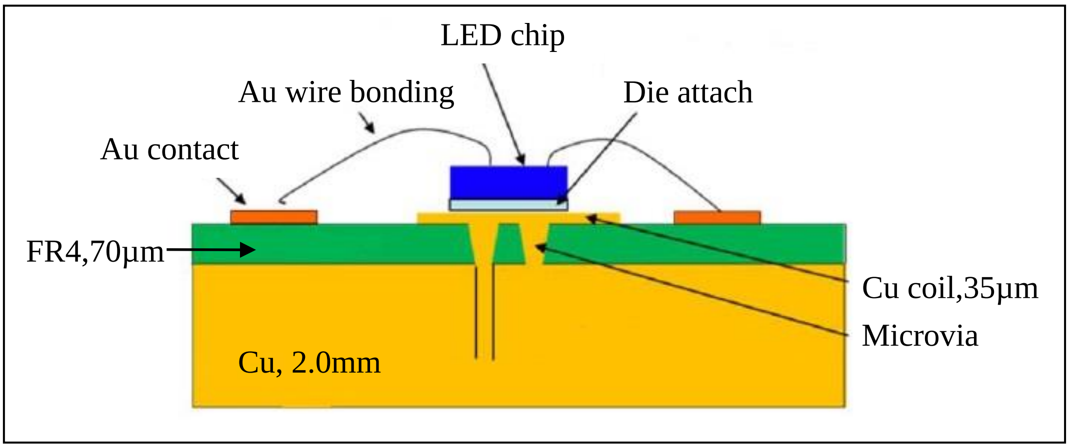


Figure 2.8: LED Module with Copper MCPCB with Vias

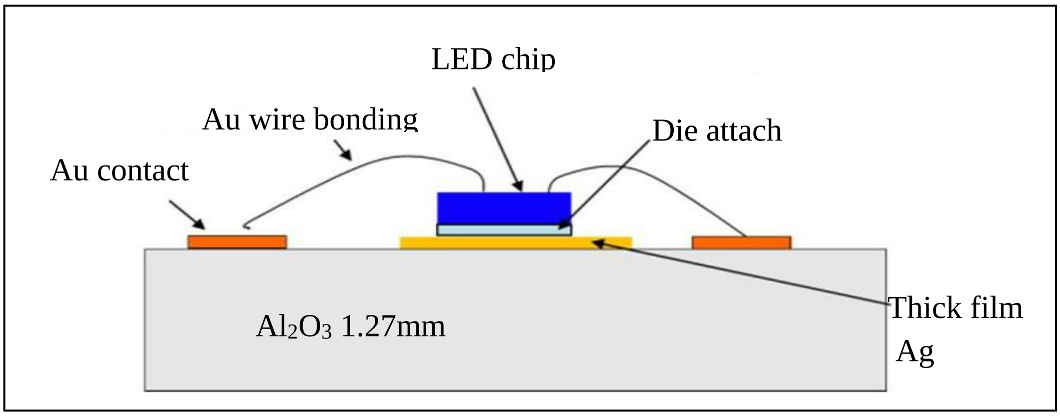


Figure 2.9: LED module with Aluminum MCPCB

Next, aluminum nitrate (AlN) is a good material to be used as substrate because it has high thermal conductivity and electric insulation. These properties make AlN substrate thinner than the MCPCB substrate because MCPCB substrate requires additional layer for the insulating material. Besides, the AlN has low thermal resistance because it does not require the high thermal resistance insulating material that needed in MCPCB. A research was carried out by Yin et al. for thermal analysis on multiple-chip LED module with different types of ceramic substrate. They found the module with AlN substrate has better heat dissipation properties than aluminum and aluminum 103 based substrate (Yin et al., 2010) However, it is not suitable to use AlN alone to build the whole substrate because it is very expensive and brittle. In the research of Jeong (Jeong et al., 2015), instead of using the AlN as the whole substrate, he has used the AlN as insulating material between the LED chips and the copper substrate. The heat management performance of the enhanced module is compared with AlN substrate based LED module and copper substrate base module. He found out that the enhanced model provides good thermal dissipation, electric insulation and high luminous output. Moreover, the cost and the risk of brittleness of the AlN material can be overcome.

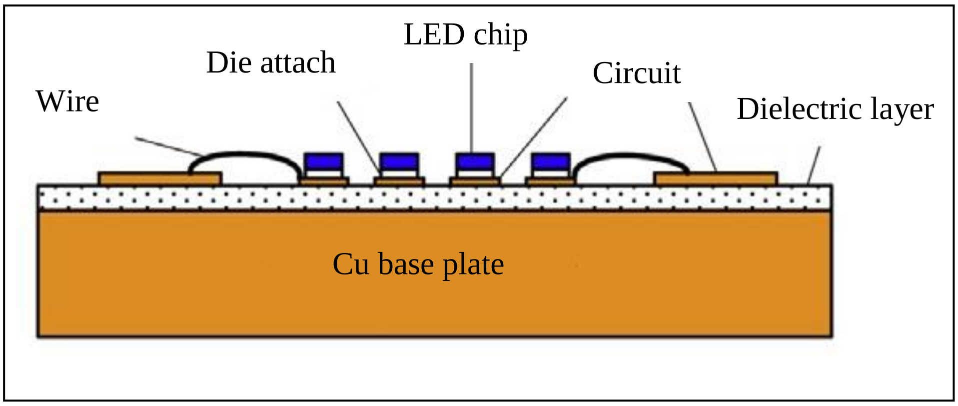


Figure 2.10: LED Module with Copper Base Substrate

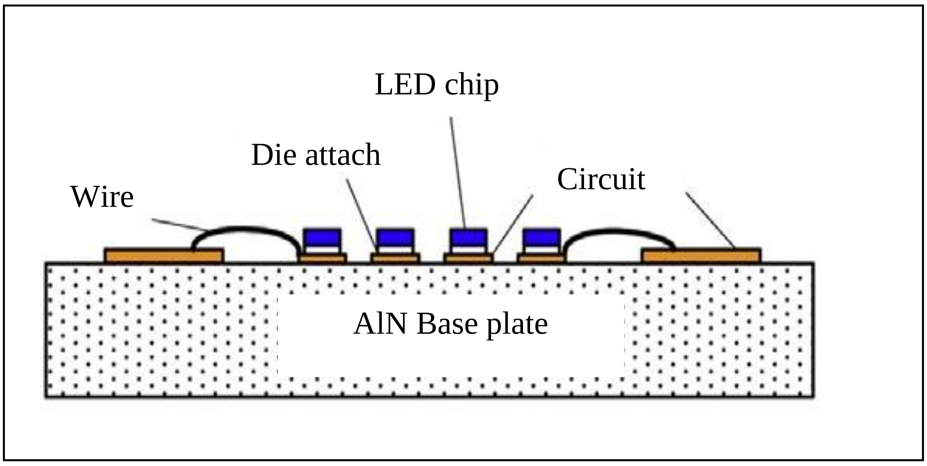


Figure 2.11: LED Module with AlN Base Substrate

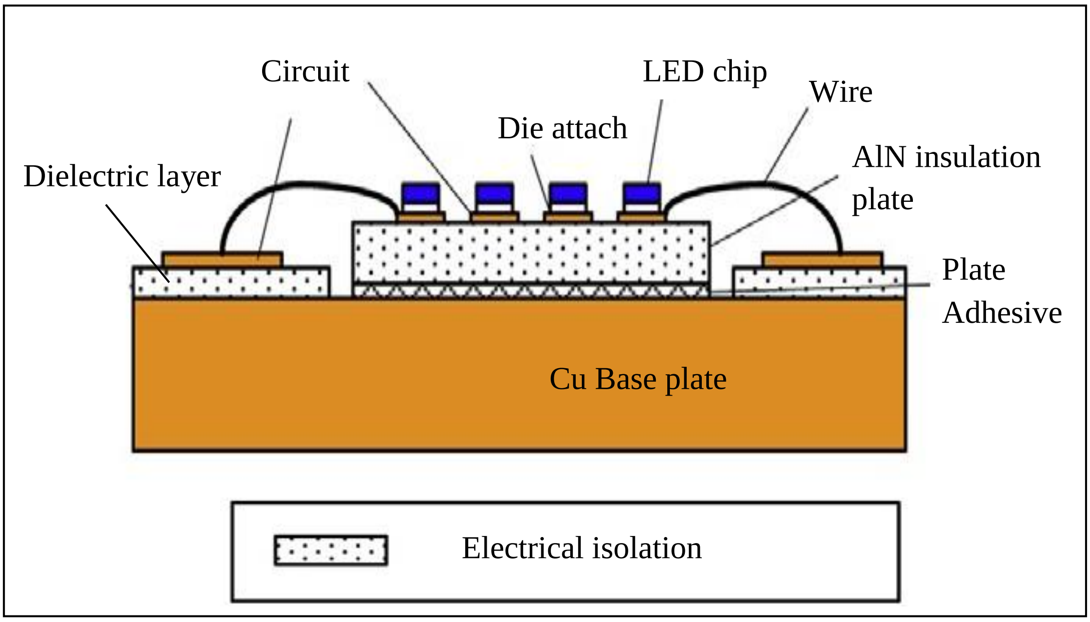


Figure 2.12: Enhanced Model

Besides considering the thermal conductivity of the material, the cost and complication of the implementation method are also very important. As an example, silver (406 W/mK) has high thermal conductivity than aluminum (205 W/mK). However, aluminum is chosen due to its low cost and light weight. Despite of the material of substrate, thermal management product can be used to improve the overall thermal management performance. In this session, some thermal management products that can help to improve the conduction of heat in LED module are discussed.

Thermal interface material (TIM) is widely used to improve the thermal management performance of LED module. This material is used to fill the air gap between the mating surface of the module and heat sink. Usually, heat sink is always used in LED application to increase the surface area of the LED module so as to improve the heat dissipation ability. However, air gaps will present at the interface of the LED module and heat sink. This greatly reduces the efficiency of heat transfer. Thus, TIM is used to fill the air gaps to reduce the thermal resistance between the LED module and the heat sink. Next, thermal conductive encapsulation resin is also a good thermal management product. In addition to protecting the LED module from environment attack, it also helps to dissipate the heat generated in the LED module to the surrounding (Electrolube, 2015).

2.5 Computational Fluid Dynamic (CFD) software and FLOTHERM

Computational fluid dynamic (CFD) software uses numerical analysis and algorithms to analyze problem involving fluid flow. Usually, computer is used to calculate and simulate the interaction of the fluid (liquid and gas) with the boundary condition (external environment of the model set by the user). Nowadays, CFD software is widely use in thermal analysis and design of LED module. This is because CFD software is accurate in simulation of LED module that involves fluid flow, heat transfer and radiation processes (Ling, 2010). Besides, it is better to use CFD software to model the thermal analysis of LED module compared to Finite Element Methodology (FEM) software because FEM only can perform only the heat conduction simulation while CFD software is capable in modeling a thermal environment that close to reality. CFD software allows user to simulate a module that consists of cooling assemblies and the air flow properties inside the module. Moreover, the external environment of the module such as the air flow, humidity, temperature can be set to analysis the heat dissipation of the module through conduction, convection and radiation (Poppe et al., 2008).

In the thermal processing, the Navier Stokes equation is fundamental mathematical formula for the fluid motion in CFD software. Besides, the heat transfer equation is used to solve the energy equation involving the heat transfer in a fluid system. The CFD software also provides a lot of models such as Turbulence Model, Eddy Viscosity Model, Reynolds Stress Model, Radiation Model and many others (Nortan, Brijesh and Sun, 2013). The simulated physical interface provided by the CFD Models allows user to model the most aspects of fluid flow single phase flow, non-isothermal flow and compressible flow. With the models provided, the heat and air flow in the LED module can be simulated accurately.

In past few years, a lot of researches have been done to prove the accuracy of the result generated using CFD software on thermal analysis. In the work of Andras Poppe, the JESD 51-1 static measurement is compared with CFD simulation on thermal analysis of LED module. He found that both methods are different in term of required time and other factors. He also claimed that both methods give a close result but different trade off should be made between the thermal simulation and physical testing. Chi et al. performed the thermal analysis of high power LED module that associated with heat sink using the CFD simulation including the heat transfer correlation and radiation of heat transfer. The research of Weng shows that detailed 3D CFD analysis can improve in the study of thermal management of the LED module. These researches show that CFD software is becoming important and popular to be used in study of thermal management of LED module.

There are various CFD softwares such as OPENFOAM, OPENFLOWER, FLASH ANSYS and many others. All these softwares work best in different kind of application. Thus, appropriate software must be used in order to get an accurate result. In this project, the CFD simulation software used is FLOTHERM. FLOTHERM is a CFD software created by Mentor Graphic. It is suitable to use in predict air flow, temperature and heat transfer of component in a system. FLOTHERM has a user friendly operation interface that allows users to design their module easily. It also has localized grid feature that support integrally matched, nested non-conformal grid interface between different parts of the solution domain. This feature allows accurate simulation result on each part of the module can be produced. Furthermore, the integral model provided by FLOTHERM together with the smart tool such as heat sink, heat pipe and PCB board allow users to create their model easily. The module created can attached with different type of material, heat dissipated, specific heat capacity, thermal conductivity and many other parameters. With these features, a simulated module that is very close to real module can be developed in a short time.

2.5.1 Simulation of FLOTHERM

Simulation study of multiple-chips LED module can be carried out using FLOTHERM as it is able to perform the thermal modeling work accurately. With the embedded CFD solver, FLOTHERM can solve the Navier Strokes equation for mass, momentum and energy conservation correctly using the finite volume technique (Panton, 1996). The equation of mass can be expressed as follows:

$$\left[\frac{\partial \rho}{\partial t} + v \cdot \nabla \rho\right] = -\rho \nabla \cdot v \tag{2.10}$$

where

ρ = density, kg/m^3

t = time,s

v = velocity vector, m/s

The equation of momentum which same direction as the velocity vector can be calculated using the equation:

$$\rho[\partial T/\partial t + v \cdot \nabla v] = -\nabla p + \rho g - 0.67 \cdot \nabla(\mu \nabla \cdot v) + 2\nabla \cdot \mu S \tag{2.11}$$

where

p = pressure,kPa

g = gravity, m/s^2

μ = viscosity, m^2/s

S = strain rate tension

After the equation of the mass and the momentum are solved, the thermal energy is presented with the equation:

$$\rho c_p\left[\frac{\partial T}{\partial t}+v\cdot\nabla T\right]=\nabla\cdot(k\nabla T)-0.67\cdot\mu(\nabla\cdot v)^2+2(\mu S\cdot S)+\beta T\cdot\left[\frac{\partial p}{\partial t}+(v\cdot\nabla)p\right] \tag{2.12}$$

where

T = absolute tempereature,K

k = thermal conductivity,W/mK

β = expensiveness

2.6 Researches

This section discusses the advantage and disadvantage of LED, structure of LED, the factors that affect the thermal resistance, method to reduce the thermal resistance, method to construct a detailed model of LED using CFD software.

Nikolay Vakrilov and his colleges have studied the effect of the topology of LED chips on the thermal management of the LED module. They have simulated a powerful COB LED module using CFD software and the thermal distributions at different locations of the chip are examined. Besides, they have designed the LED module with different kind of substrates which are Alumina (typical), Alumina (94%), Alumina (96%) and AlN. The thermal efficiencies of the four LED modules were examined. They also compared their result with real life thermal measurement result and found out that the result produced using the CFD software is close to the result of real life thermal measurement.

Mohammad Abdullah has studied the thermal efficiency of LED module with different arrays of LED arrangement. The LEDs are arranged in array shape as square, triangle, hexagon and circle. The junction temperature of the LED was measured using a K-type thermocouple. This research is a good guideline for the author to carry out the project. The author has carried out the same experiment based on the methodology provided. Instead of using K-type thermocouple, the author used CFD software to model the modules and obtained the result through simulation. The author has verified the method used to model LED module and the result obtained through FLOTHERM software before the author start to model his own LED module (Abdullah et al., 2013)

Christenensen and Graham has examined the thermal behavior of high power LED module due to different distances between the LEDs array and effect of different material of package level and system level. They found out that when the distance between the LED is close, the junction temperature of the LED is high while the junction temperature of the LED is low when the distance between the LED is far (Christenensen and Graham, 2007).

CHAPTER 3

METHODOLOGY

This chapter explains the method and process to implement this project. It includes the detailed process and step which are deemed necessary in the simulation task. Besides, the method of software design and development will be explained in this chapter too.

3.1 Project overview

1. First, the title “Thermal simulation of multiple-chips LED module using Computational Fluid Dynamic software“ is chosen from the list of topics for final year project provided by Universiti Tunku Abdul Rahman.
2. After the proposal was submitted and approved by the supervisor, literature studies were carried out to understand the structure of the LED module. Related information about the modeling method for LED module using the CFD software and that to measure the junction temperature were acquired through online articles, online journals and research papers.

3. In this section, software implementation process using the CFD software will be discussed in details. Figure 3.1 shows the progress and pace of the project carried out.

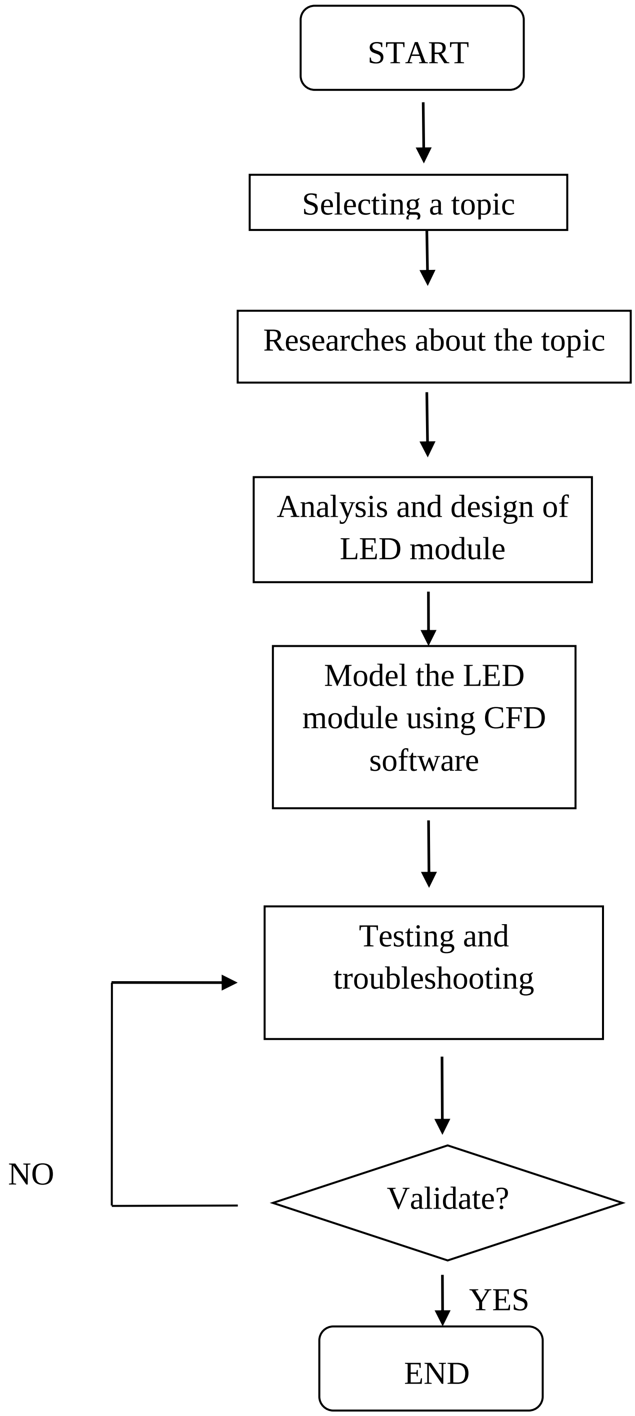


Figure 3.1: The progress and pace of project

3.2 Software Methodology

In order to study the thermal behavior of the multiple-chip LED module, a LED module with multiple chips was modeled using CFD software named FLOTHERM. After that, steady state thermal simulation was run to measure the junction temperature. In the simulation, the conduction, convection and radiation heat transfer process were included. In this project, the author has carried out thermal management study considering three criteria, namely thermal conductivity of material, LED arrangement and heat sink design.

The first step to carry out FLOTHERM study is to scope out the project and define the data required. In this step, the author has studied the geometry and physical properties of the real LED module provided by supervisor. The LED chip used has a dimension of 1 mm × 1 mm × 0.5 mm. The forward voltage to the LED chip, V_f is 3V and the current flow through the LED chip, I_f is 0.95A. The author assumed that the thermal coefficient of the LED is 30%. This means 70% of the power provided to the LED will be converted to heat energy. The estimated thermal power loss of the LED chip is calculated using the formula:

$$P_{th} = V_f \times I_f \times H \tag{3.1}$$

where

P_{th} = estimated thermal power loss in the junction of the LED chip, W

V_f = forward voltage of the LED module, V

I_f = current flow through the LED module, A

H = thermal coefficient (percentage of power converted to heat),%

Note that the estimated thermal power loss of LED chip used throughout the project is 2W.

The second step is to structure the LED module. When building the module, smart parts such as heat sink, cuboids, hole and many others were considered. Smart parts were used since they can be constructed parametrically, making it easier to control the parameter of the object such as position and dimension. The module was built with reasonable tolerance by avoiding small gaps between the smart parts to improve the quality of the grid. After that, the smart parts were attached with material and thermal power loss required. Once the module was developed, the solution domain is set. The solution domain is the air around the module required to be studied. It must be set bigger than the module developed in order to numerically study all the thermal process such as temperature, heat flux, conduction process, convection process and radiation process around the LED module. Figure 3.2 shows the working environment of the FLOTHERM and the properties of the solution domain used throughout the project are tabulated in Table 3.1

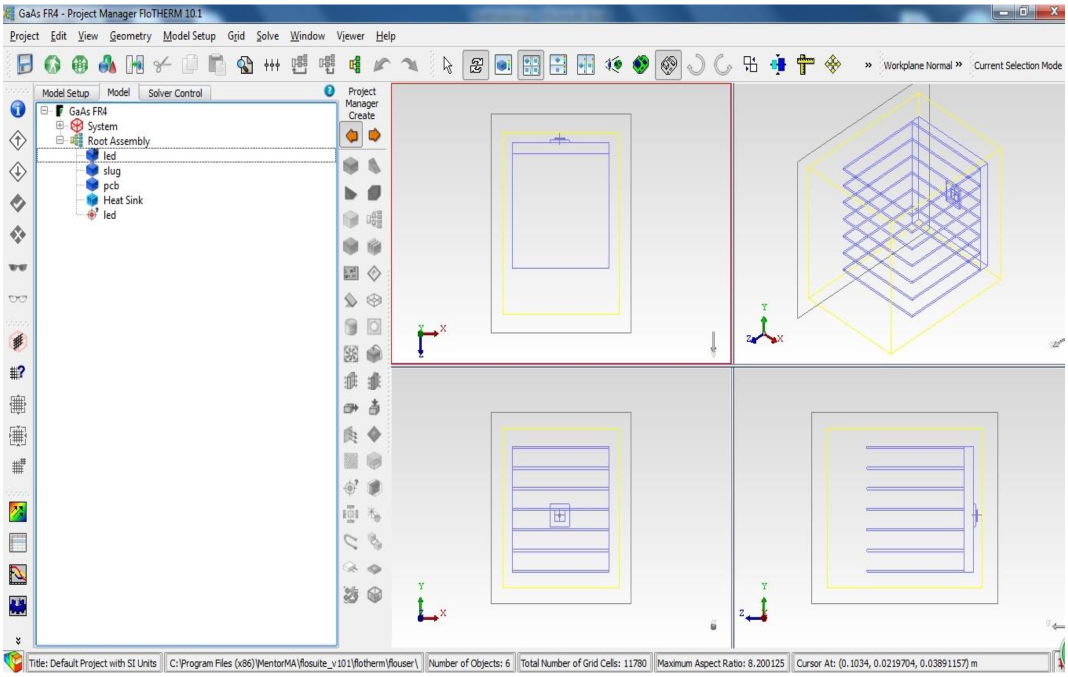


Figure 3.2: Working environment of FLOTHERM

Table 3.1: Properties of Solution Domain

Conductivity	0.02569 W/mK
Viscosity	1.824×10^{-5} N s/m^2
Density	1.88 kg/m^3
Specific heat capacity	1007 J/(kg K)
Expansibility	0.003421 K^{-1}
Ambient temperature	25 ^{o}C
Pressure	1 Atm

This solution domain is an important parameter and it must be set accurately. A slightly change in the properties of the solution domain will affect the result simulated. Different size of solution domain was used in the three criteria as the dimension of the LED modules used in each criterion is different. Monitor points were added to the LED chip to allow the author to observe the changes in the temperature of the LED chip when the solver is running. The cell size of the system grid was then set. The smaller the cell size, the higher the accuracy. However, high accuracy result required very long time to be generated because the simulation speed depends on the performance of the computer. The cell size was set in a range of 0.01 mm to 194.2 mm. In this range, the result generated is accurate and the time required to generate the result is reasonable. Localized grid feature was used at the LED chip as junction temperature of the chip is one of the main factors. Localized grid feature allows high resolution grid set at the LED chip to improve the accuracy of the simulation result.

Once the module was finish developed the solver was set to run. The profile window showed the residuals and the temperature of the monitoring points which are the junction temperature of the LED during the solver process. Figure 3.3 shows the result on the profile window. Although the FLOTHERM is powerful software, the users must keep an eye on both the residuals and values of monitoring points. If all the variables in the residual table does not reach zero at the end of the simulation, steady solution is not converged and an inaccurate result might be produced undesirably. User has to stop the simulation and fix the error. On the other hand, if all the variables reach zero, steady solution is converged. The simulation result can be viewed in Visual Editor to study the result in graphical or tabular format. Figure 3.4 shows the environment of the visual editor. In the visual editor, the temperature and heat flux of each part of the module can be viewed.

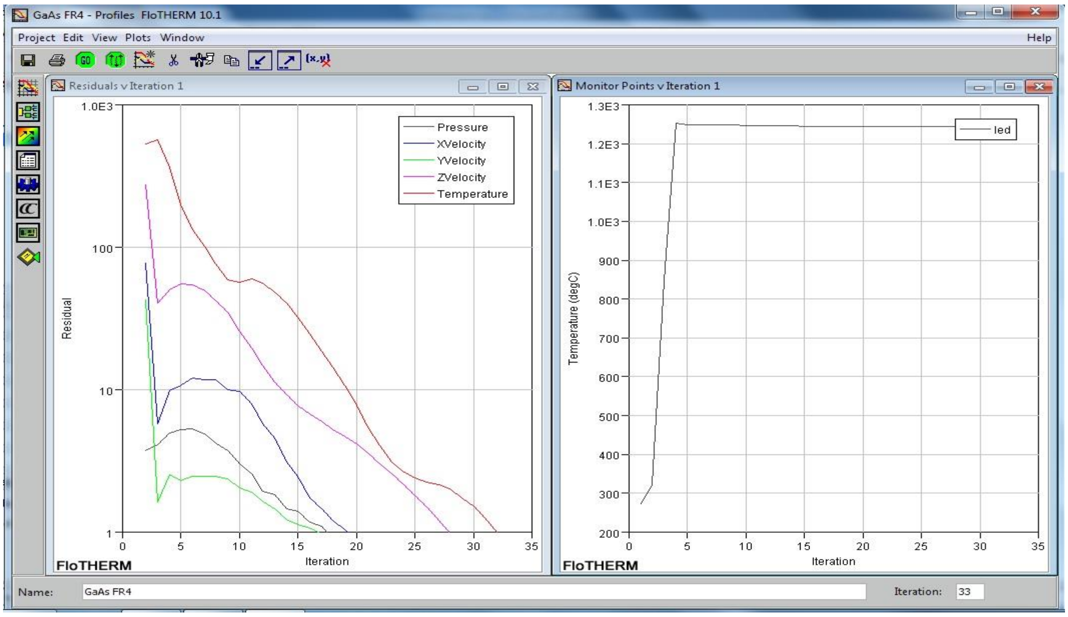


Figure 3.3: Profile Window

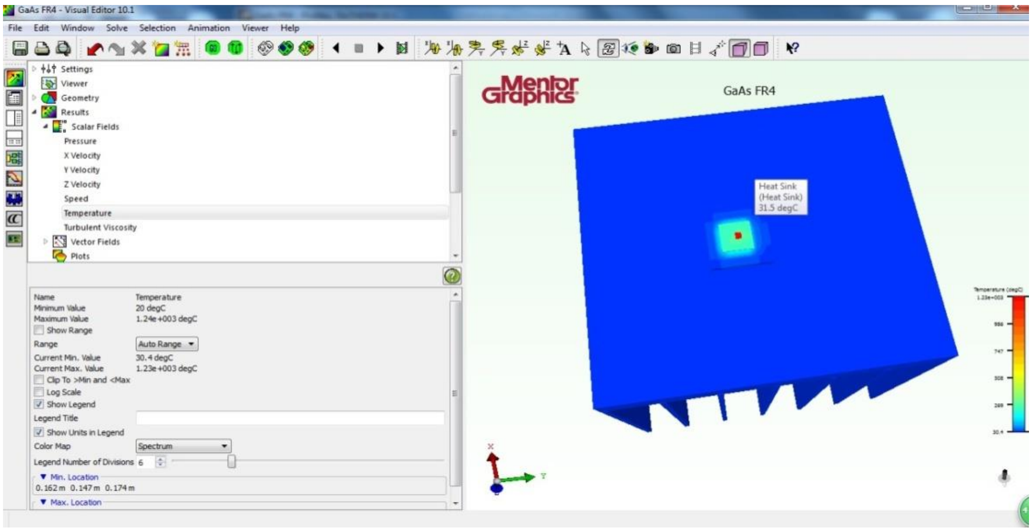


Figure 3.4 Visual Editor

3.3 Study of Thermal Conductivity of Material

In this session, a single chip LED module was modeled. The module consists of one LED that have a dimension of 1 mm × 1 mm × 0.5 mm. The thermal power dissipated of the LED is 2 W. The LED was attached on a copper slug which has a dimension of 5 mm × 5 mm × 0.5 mm. After that, the LED and slug is then disposed on a substrate which has a dimension of 10 mm × 10 mm × 1 mm. The solution domain used is 60 mm × 70 mm × 80 mm. Figure 3.5 shows the LED module design layout.

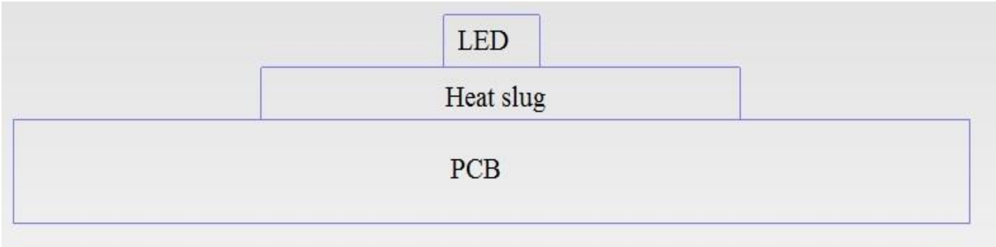


Figure 3.5 LED module design layout

In this simulation, the LED module was placed on an aluminum heat sink. The aluminum heat sink is with a size of 50 mm × 55 mm × 5 mm. It has 5 plate fins with fin height of 50 mm and fin width of 1 mm. Table 3.2 shows the properties of heat sink. Figures 3.6, 3.7, 3.8 and 3.9 show the dimension of the heat sink, dimension of the fins and length of the fins, respectively. Besides, the LED module that was attached directly on the heat sink is shown in Figure 3.10.

Table 3.2 Properties of Heat Sink

Dimension	50 mm × 55 mm
Thickness	5 mm
Number of fin	5
Fin height	50 mm
Fin width	1 mm
Material	Aluminum

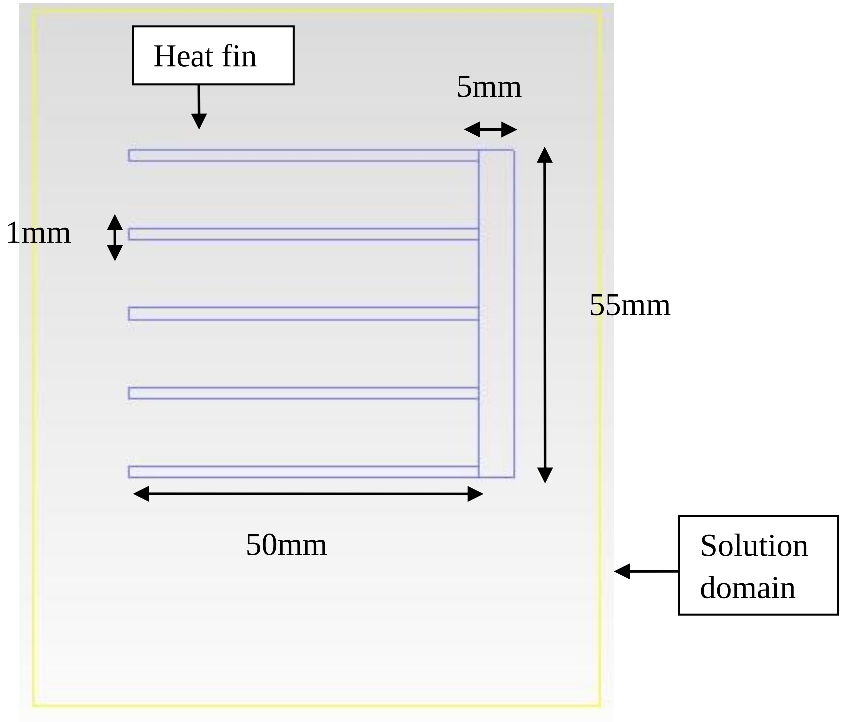


Figure 3.6: Heat Sink View on X Plane

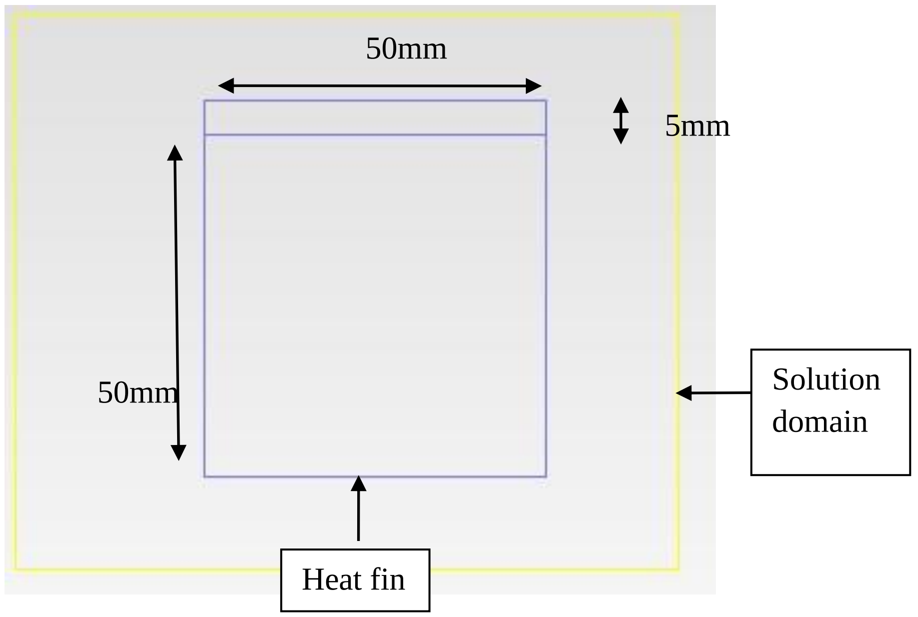


Figure 3.7: Heat Sink Viewed on Y Plane

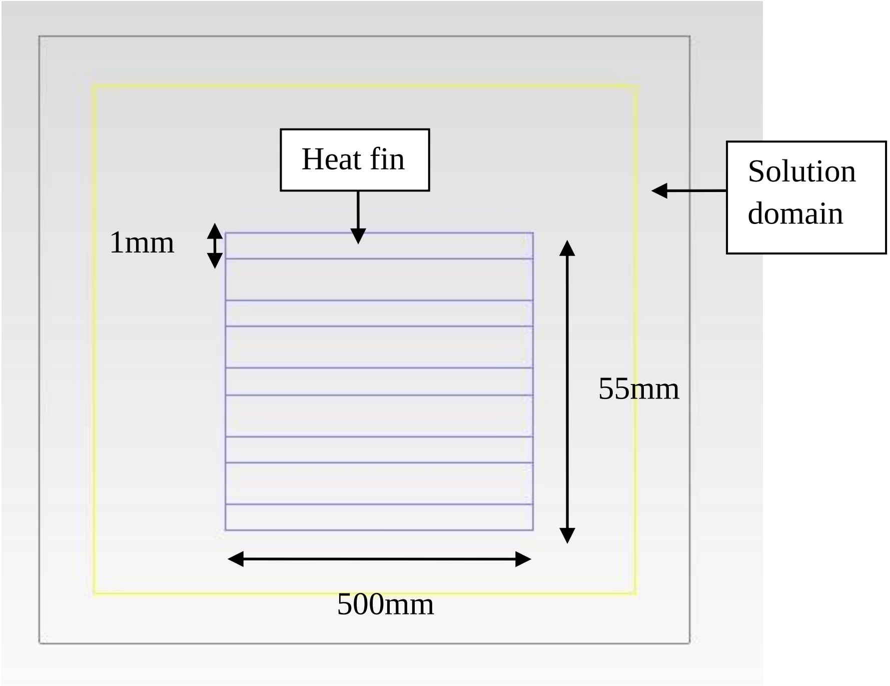


Figure 3.8: Heat Sink Viewed on Z Plane

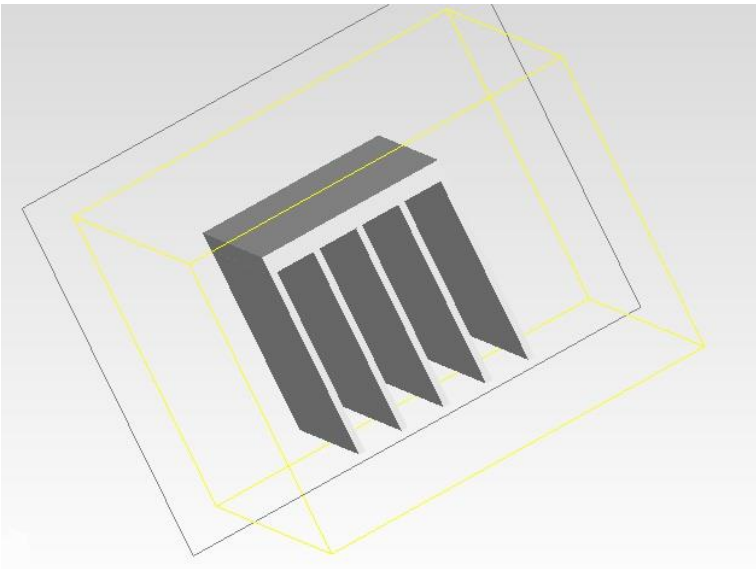


Figure 3.9: 3D View of the Heat Sink

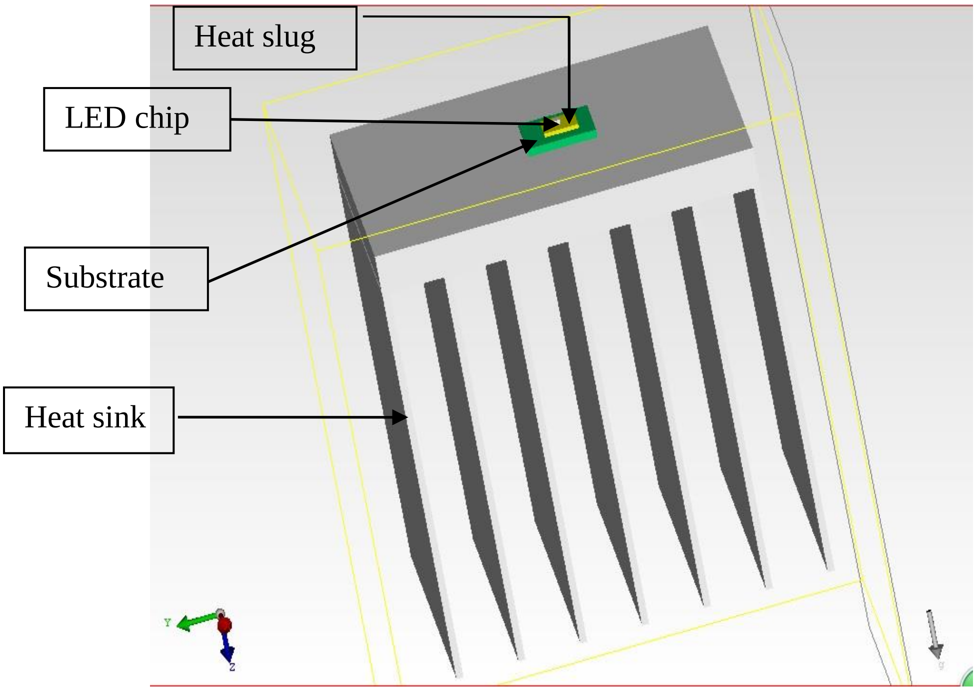


Figure 3.10: 3D View of the LED Module

3.3.1 Thermal Conductivity of LED Chip

LED chip that manufactured using different type of materials were tested. The layout of the LED modules is same as the layout shown in Figure 3.10. Table 3.3, Table 3.4 and Table 3.5 show the properties of the LED modules studies in this session.

Table 3.3: Properties of GaAs LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Gallium Arsenide (GaAs)	1 × 1	0.5	52
Slug	Copper	5 × 5	0.5	385
PCB substrate	FR4	10 × 10	1	0.3
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	50 × 50	10	201

Table 3.4: Properties of GaP LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Gallium Phosphide (GaP)	1 × 1	0.5	110
Slug	Copper	5 × 5	0.5	385
PCB	FR4	10 × 10	1	0.3
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	50 × 50	10	201

Table 3.5: Properties of GaN LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Gallium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	5 × 5	0.5	385
PCB substrate	FR4	10 × 10	1	0.3
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	50 × 50	10	201

3.3.2 Thermal Interface material (TIM)

A layer of thermal interface material (TIM) was added to the LED module as shown in Figure 3.10, so as to study the effect of the TIM on the thermal management performance. Figure 3.11 shows the design layout of the modified LED module and Table 3.6 shows the property of modified LED module used.

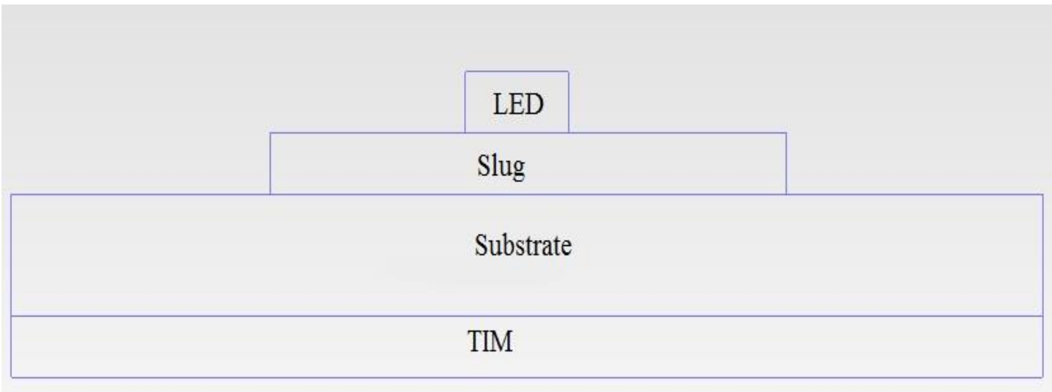


Figure 3.11: LED Module Design Layout

Table 3.6: Properties of the LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Gallium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	5 × 5	0.5	385
PCB substrate	FR4	10 × 10	1	0.3
TIM	Dow coning TC-5022	50 × 50	0.025	4
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	1 × 1	10	201

3.3.3 Thermal conductivity of Substrate

Moreover, two different types of substrates namely MCPCB and DBC were studied. Figure 3.12 and 3.13 show the layout LED module with MCPCB substrate and DBC. Table 3.7 and 3.8 show the properties of the LED module with MCPCB substrate and DBC substrate.

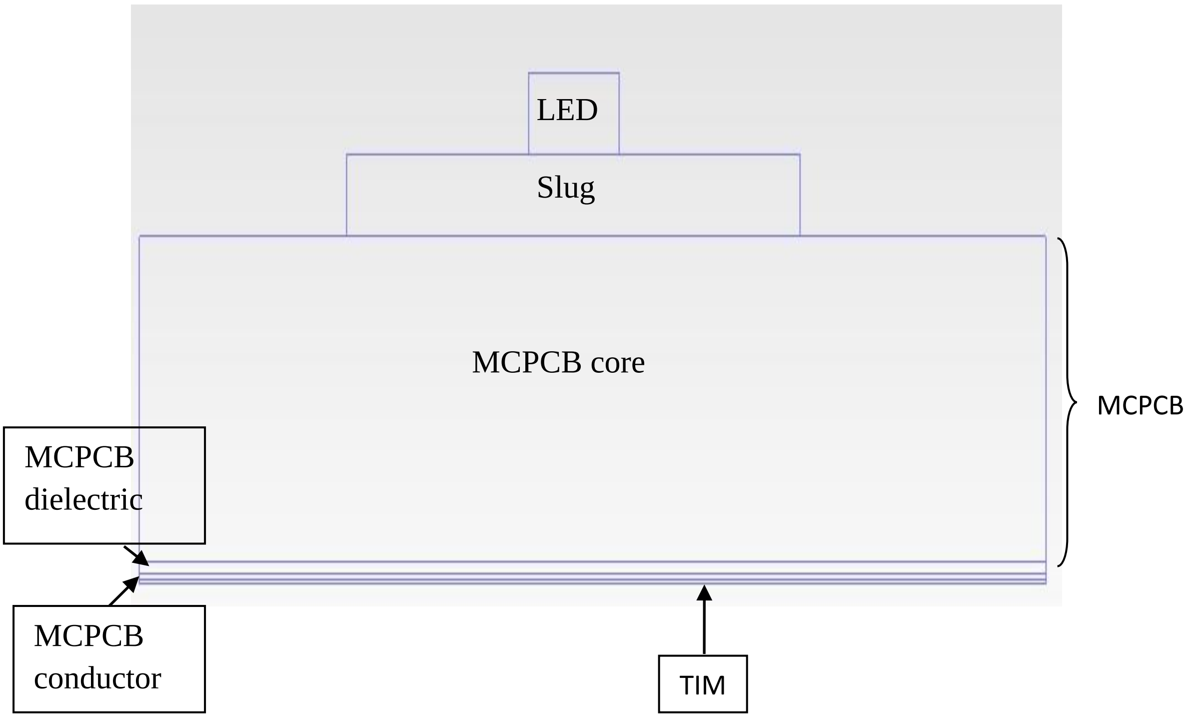


Figure 3.12: LED module with MCPCB Substrate Design Layout

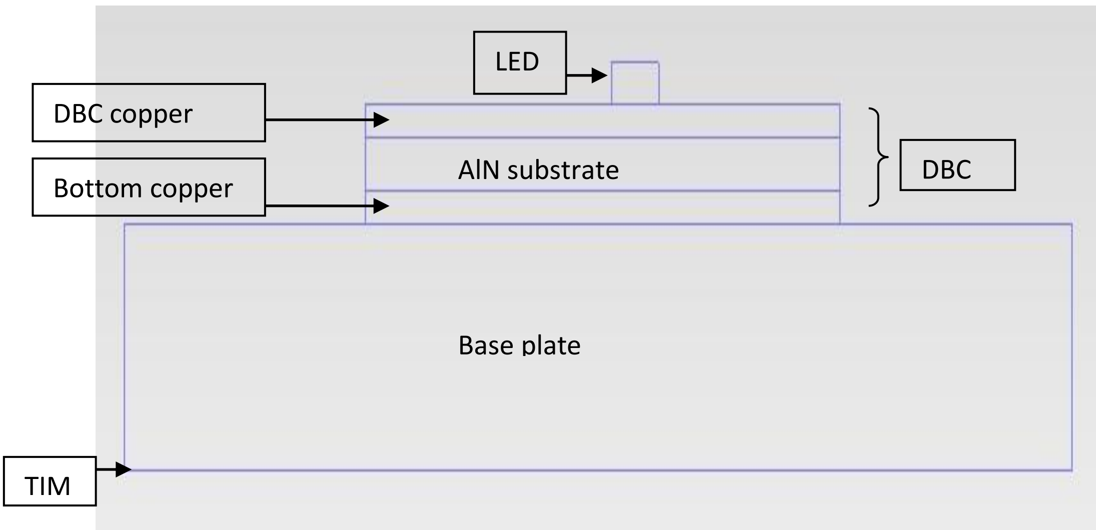


Figure 3.13: LED Module with DBC Substrate Design Layout

Table 3.7: Properties of the LED Module with MCPCB Substrate

Component	**Material**	**Dimension (mm)**	**Thickness (mm)**	**Conductivity (w/mk)**
LED	Gallium Nitrate (GaN)	1×1	0.5	130
Slug	Copper	5×5	0.5	385
MCPCB				
core	Copper	10×10	2	385
dielectric	FR4,IT-180	10×10	0.07	0.88
conductor	Copper	10×10	0.035	385
TIM	Dow coning TC-5022	10×10	0.025	4
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	50×50	10	201

Table 3.8: Properties of the LED Module with DBC Substrate

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Galium Nitrate (GaN)	1 × 1	0.5	130
DBC				
DBC copper	copper	10 × 10	0.41	385
AlN substrate	AlN	10 × 10	0.64	170
Bottom copper	copper	10 × 10	0.41	385
Base plate	copper	20 × 20	3	385
TIM	Dow coning TC-5022	20 × 20	0.025	4
Heat sink Number of fin=7 Fin height=50 mm Fin width=1 mm	Aluminum	50 × 50	10	201

3.4 LED Arrangement

This stage involves the study of temperature distribution in the LED modules due to the number of LED chip, distance between LED chip and arrangement of the LED chip. The design layout is same as the layout shown in Figure 3.12 and it is attached directly on an aluminum heat sink. Table 3.9 shows the properties of the LED module used in this criterion. The size of the solution domain is 120 mm × 117 mm × 109 mm.

Table 3.9: Properties of the LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED	Gallium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	1 × 1	0.5	385
MCPCB				
core	Copper	30 × 30	2	385
dielectric	FR4,IT-180	30 × 30	0.07	0.88
conductor	Copper	30 × 30	0.035	385
TIM	Dow coning TC-5022	30 × 30	0.025	4
Heat sink Number of fin=12 Fin height=80 mm Fin width=1.2 mm	Aluminum	100 × 100	10	201

3.4.1 Number of LED Chips

In this section, the author built three modules with different number of LED chips in order to study the effect of number of LED chips on the average junction temperature of the LED chips. Figure 3.14 shows the LED modules developed. The distance between the LED chips was set to 2 mm for the three LED modules developed.

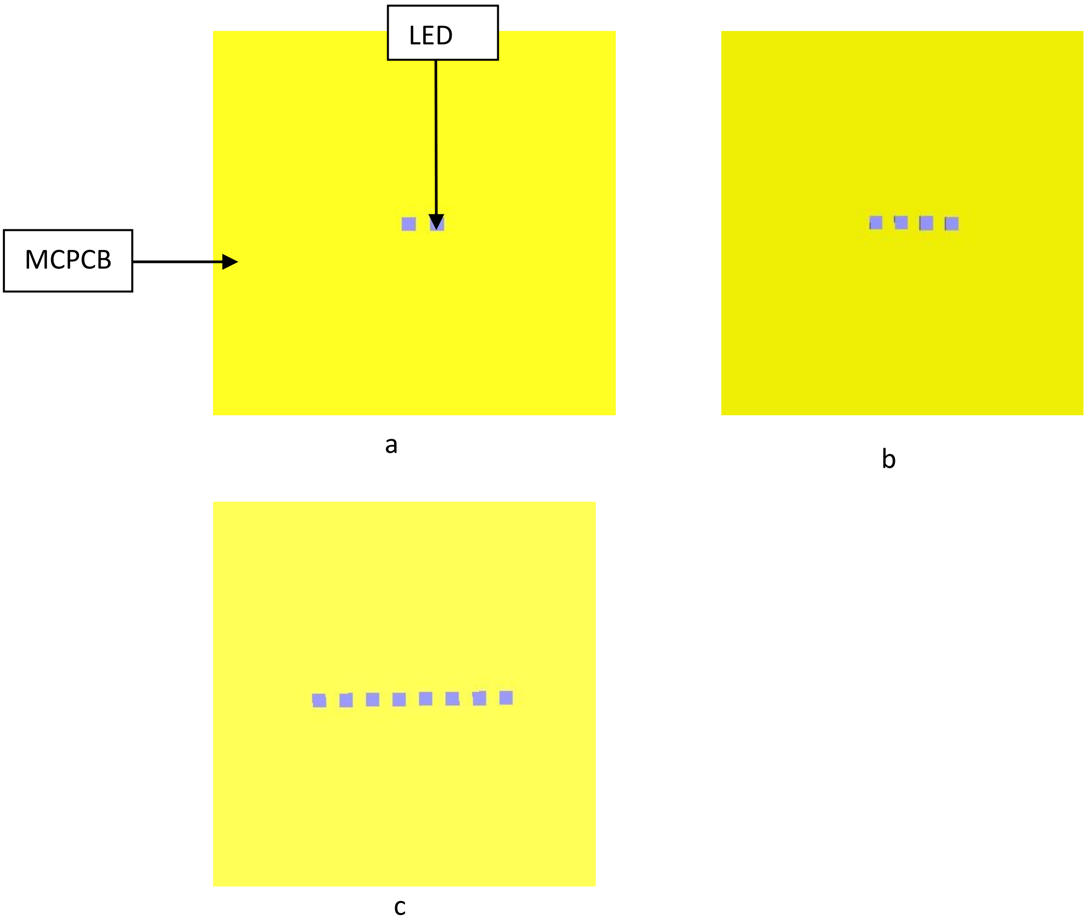


Figure 3.14: Z view of the LED module a) two LED chips module b) four LED chips module c) eight LED chips module

3.4.2 Distance between the LED Chips

Modification was performed on the LED module which has eight LED chips that was developed in the Section 3.4.1. Thermal simulation was carried out using the LED module with different distance between the LED chips in 4 mm, 6 mm and 8 mm. Figure 3.15 shows the Z-plane view of the modified module.

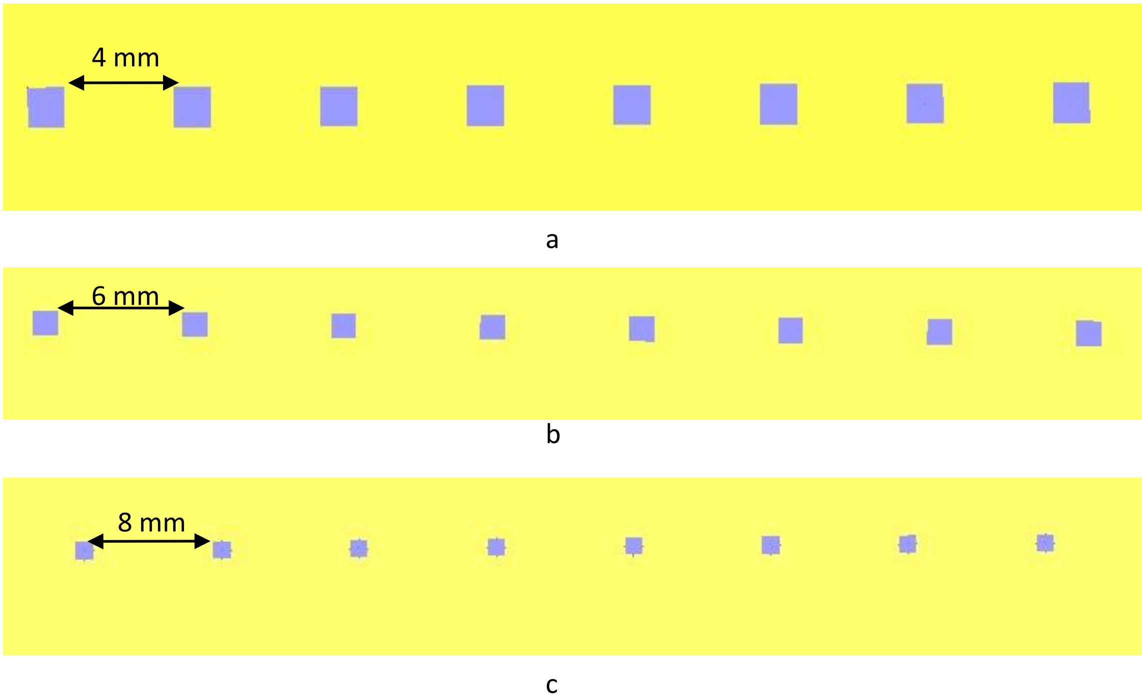


Figure 3.15: Z view of the 8 LED chips module with a) 4 mm distance b) 6mm distance and c) 8mm distance

3.4.3 Orientation of LED chips

The eight LED chips modules was then modified to have different orientations. Figure 3.16 shows the different orientation designed. In this session, author has studied the effect of the orientation of LED chips to the average junction temperature of the eight LED chips.

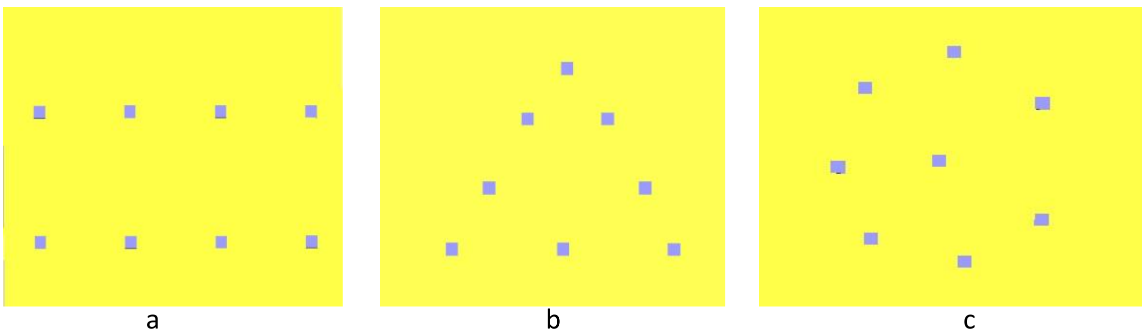


Figure 3.16: Z view of the 8 LED chips module with orientation of a) square b) triangle and c) circle

3.5 Heat sink design

In assessing this criterion, various heat sinks in different design parameters were developed so as to study their ability to dissipate the heat generated by the LED module. The LED module used is the four chips LED module that is same as the module shown in Figure 3.14b. However, the distance between the LED chips is set to 8 mm and the size of the solution domain is 120 mm × 117 mm × 109 mm. The LED module was attached to different type of heat sinks during the simulation. Figure 3.17 shows the LED module used in this section and Table 3.10 shows the dimension and properties of the LED module. Figure 3.18 shows the original heat sink used in this section while its properties are listed in Table 3.11.

Figure 3.17: Z View of the LED Module

Table 3.10: Properties of the LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED x4	Galium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	5 × 5	0.5	385
MCPCB				
core	Copper	40 × 40	2	385
dielectric	FR4,IT-180	40 × 40	0.07	0.88
conductor	Copper	40 × 40	0.035	385
TIM	Dow coning TC-5022	40 × 40	0.025	4

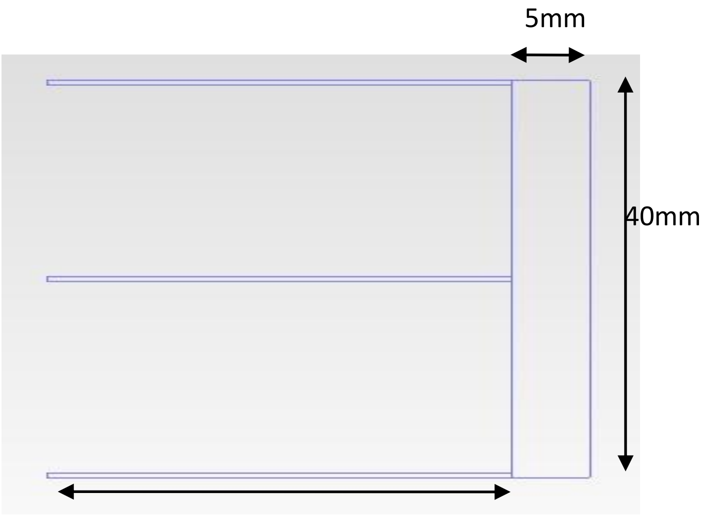


Figure 3.18: Heat Sink Viewed on X Plane

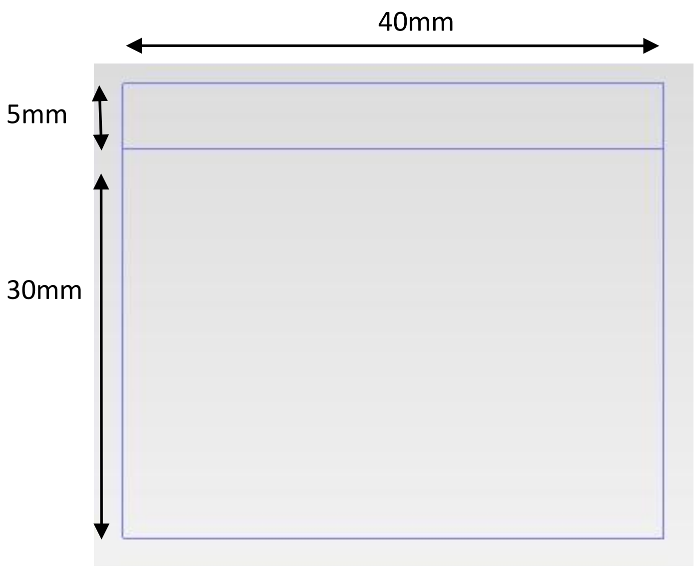


Figure 3.19: Heat Sink Viewed on Y Plane

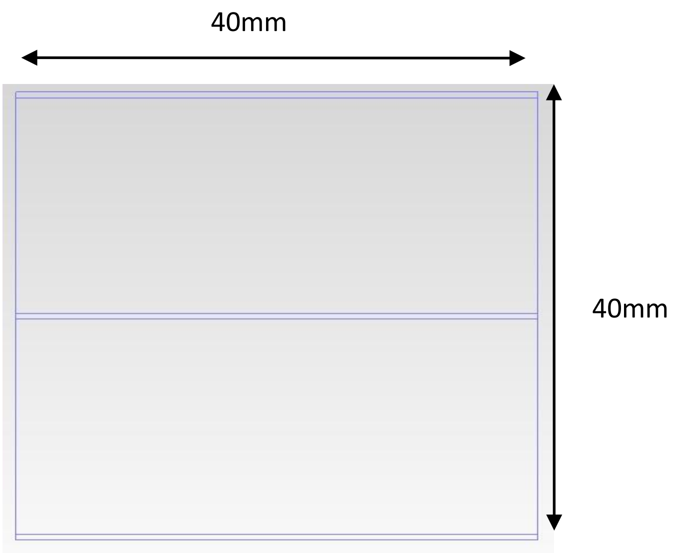


Figure 3.20: Heat Sink Viewed on Z Plane

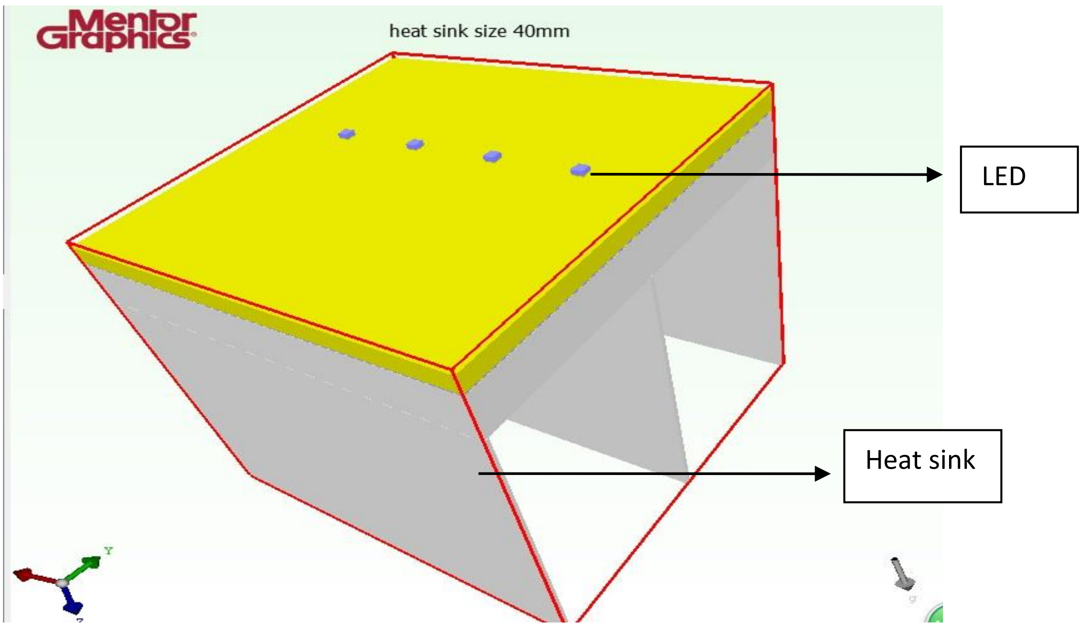


Figure 3.21: 3D view of the LED Module

Table 3.11: Properties of the Heat sink

Dimension (x × y)	60 mm × 60 mm
Thickness	5m m
Number of fin	3
Fin height	30 mm
Fin width	0.5 mm
Material	Aluminum

Thermal performance analysis of the heat sink that was modified in a number of different ways will be discussed in the following chapter.

3.6 Project Planning

In the period of two semesters or 28 weeks, various tasks were performed in developing the detailed LED module and studying the thermal performance of the module. Project planning is a very important step to make sure every assigned task can be completed on time and systematically. Based on the project planning, the progress of tasks was considered satisfactory and all of the tasks were completed.

Figure 3.22 and 3.23 show the Gantt charts developed for this project. The chart is used to keep tracking the software and report development schedules. It is useful to shows additional information about the various tasks of the project.

Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research on background of the project														
Preparation and submission of proposal														
Model the LED module using FLOTHERM														
Preparation of log report														
FYP Progress report submission														
Oral presentation														

Figure 3.22: Gantt Chart for FYP1

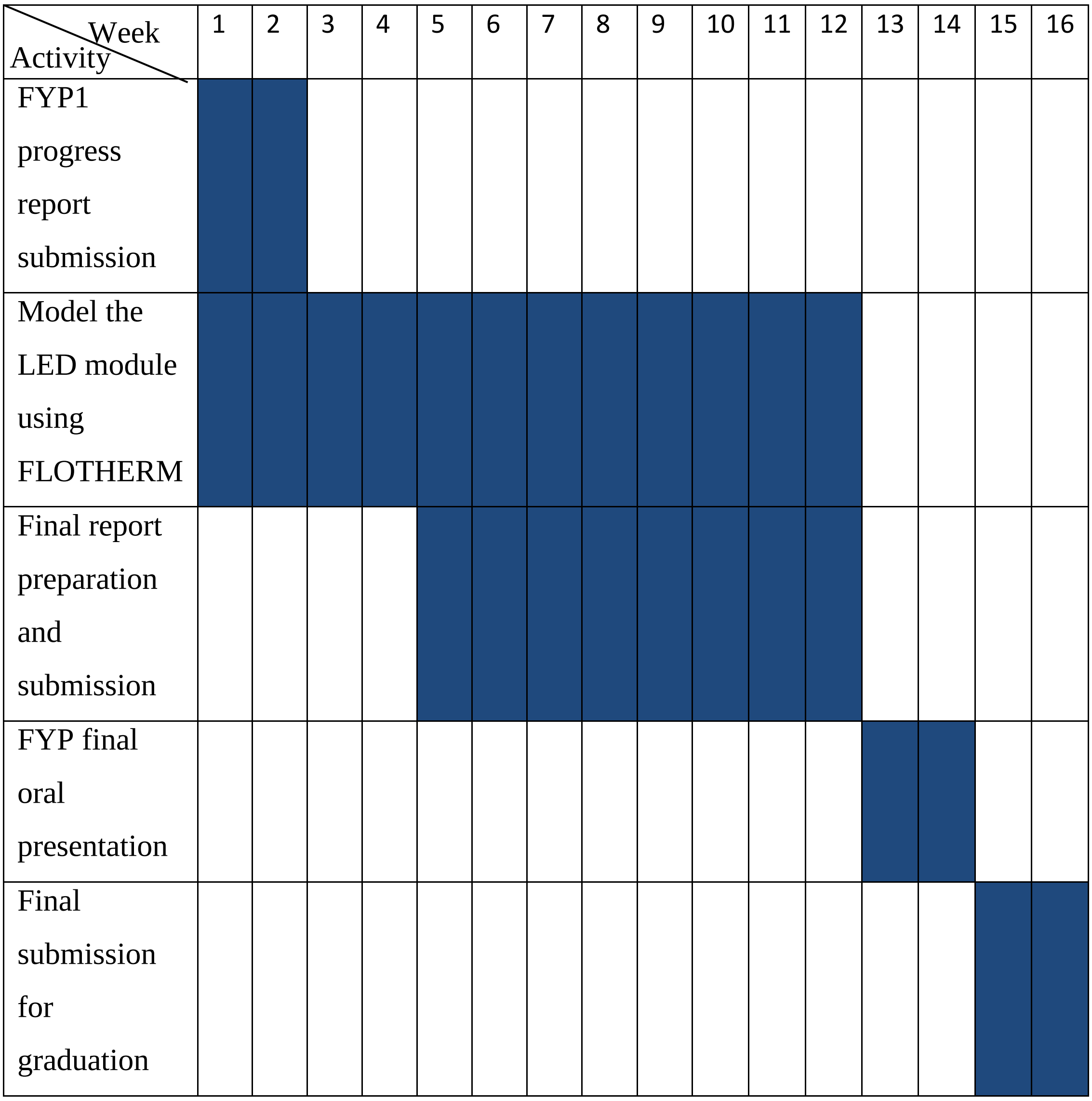


Figure 3.23: Gantt Chart for FYP2

CHAPTER 4

RESULT AND DISCUSSION

4.1 Study of Thermal Conductivity of Material

In present section, different LED chip materials, substrate and TIM were studied in order to find out the optimized design. It is a crucial work to determine the most suitable material that contributes to the good thermal performance LED module. If the LED module is not designed well, the thermal performance of the LED module would not be improved even with a good heat sink, owing to the fact that the heat cannot be conducted to the heat sink effectively.

4.1.1 Thermal Conductivity of LED

In this section, LED chips that made up of different materials were studied. From Table 4.1, the GaP and GaN LED chip have lower junction temperature compared to GaAs LED chip because of its high thermal conductivity characteristic. This phenomenon can be explained using the equation as follows:

$$q/a = k \times (dT/s) \tag{4.1}$$

where

q/a = heat transfer per unit area ,W/m^2

k = thermal conductivity, W/mK

dT = the temperature difference , ^{o}C

s = thickness of the material ,m

From the equation, the heat transfer per unit area is directly proportional to thermal conductivity of material. Thus, the high thermal conductivities of GaN and GaP LED chips allow large amount of heat to pass through easily and hence reducing the junction temperature. On the other hand, low thermal conductivity of GaAs LED chip has high thermal resistance as thermal conductivity is a reciprocal of the thermal resistance.

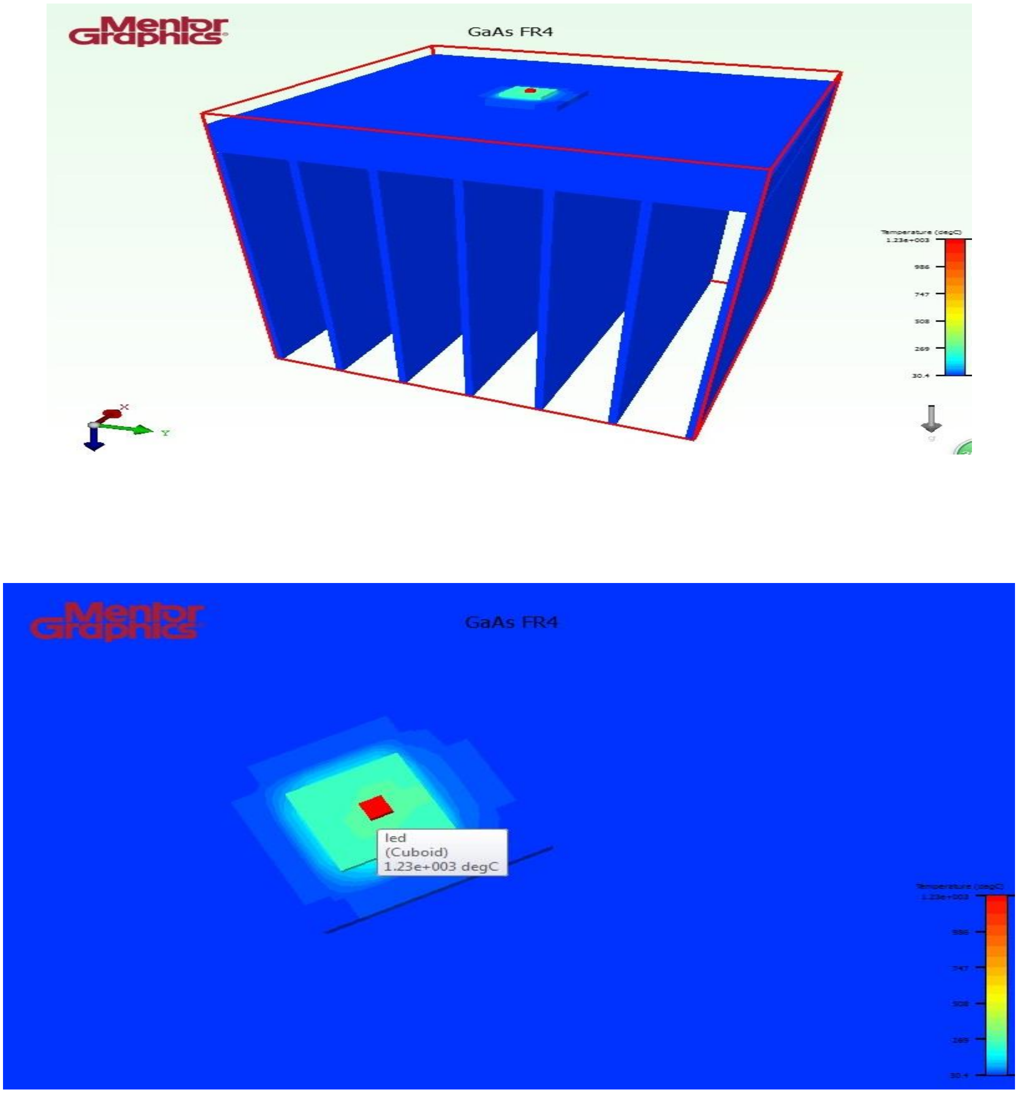


Figure 4.1: Result of GaAs LED Chip

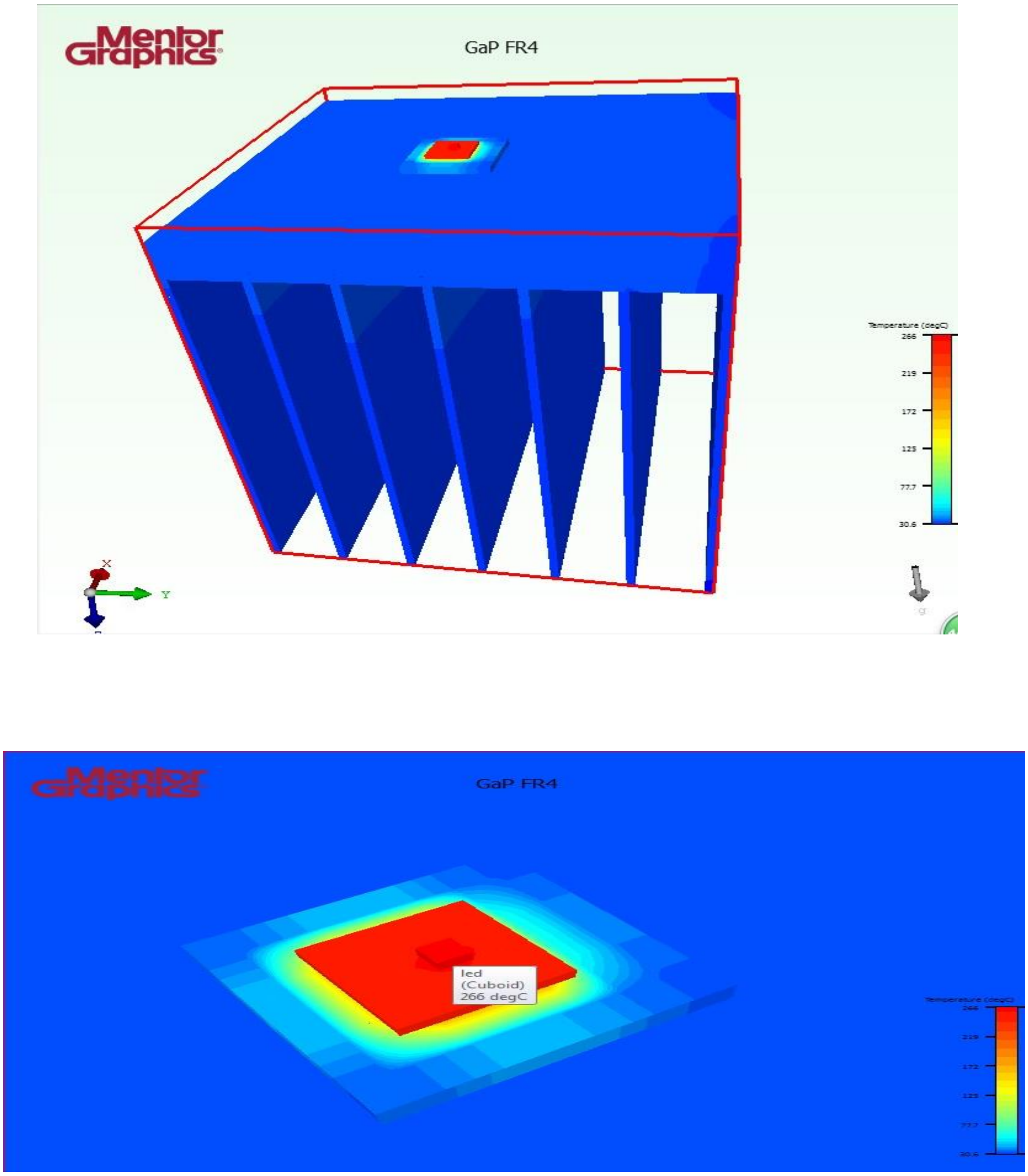
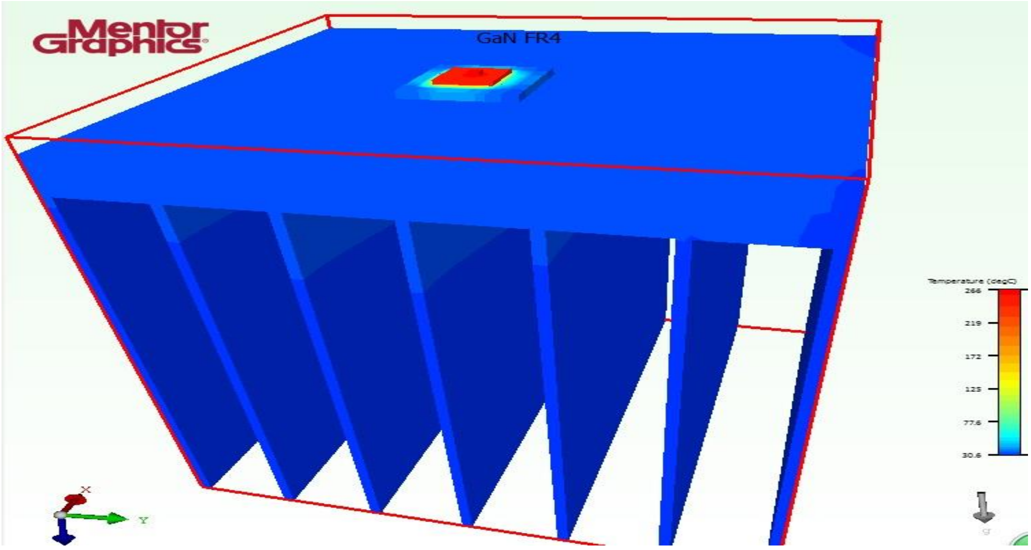


Figure 4.2: Result of GaP LED Chip



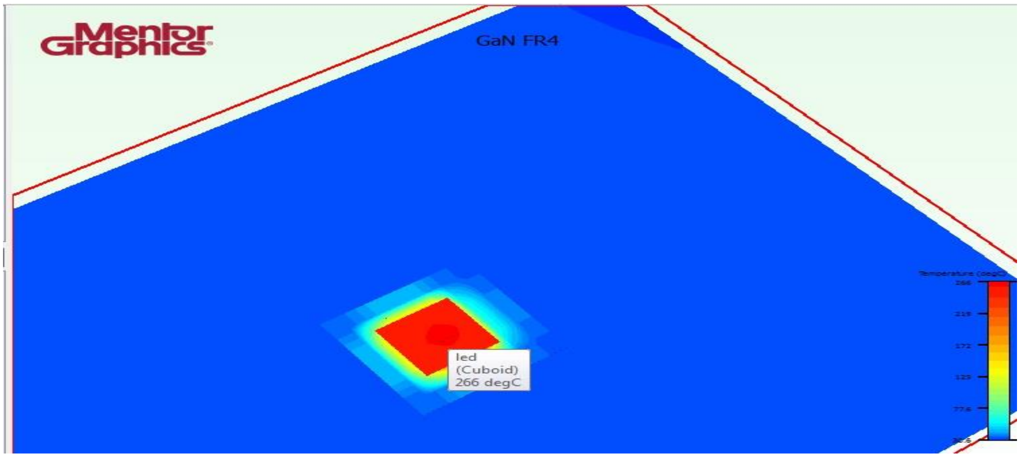


Figure 4.3: Result of GaN Chip

Table 4.1: Comparison of Result

Material	Thermal Conductivity (W/mK)	Junction Temperature (^{o} C)	Color
GaAs	52	1230	Infrared (black)
GaP	110	266	Orange, Yellow, Green
GaN	130	266	Blue

The high thermal resistance of the GaAs LED chip creates some pressure inside the chip and causes heat cannot be conducted easily. As a result, more and more heat accumulates inside the LED chip which leads to the increase of the junction temperature. In this section, the author decided to use GaN LED chip to continue the studies though GaN and GaP LED chips give the same junction temperature. GaN LED chip is chosen as it is more stable and convenient in implementation compared to GaP LED chip. Besides, GaN LED chip that generates blue light can be combined with phosphor to create white light. LED chip that generates white light has a wide range of application field as it gives high luminosity and cooler light. On the other hand, GaP LED chip which can only produce yellow or green light is not suitable to be used in many industry fields that require a bright working environment since yellow light is a low lumen light.

4.1.2 Thermal Interface Material (TIM)

Next, the GaN LED module was added with a thin layer of TIM before it is attached to the aluminum heat sink. Based on the experience in section 4.1.1, TC-5022 TIM material was chosen as it has the highest thermal conductivity. The junction temperature of the module is 271 ^{o}C which is 5 ^{o}C higher than the original GaN LED module used in section 4.1.1. Table 4.2 tabulates the thermal conductivity of various TIM materials, whereas Figure 4.4 shows the thermal distribution map of the module that added with TIM layer.

Table 4.2: TIM Tested by Designer (Narumanchi, et al., 2008)

Thermal Interface Material	Thermal Conductivity (W/mK)
Wacker Silicone P12	0.54
Aavid Thermalloy Thermalcote 251 G	0.4
Artic Silver 5	0.94
Thermaxtect Xt-flux-GA	0.78
Dow Corning TC-5022	4.0

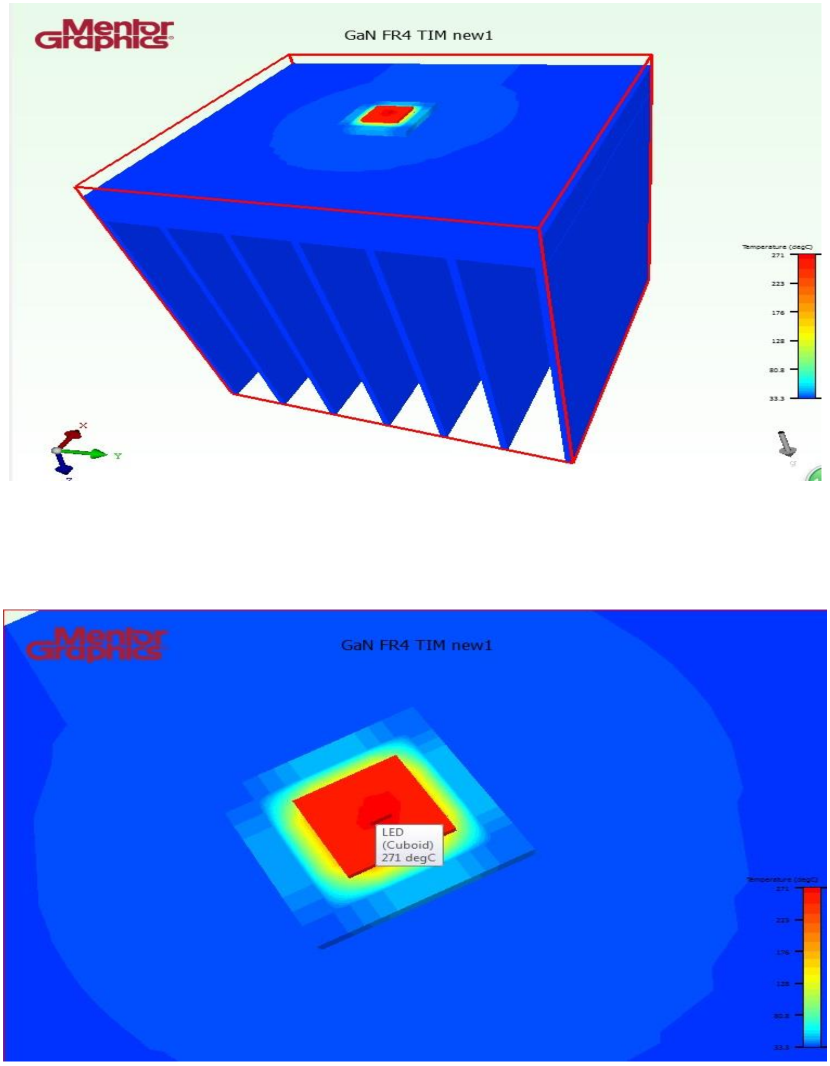


Figure 4.4: Result of GaN LED Chip Module with TIM Added

In real life, attaching the LED module to a heat sink require the surface of the LED module and heat sink to be brought into intimate contact. These surfaces have a twisted shape when observed in microscopic surface roughness viewed. As a result, contact between the surfaces is not perfect and air gap formed between the surfaces which cause a significant thermal resistance to the LED module. Thus, TIM material is required to fill the air gap by covering the uneven surfaces. Yovanovich et al. have calculated that using TIM grease to replace the air can reduced the thermal resistance by factor of five depending on the surface and contact pressure. Because of using TIM which has higher thermal conductivity than air to replace the air gap, the thermal resistance between the surfaces has decreased and this greatly reduce the junction temperature of the LED chip. Figure 4.5 shows the effect of apply the TIM material.

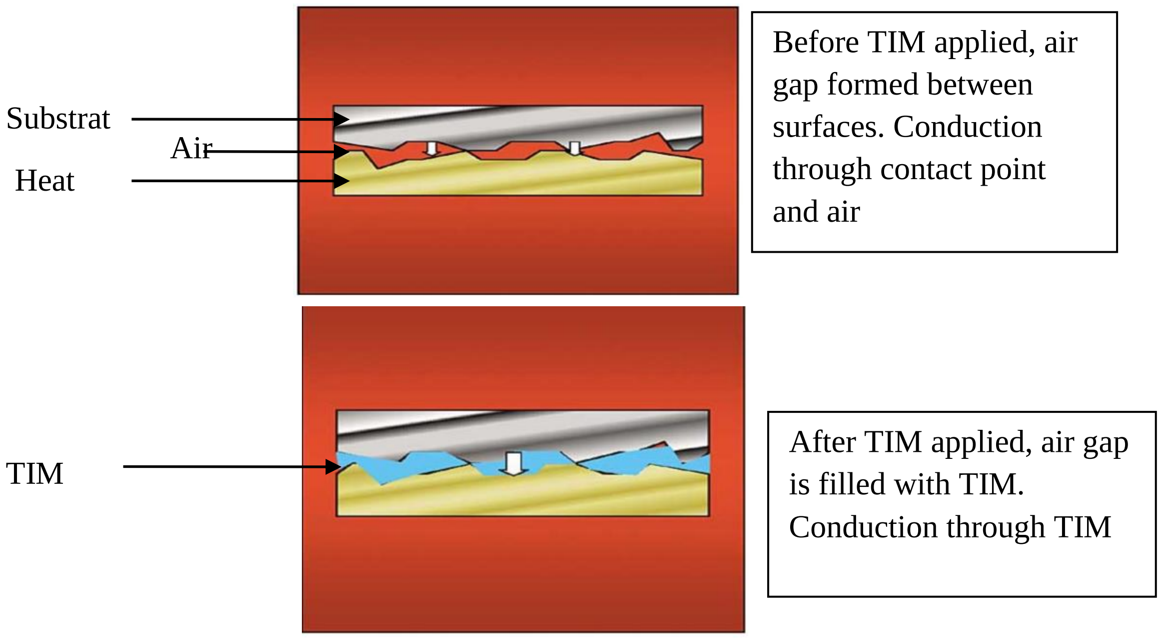


Figure 4.5 Effect of Applying TIM

However, the LED module and the heat sink are in a perfect contact condition when it is modeled by using CFD software. Adding a layer of TIM creates thermal resistance between the surface due to its low thermal conductivity compared to the thermal conductivity of the substrate and heat sink. However, there is only a mere increase in the junction temperature since the TIM layer is very thin. Based on the equation (4.1), the thin layer of TIM which is only 0.025 mm does not restrict the conduction of heat seriously and the simulation result is still acceptable. Thus, the author decided to add a layer of TIM while analyzing the LED modules so as to mimic the structure of the real life LED module.

4.1.3 Thermal Conductivity of Substrate

The FR4 substrate (a material for printed circuit board) that used in the GaN LED module was replaced with a copper MCPCB and DBC in order to study the thermal performance of the module.

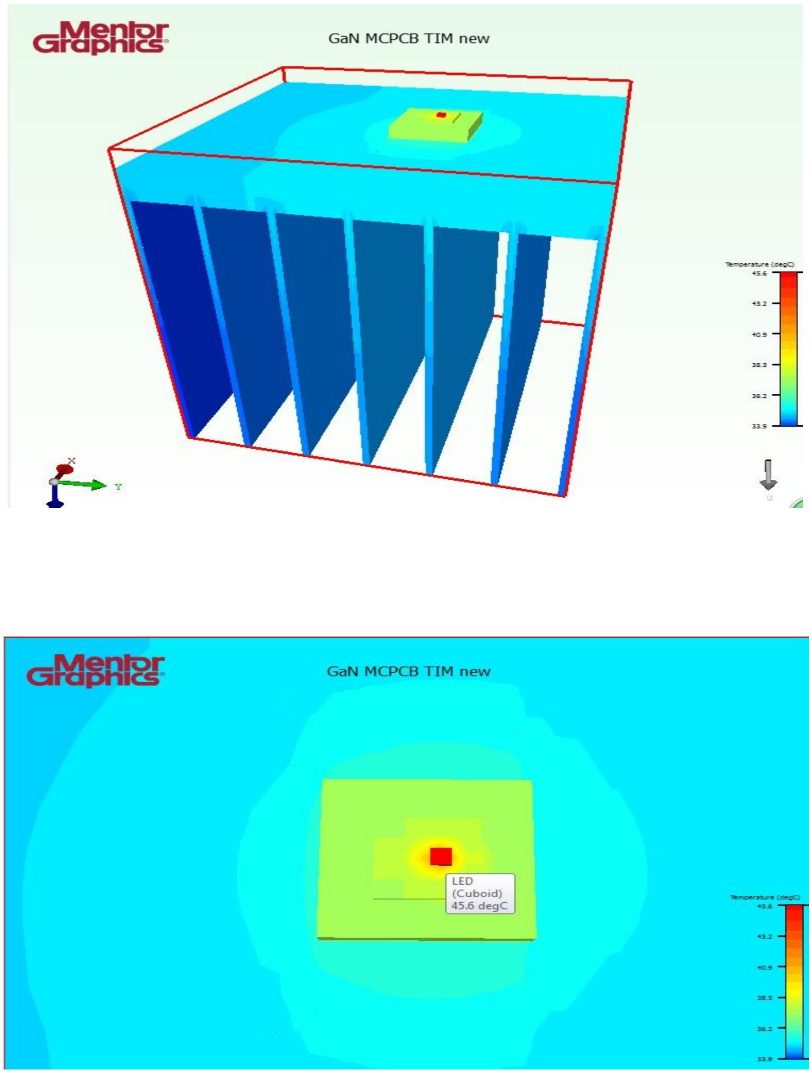
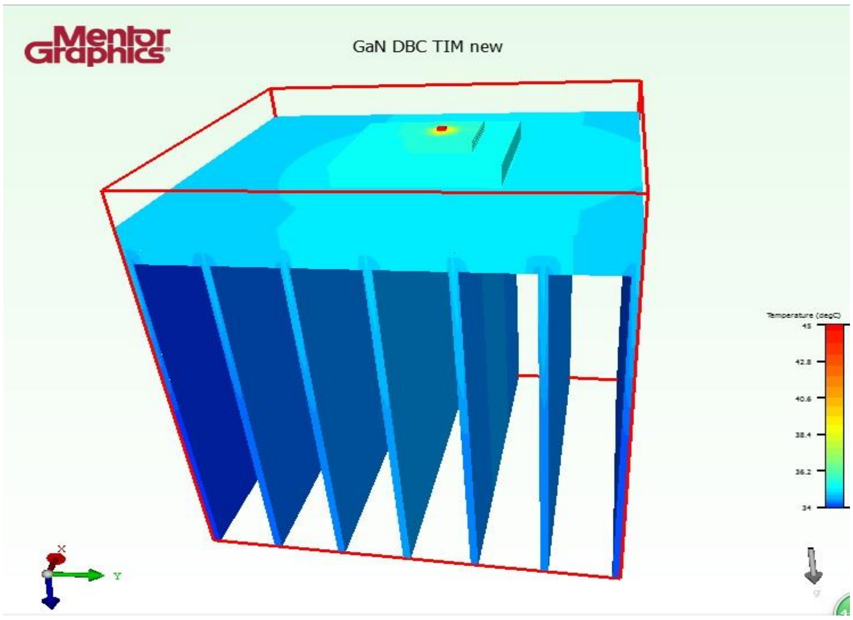


Figure 4.6: Result of GaN LED Module with MCPCB Substrate



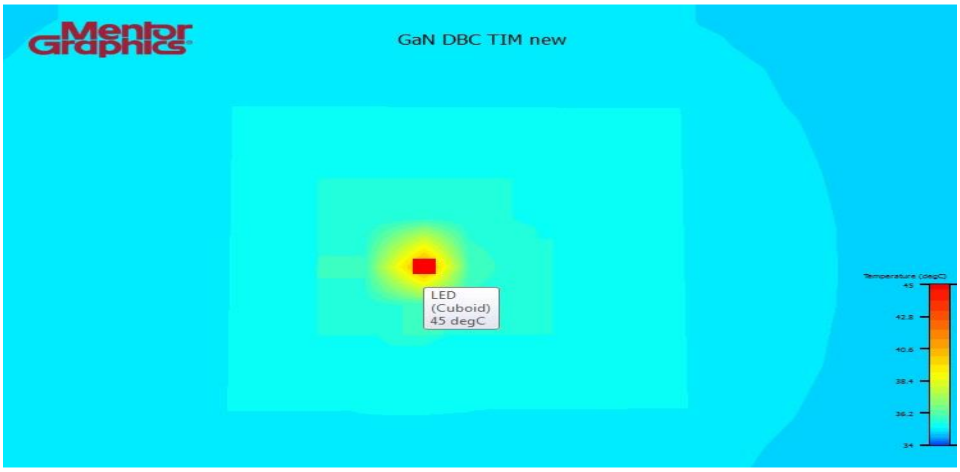


Figure 4.7: Result of GaN LED Module with DBC substrate

The junction temperature of the GaN LED module with MCPCB substrate is 45.6 ^{o}C and junction temperature of the GaN LED module with DBC substrate is 45 ^{o}C. The results show that MCPCB and DBC are better material than FR4 substrate. This is because MCPCB and DBC have a thermally conductive dielectric layer that has relatively higher thermal conductivity than the FR4. The dielectric layer acts as a good thermal bridge between the LED chips and the base copper plate. Besides, the base copper plate can conduct the heat effectively to the heat sink to be dissipated to the atmosphere. Besides of being thermal conductive, the dielectric layer has good electric insulation that can help to prevent short circuit between the LED module and heat sink. This helps increasing the stability of the LED module. The copper core, which is a traditional PCB board on top of the dielectric layer, also helps to dissipate some of the heat to the atmosphere directly. Eventually, it can reduce the junction temperature of the LED chip. On the other hand, FR4 only can remove heat with the use of heat sink. As a result, the thermal dissipation performance of the overall LED module is poorer compared to LED module that has MCPCB or DBC substrate.

By comparing the thermal management performance of the MCPCB substrate and DBC substrate, the author decided to use MCPCB though DBC has better thermal management performance. This is because DBC has low thermal mechanical reliability. It cracks easily in extreme temperature condition causing loss of isolation properties. DBC also lack of flexibility in design to allow multiple copper thicknesses and it cannot fabricate metalized via through ceramic substrate. Therefore, MCPCB is chosen as it is more reliable and flexible in LED module design (Person and Gundel, 2015).

4.2 LED Arrangement

In order to assess this criterion, multiple-chip LED module was generated through the modeling software whereby the different orientations of the LED chips were thus studied.

4.2.1 Number of LED Chips

Based on Table 4.3, an increase in number of LED chips yields an increment in average junction temperature. The estimated thermal power loss of a single LED chip is 2W. When the number of LED chips was increased by a factor of *n*, the estimated thermal power loss increased by *n* too. This causes large amount of heat generated around the LED chips. On the other hand, the heat sink used throughout this section remains unchanged. When a module with eight LED chips was used, the heat sink failed to dissipate the large amount of generated heat to the surrounding effectively. This causes the rise in the average junction temperature. However, the author decided to use the eight LED chips module to carry out simulation for this criterion because average junction temperature of 62.93 ^{o}C is still acceptable.

Table 4.3 Comparison of Result

Number of LED chips	Average Junction Temperature (^{o}C)
2	46.60
4	50.95
8	62.93

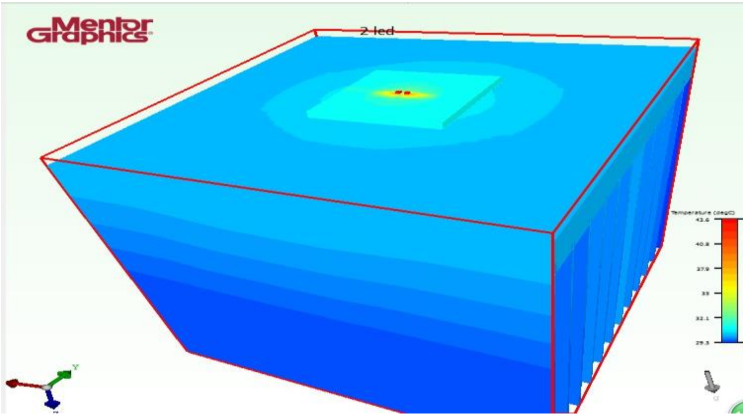


Figure 4.8: Multiple-Chips LED Module with Two LED Chips

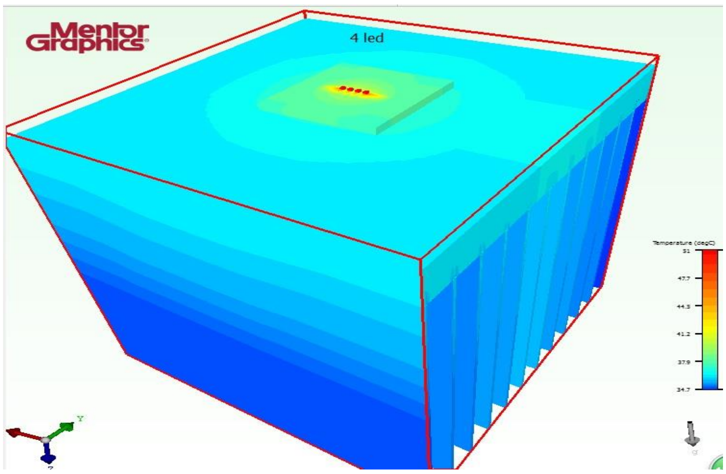


Figure 4.9: Multiple-Chips LED Module with four LED Chips

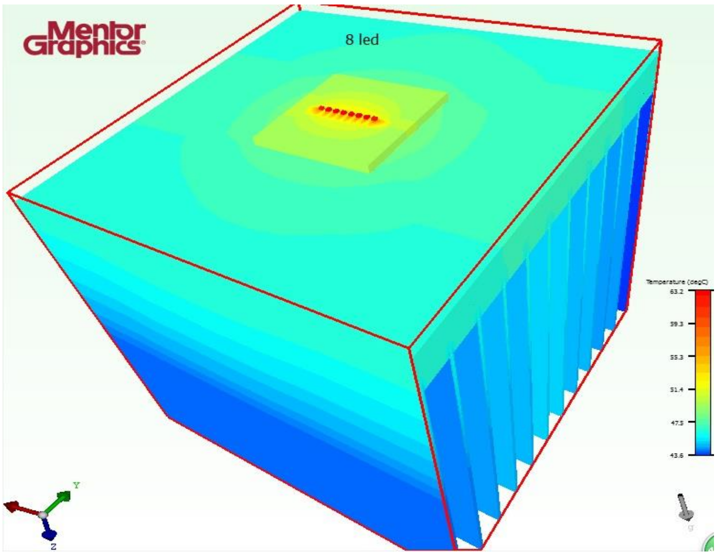


Figure 4.10: Multiple-Chips LED Module with eight LED Chips

4.2.2 Distance between the LED Chips

In this section, the eight LED chips module shown in Figure 4.10 has a distance of 2 mm between each LED chips. The module was further modified to have different distance between the LED chips. Table 4.4 shows the simulation result of the LED module with distance between LED chips of 2 mm, 4 mm, 6 mm and 8 mm.

Table 4.4: Comparison of Result

Distance between LED chips (mm)	Average Junction Temperature (^{o}C)
2	62.93
4	60.38
6	59.79
8	59.59

The results from Table 4.4 clearly show that a further distance between the LED chips increases the average junction temperature. The temperature difference between the multiple-chips LED module with distance between the LED chips of 8 mm and 2 mm is about 3 ^{o}C. When the gap between the LED chips is big, the heat can be dissipated easily since there is less heat influence between the LED chips. Besides, the outermost LED chips which are the first and the last LED chips always have lower junction temperature compared to other LED chips. This is due to the fact that there is more space for the first and the last LED chips to dissipate the heat. As a result, more heat can be dissipated and this decreased the junction temperature. Figure 4.11 shows that the first and last LED chips have larger area to dissipate the heat when the distance between the LED chips is 2 mm. However, other designs were not able to dissipate heat well due to heat influence. Figure 4.12 shows that all the LED chips dissipate heat equally to all direction due to less heat influence.

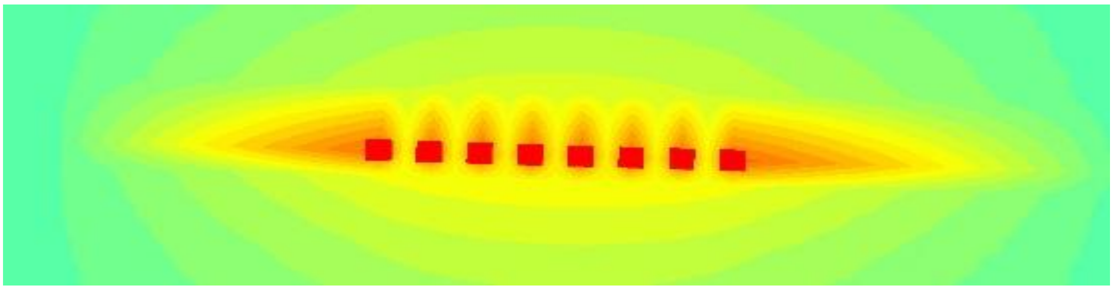


Figure 4.11: Simulation Result of Multiple-Chips LED Module with Distance between LED Chips of 2mm

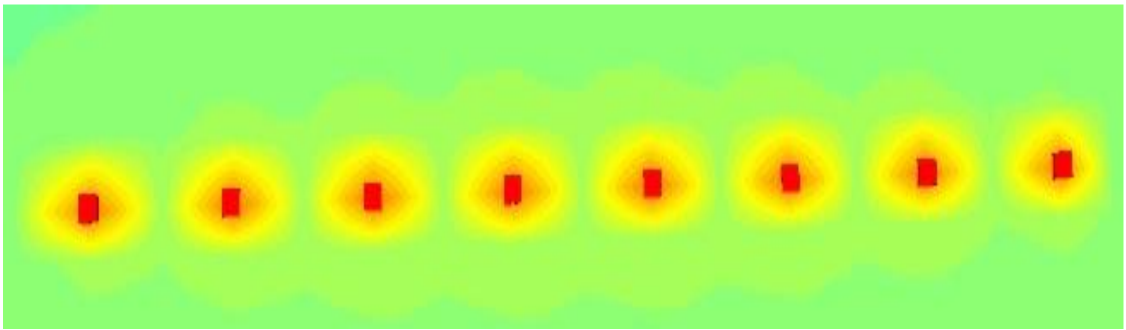


Figure 4.12: Simulation Result of Multiple-Chips LED Module with Distance between LED Chips of 8mm

4.2.3 Orientation of the LED Chips

Moreover, the eight chips LED module was modified to have different orientation of the LED chips in rectangle orientation, triangle orientation, circle orientation and line orientation. Figure 4.13, 4.14, 4.15 and 4.16 show the simulation result of the modified eight chips LED chips module, respectively. Table 4.5 shows comparison of the simulation results.

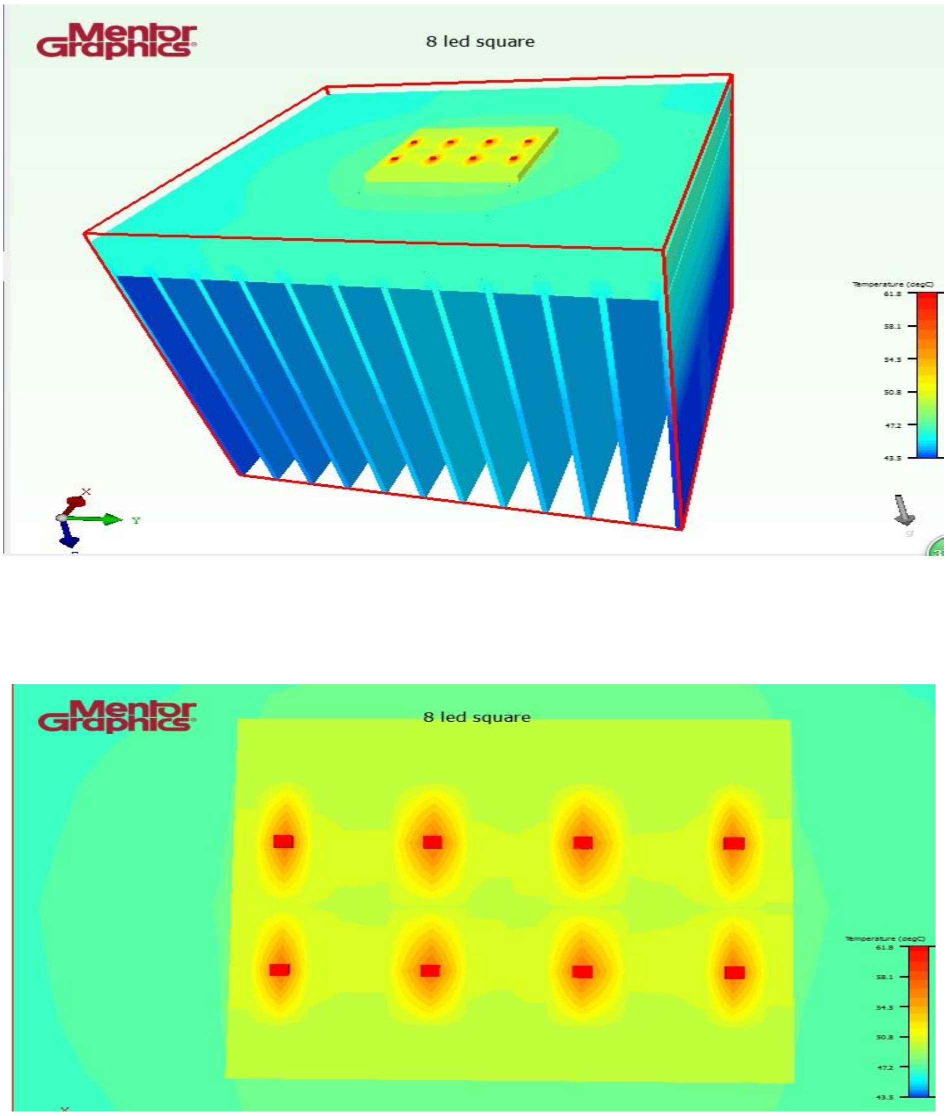
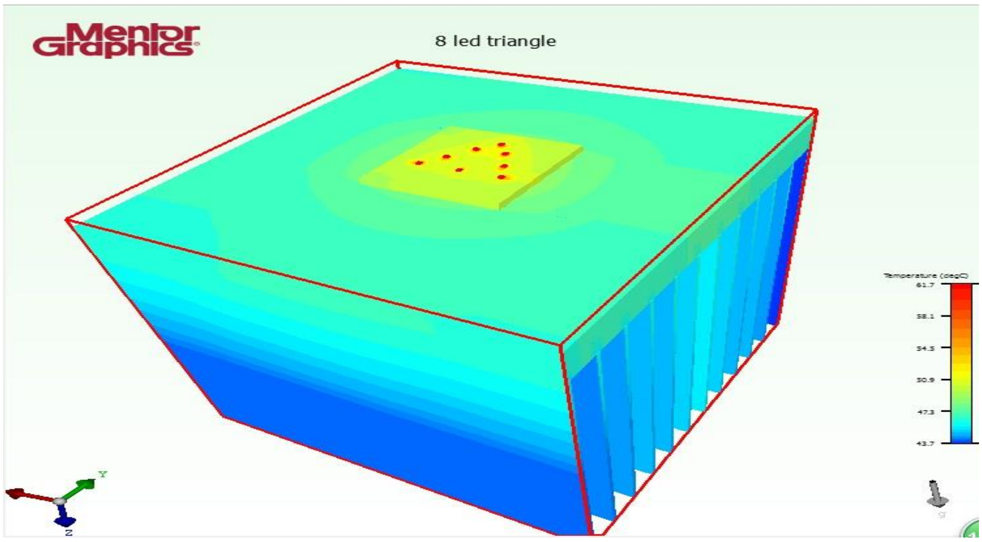


Figure 4.13: Simulation Result of Eight Multiple-Chips LED Module with Rectangle Orientation



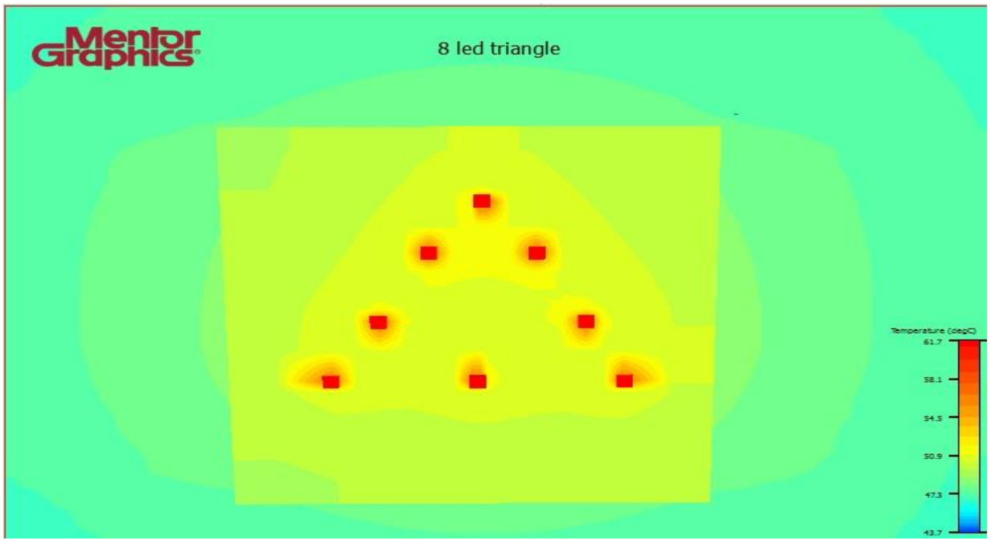


Figure 4.14: Simulation Result of Eight Multiple-Chips LED Module with Triangle Orientation

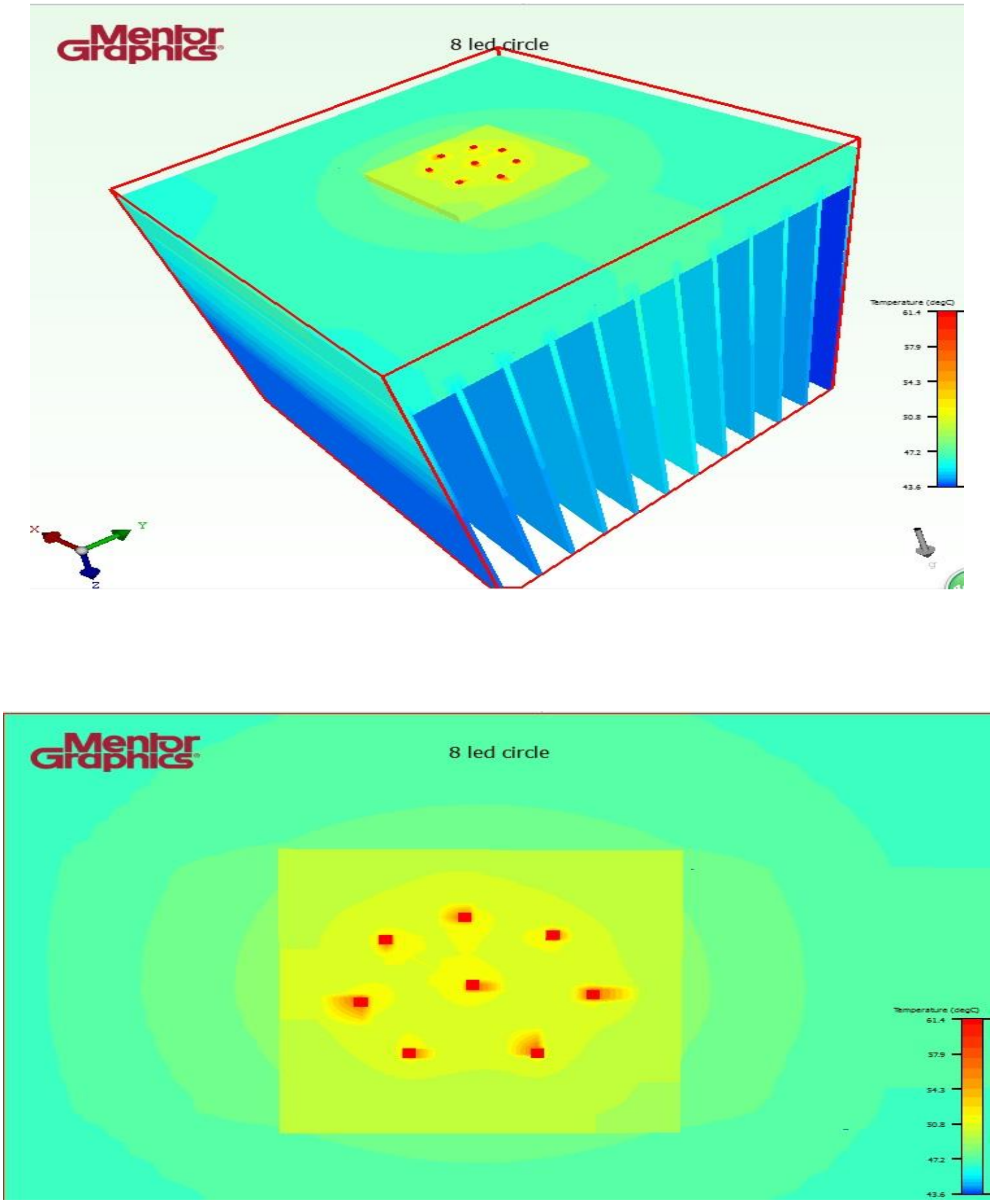
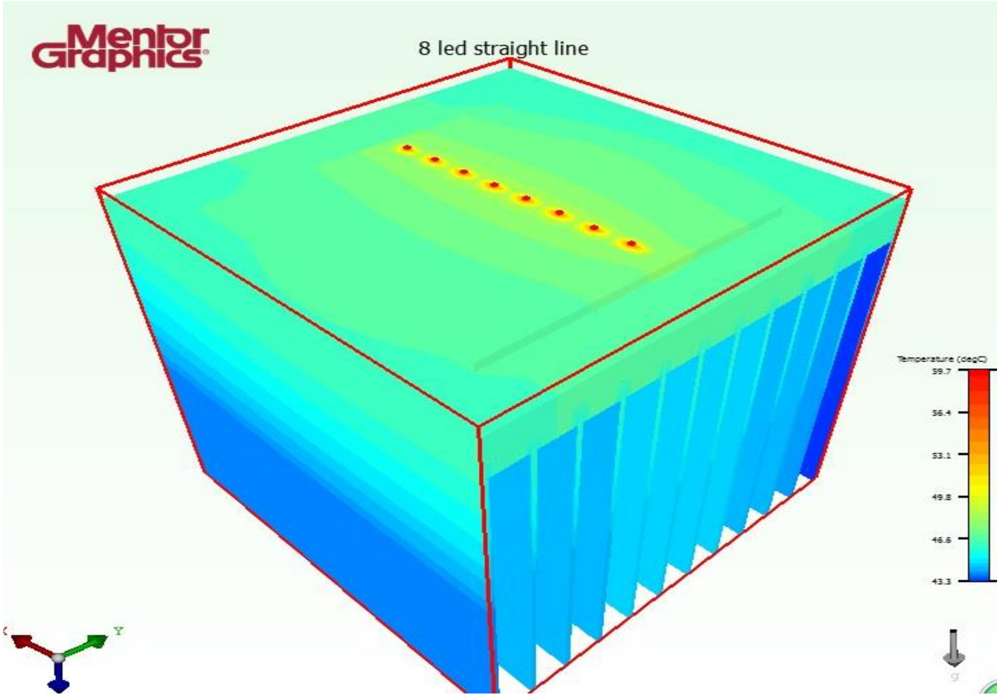


Figure 4.15: Simulation Result of Eight Multiple-Chips LED Module with Circle Orientation



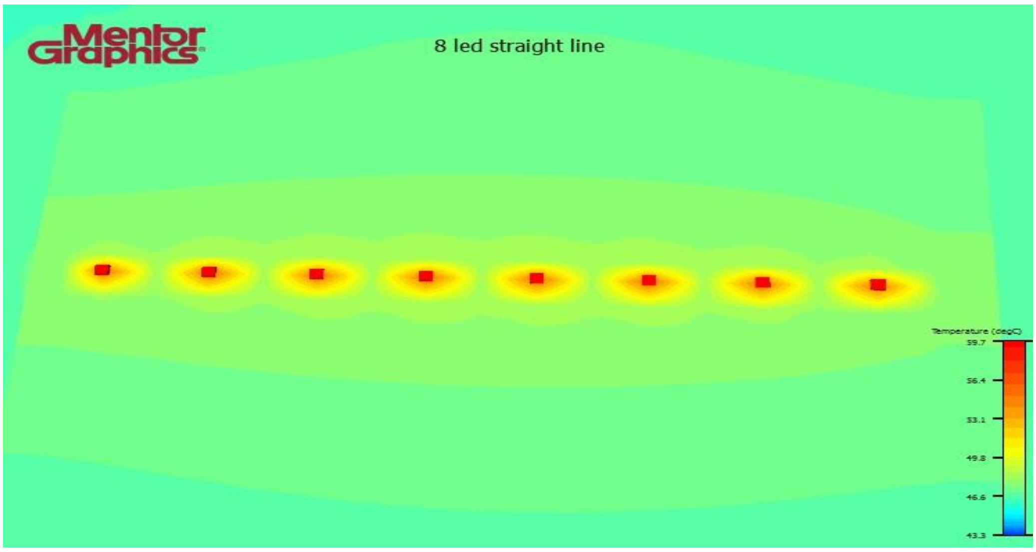


Figure 4.16: Simulation Result of Eight Multiple-Chips LED Module with Straight Line Orientation

Table 4.5 Comparison of result

Orientation	Average junction temperature (°C)
Rectangle	61.64
Triangle	61.47
Circle	61.33
Line	59.59

Based on the results shown in Table 4.5, rectangle, triangle and circle orientation of LED chips do not affect the thermal dissipation performance much and the average junction temperature of the three multiple-chips LED module are almost same. Line orientation allows the LED chips to dissipate the heat effectively and causes the average junction temperature to be lower by 2 °C compared to other orientations. However, line orientation occupies more spaces compared to other orientation. If the size of the substrate is a limiting factor, then circle orientation would be a good alternative.

4.3 Heat Sink Design

In this section, the author designed a heat sink to study the parameters that can affect the heat dissipation performance of the heat sink. The parameters studied include heat sink area, heat sink thickness, fin height, fin width and number of fins. In the studies for achieving optimum thermal performance, each parameter is independent to each other. However in real life, these parameters maybe interdependent and it may affect the overall thermal dissipation ability. Figure 4.17 shows the heat sink used in present section and the average junction temperature of the LED chips are 137 °C.

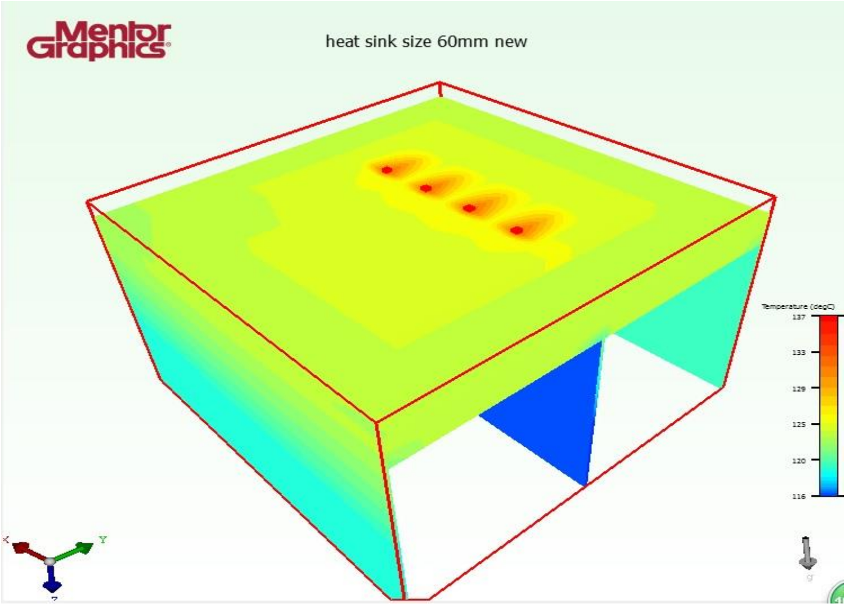


Figure 4.17: Heat Sink Used Before Modification

4.3.1 Area of Heat Sink

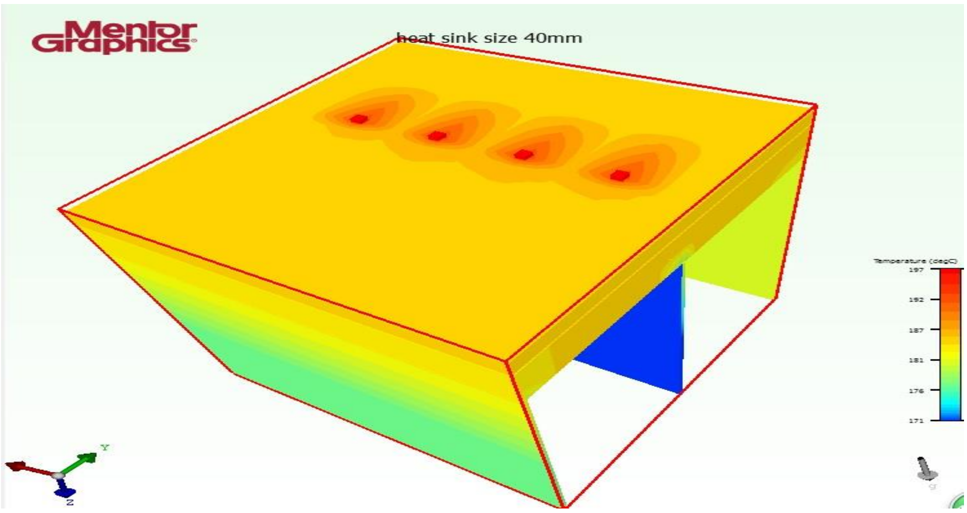


Figure 4.18: Result of LED Module with Area of 40 mm^2

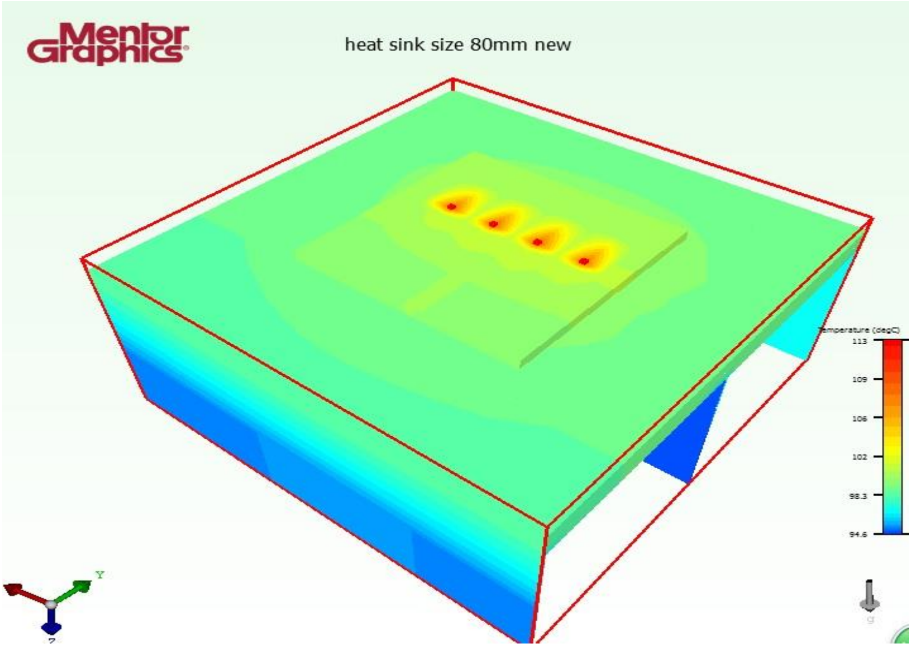


Figure 4.19: Result of LED Module with Area of 80 mm^2

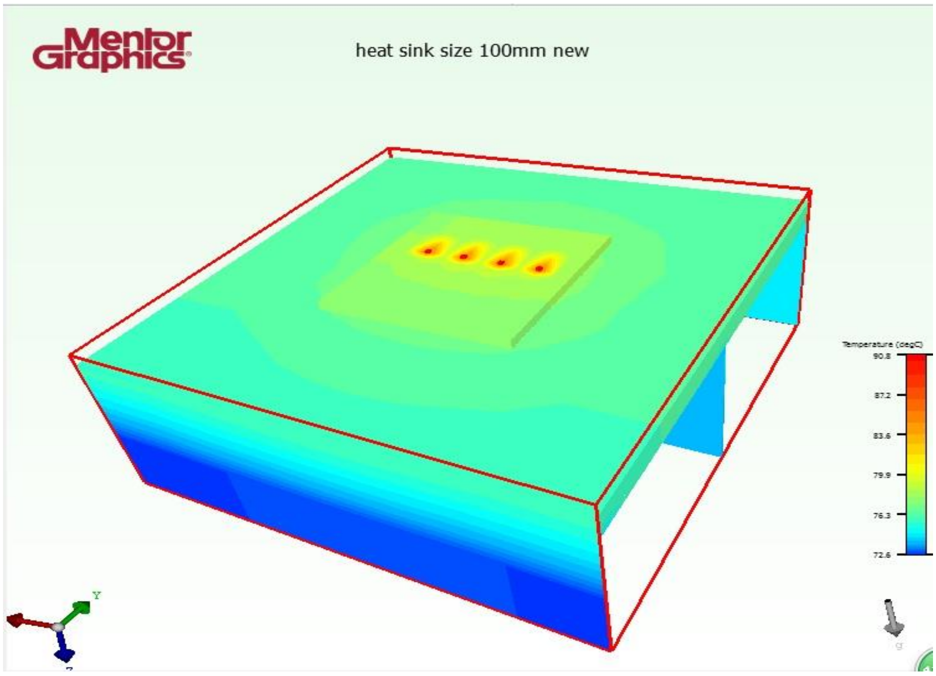


Figure 4.20: Result of LED Module with Area of 100 mm^2

Table 4.6: Comparison of Result

Area of heat sink (mm^2)	Average junction temperature (ºC)
40	197.00
60	137.00
80	113.00
100	90.73

In this study, ambient air is considered as the cooling medium. Without the heat sink, heat transfer from the LED chips to the air is not efficient as the area of the LED chips is very small. By using the heat sink, the surface area of that contact with the air becomes larger. This allows more heat to dissipate and the average junction temperature can be thus reduced. Based on the Table 4.6, increment in area of heat sink causes the decrease in junction temperature. It can be explained using the Fourier's law of heat conduction. The formula of the Fourier's law of conduction is shown as follows:

$$Q = -k \times A \times dT/dx \tag{4.2}$$

where

Q = rate of heat transfer, W

k = thermal conductivity of heat sink, W/mK

A is the area of the heat sink, m^2

dT/dx is the temperature difference

From the formula, the area of the heat sink is directly proportional to the heat transfer. The larger the area of the heat sink, the higher the rate of heat transfer to the ambient. This can greatly reduce the average junction temperature of the LED chips.

4.3.2 Thickness of Heat Sink

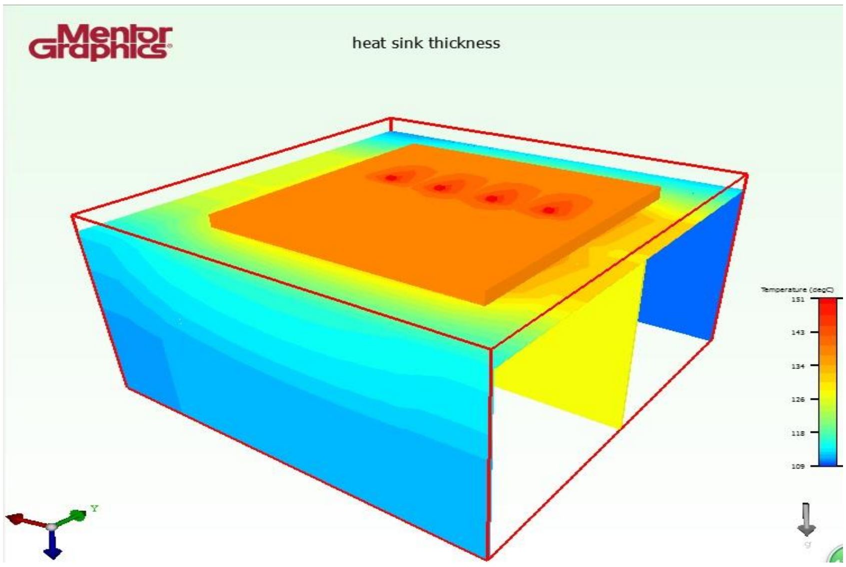
The heat sink thickness greatly affects the spreading resistance of the heat sink. Spreading resistance occurs when the heat is transfer from a smaller area substance to a larger area substance. In the heat sink, the spreading resistance causes the heat cannot distribute evenly throughout the heat sink base which causes heat cannot be transfer to each fins uniformly. As a result, there is a large temperature difference between the centre of the heat sink and the edge of the heat sink (Advanced Thermal Solution, 2007). From Table 4.7, increase in heat sink thickness causes decrease in average junction temperature. It can also say that increase in the thickness of the heat sink decreases the spread resistance of the heat sink.

Based on Figure 4.21, when the thickness is 0.1 mm, the spread resistance of the heat sink becomes large. As a result, the heat cannot spread and all the heat can only dissipate to the atmosphere through the fin that located at centre of the heat sink. This implies that the heat sink is not fully utilized.

On the other hand, when the thickness of the heat sink was increased to 10 mm as shown in Figure 4.23, the temperature gradient between the centre of the heat sink and edge of the heat sink became zero. This shows that the spread resistance is reduced to the minimum value. The heat sink is fully utilized and the heat can spread evenly through all the fins. Large amount of heat can be removed to atmosphere and this reduces the junction temperature of the LED chips.

Table 4.7 Comparison of Result

Heat sink thickness (mm)	Average junction temperature (^{o}C)
0.1	151
1	138
10	133



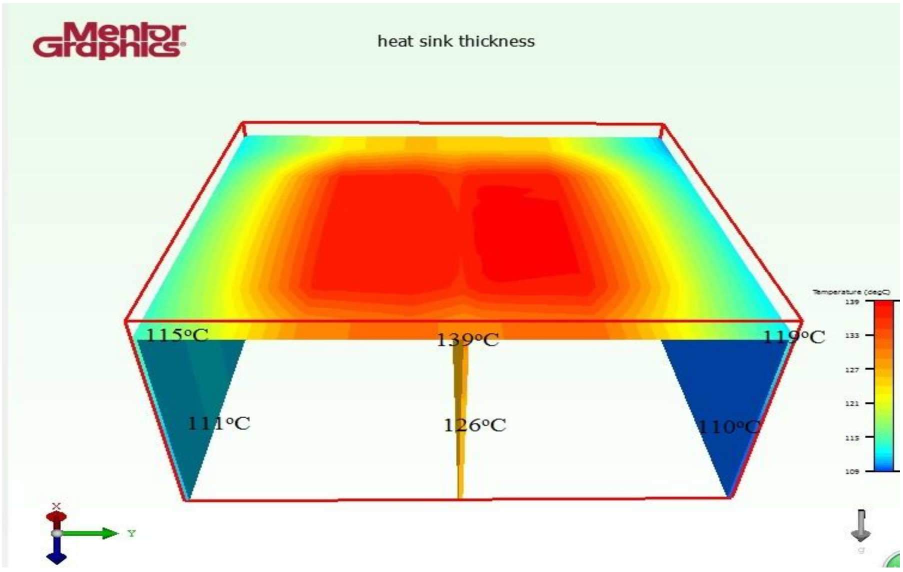


Figure 4.21: Result of LED Module with Thickness of 0.1mm

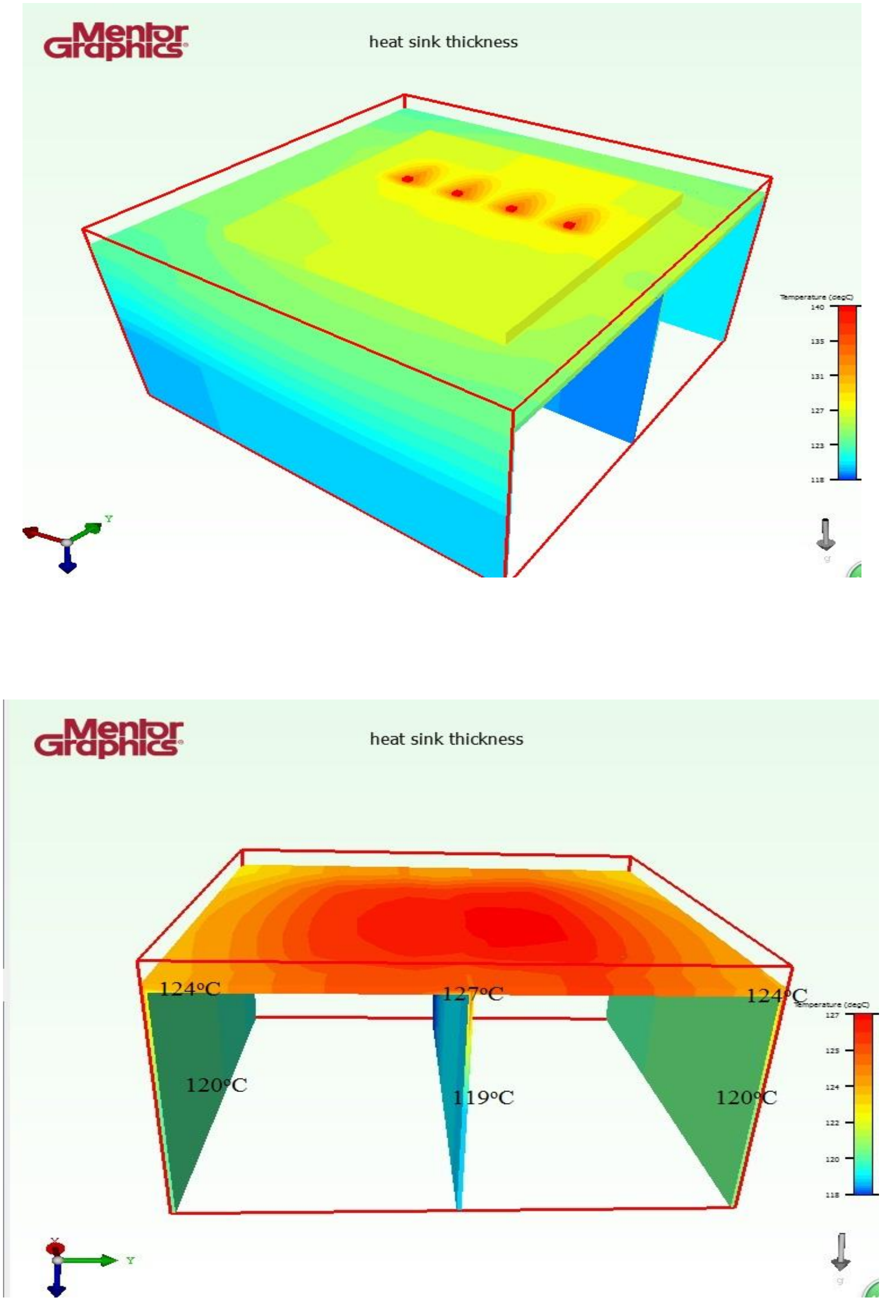


Figure 4.22: Result of LED Module with Thickness of 1mm

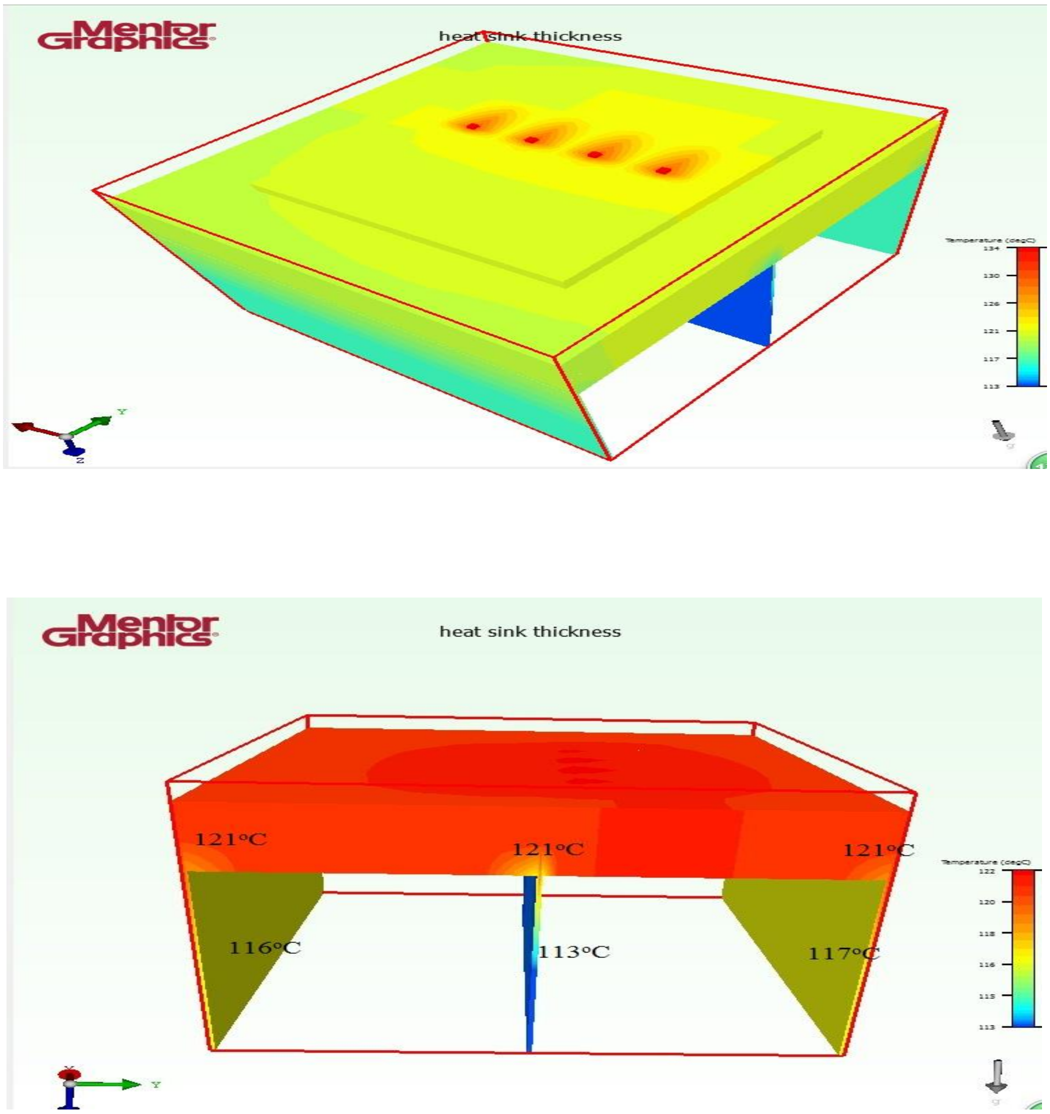


Figure 4.23: Result of LED Module with Thickness of 10mm

However, the heat sink cannot be designed to have the maximum thickness. In fact, if the thickness exceeds the optimum thickness, the thermal resistance of the heat sink would consequently increase. To explain it in a simple way, the heat cannot transfer from base to the fins of the heat sink. The heat may accumulate at the base of the heat sink and cause the rise in the average junction temperature.

4.3.3 Fin Height

Moreover, the heat sink was modified to have different fin heights. Table 4.8 shows the comparison of three different heat sinks with fin height of 15 mm, 40 mm and 60 mm.

Table 4.8: Comparison of Result

Fin height (mm)	Average junction temperature (°C)
15	161
40	126
60	112

Based on the result from Table 4.8, the heat sink which has longer fin height has better heat dissipation performance. This is owing to the fact that longer fin height provides additional contact area with the atmosphere that allows more heat to be dissipated.

4.3.4 Fin Number

Increase in fin number causes increment in total convective surface area. Besides, it also causes fin flow velocity decrease as a result of pressure drop. Based on Table 4.9, initially, increase in fin number increase the heat dissipation performance and of the heat sink. This is because the gain from increase in surface area is greater than loss in reduction of fin flow velocity. However, when the fin number exceeds the optimum number which is 15 fins, increase in fin number causes decrease in heat dissipation performance. Now, the lost due to reduce in fin flow velocity is greater than gain from surface area. It can be said that the excessive fins block the air flow and causes the hot air to stagnant between the fins. As a result, the heat cannot be dissipated efficiently. The temperature gradient between the air and the fin is small and conduction of heat cannot be carried out easily. Furthermore, the thermal dissipation performance of 11 fins heat sink is almost the same as thermal dissipation performance of the heat sink with optimum number of fin which is 15 fins. It is recommended to use the heat sink with 11 fins because increase the number of fins to 15 is just adding the cost due to more material is needed but giving a result which is almost the same as the heat sink of 11 fins. Besides, a different manufacturing method is needed to produce the heat sink which has more than 11 fins. The manufacturing method is time consuming and very expensive (Lee 1995).

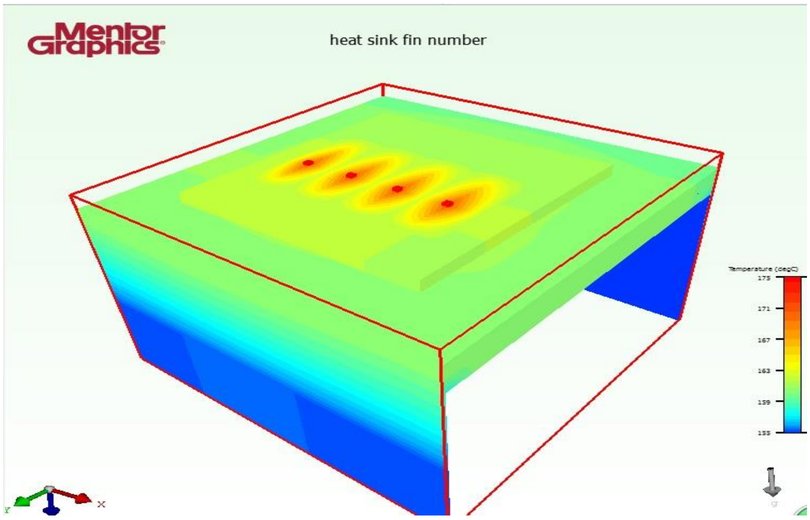


Figure 4.24: Result of LED Module with 2 Fins

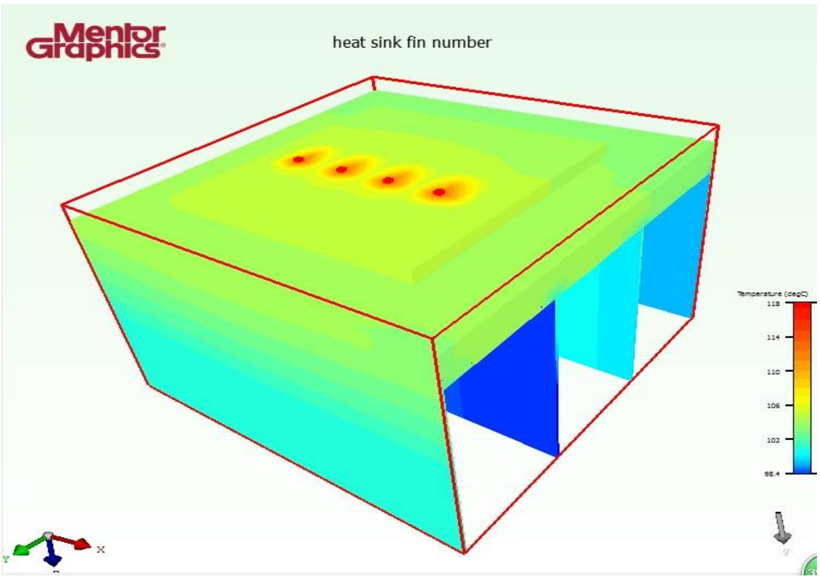


Figure 4.25: Result of LED Module with 4 Fins

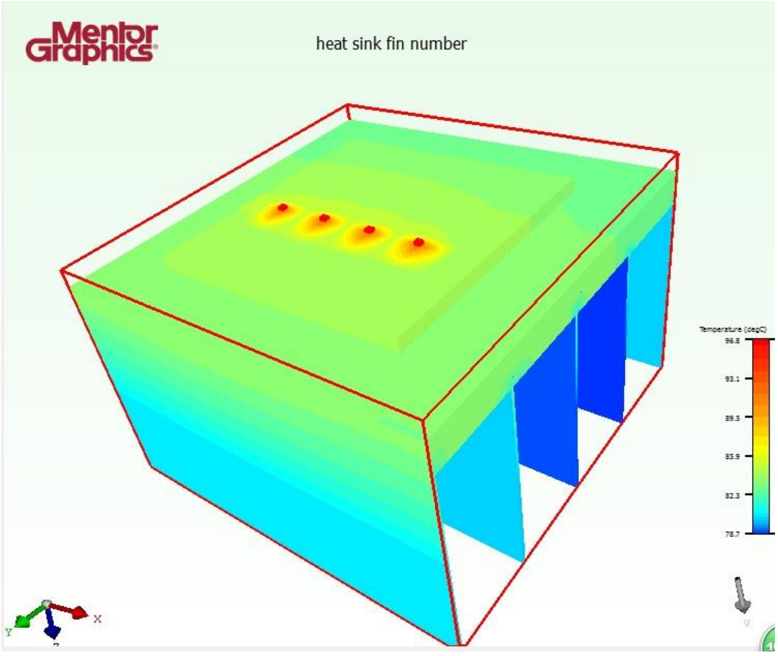


Figure 4.26: Result of LED Module with 5 Fins

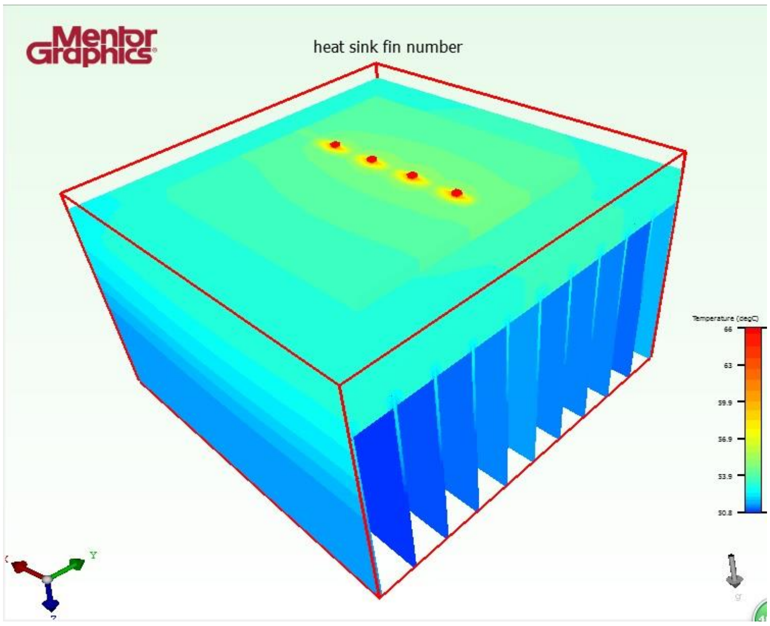


Figure 4.27: Result of LED Module with 11 Fins

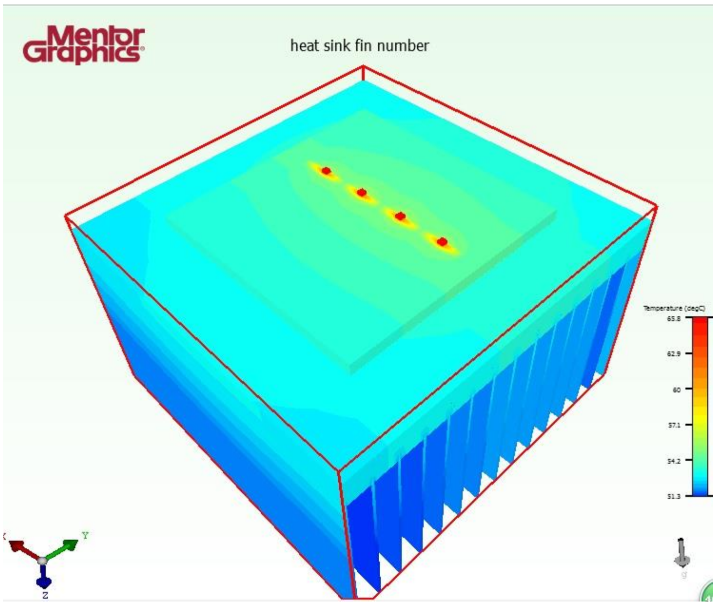


Figure 4.28: Result of LED Module with 15 Fins

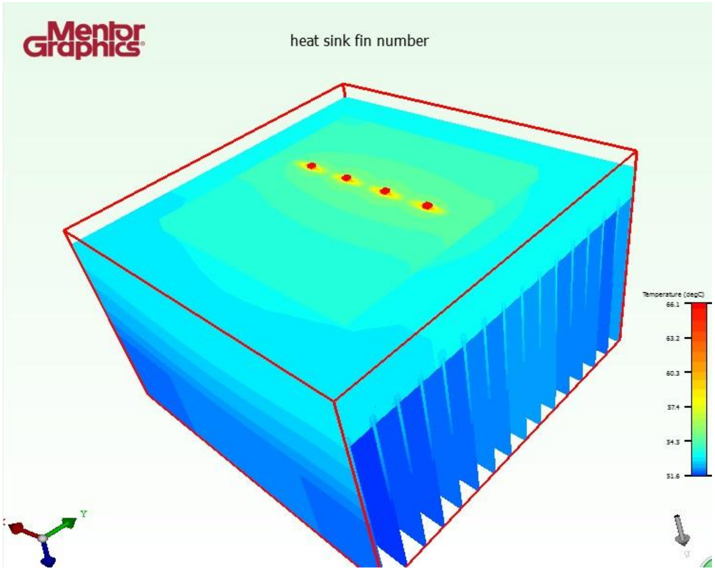


Figure 4.29: Result of LED Module with 16 Fins

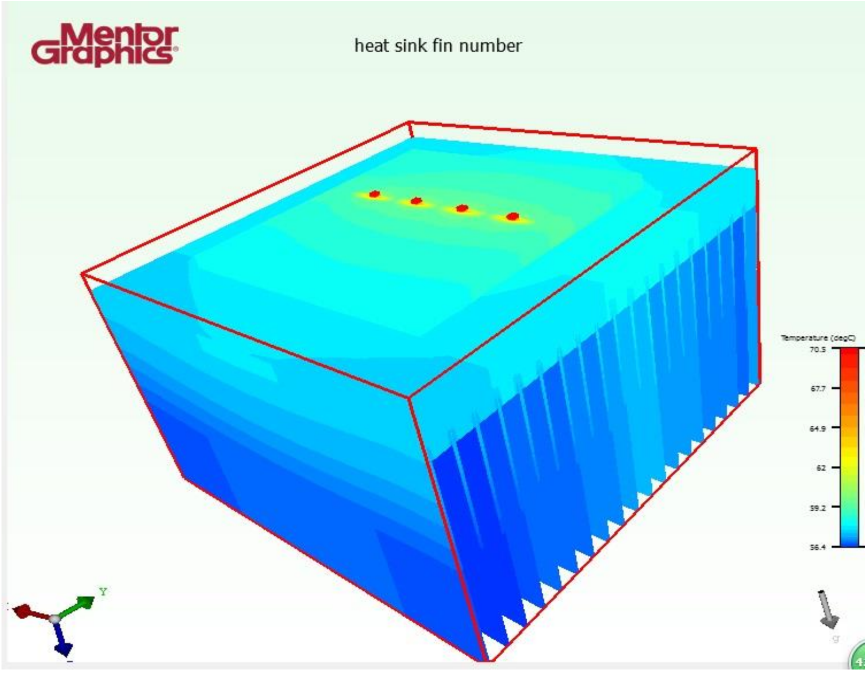


Figure 4.30: Result of LED Module with 20 Fins

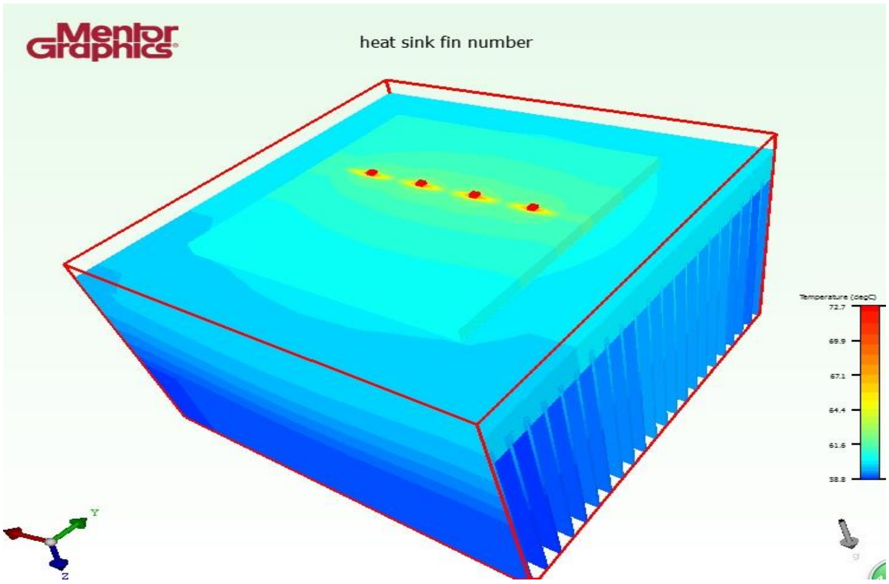


Figure 4.31: Result of LED Module with 22 Fins

Table 4.9: Comparison of Result

Fin number	Average junction temperature (°C)
2	174
4	118
5	97.15
11	65.90
15	65.65
16	65.98
20	70.40
22	72.57

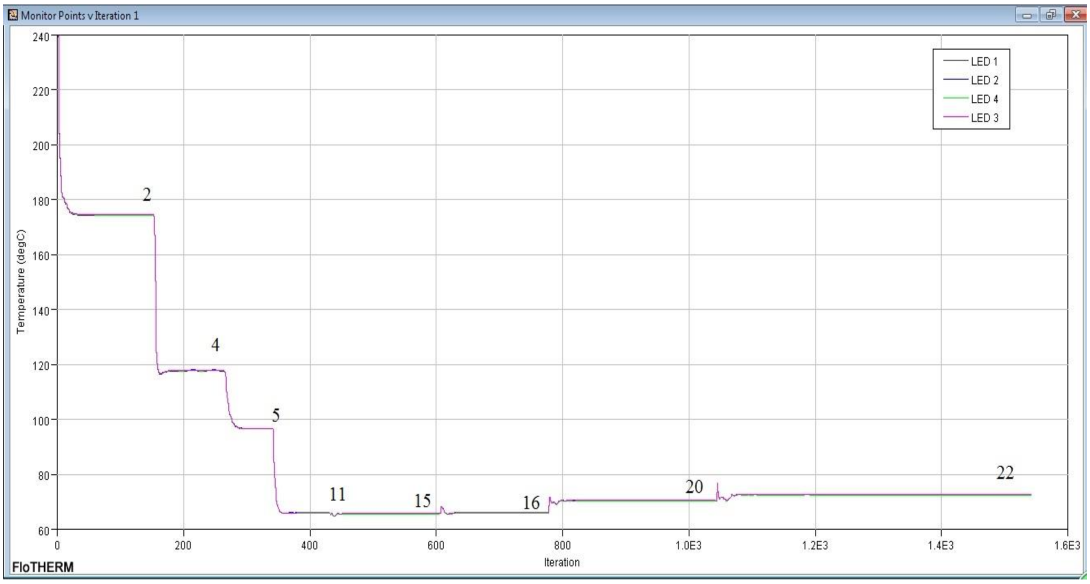


Figure 4.32: Graph Temperature Versus Fin Number

4.3.5 Fin width

Based on Table 4.10, increase in fin width beyond the optimum value which is 7 mm causes increase in average junction temperature of the LED chips. It can be explained as the case of increment the fin number beyond the optimum number.

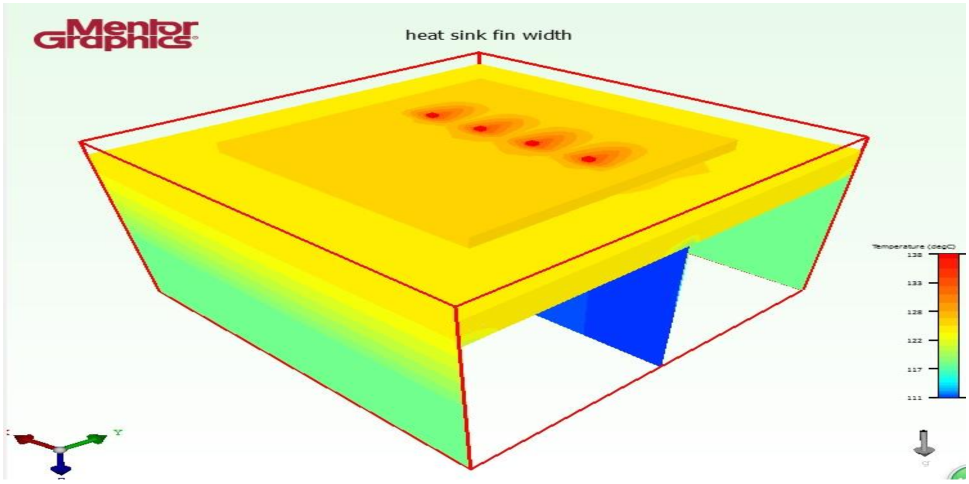


Figure 4.33: Result of LED Module with Fin Width of 0.25mm

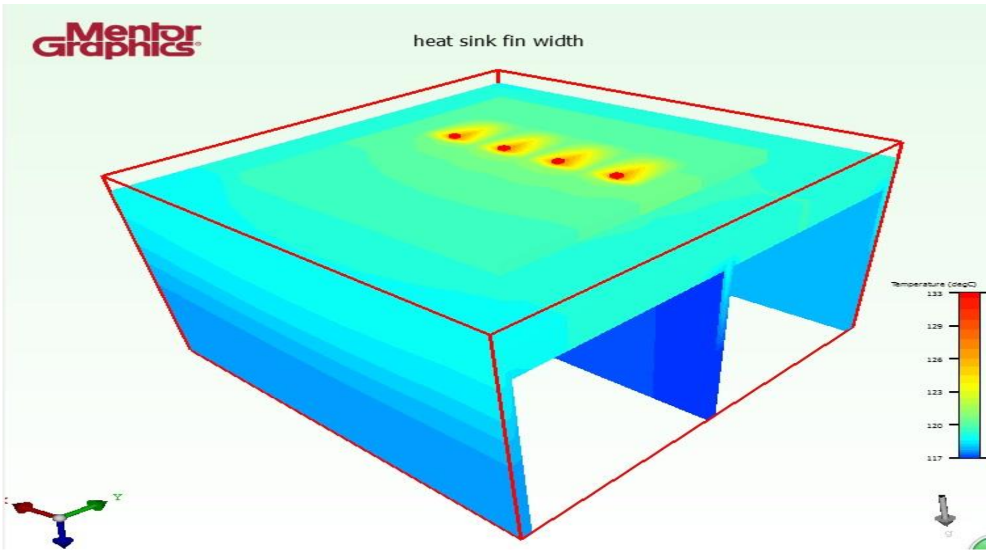


Figure 4.34: Result of LED Module with Fin Width of 1.5mm

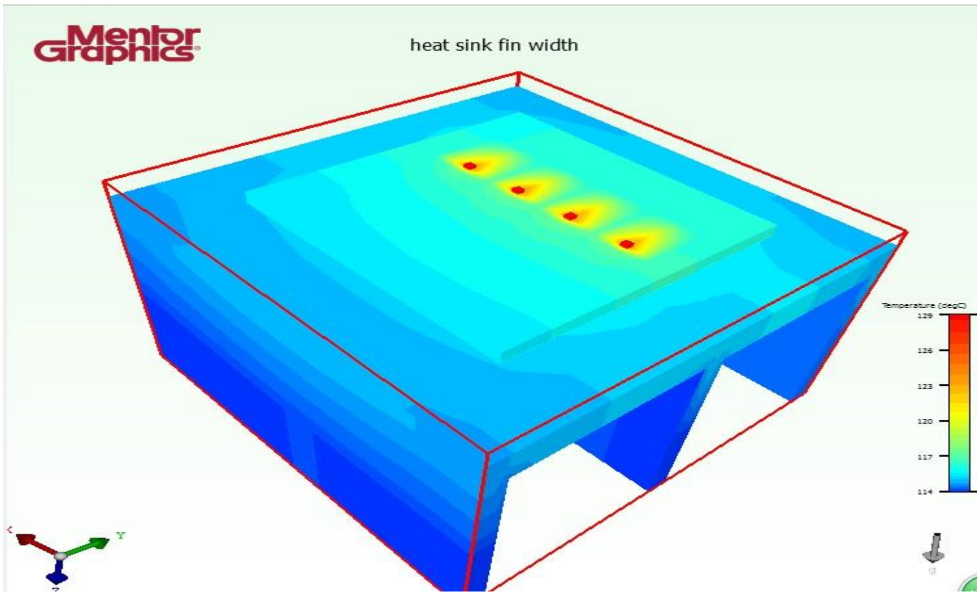


Figure 4.35: Result of LED Module with Fin Width of 3mm

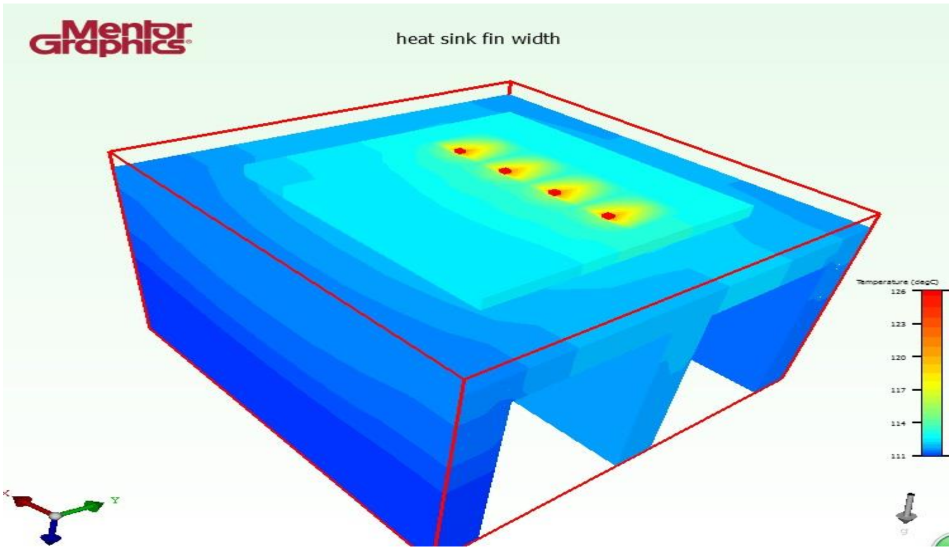


Figure 4.36: Result of LED Module with Fin Width of 6mm

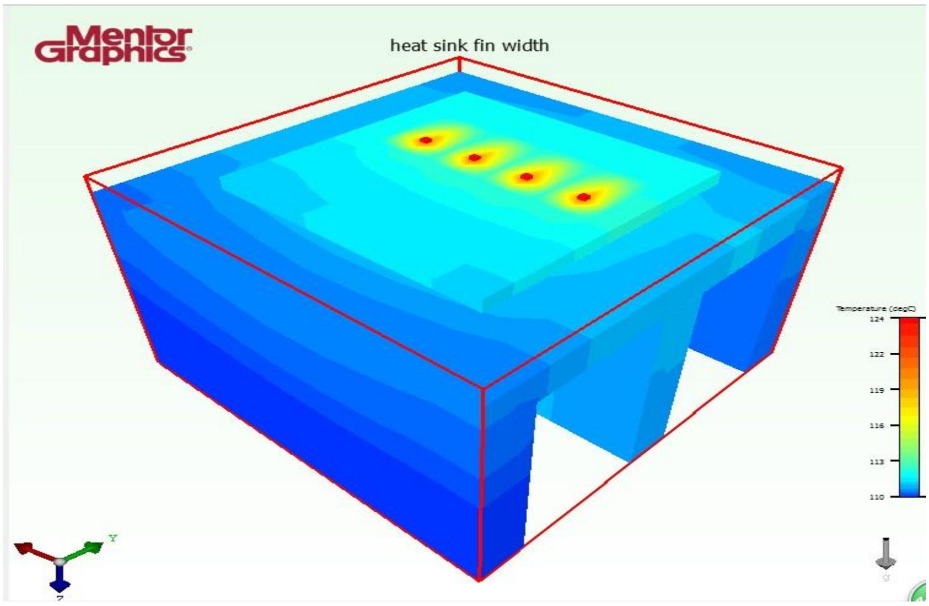


Figure 4.37: Result of LED Module with Fin Width of 7mm

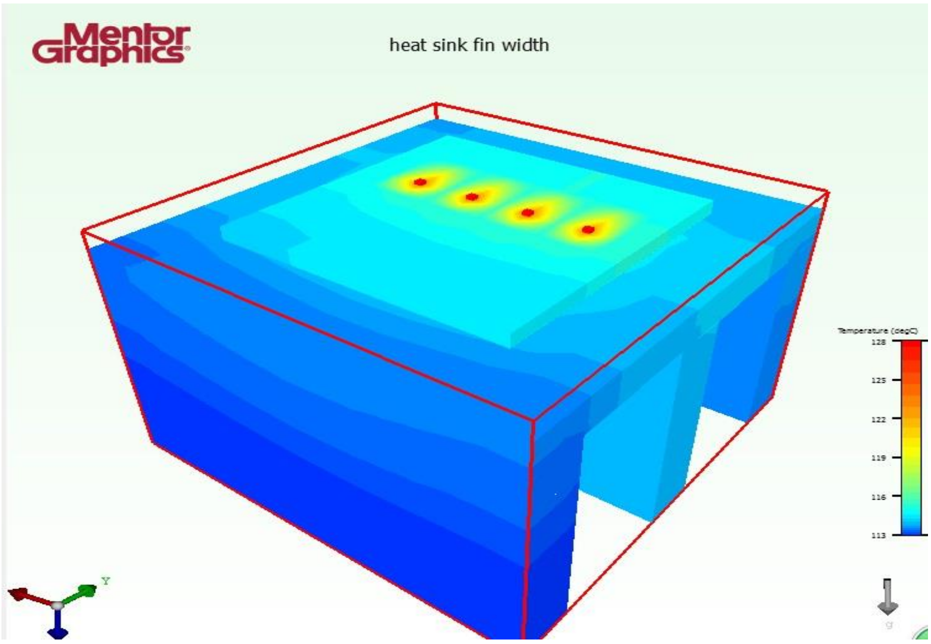


Figure 4.38: Result of LED Module with Fin Width of 8mm

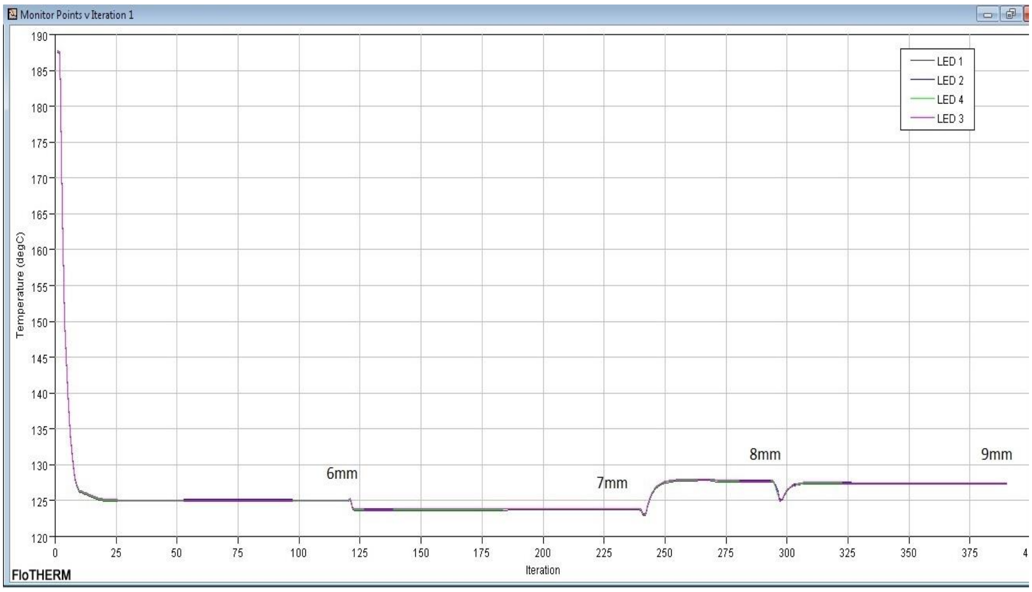


Figure 4.39: Graph of Temperature Versus Fin Width

Table 4.10 Comparison of Result

Fin width (mm)	Average junction temperature (ºC)
0.25	138.00
1.5	132.75
3	129.00
6	125.00
7	124.50
8	128.00

4.3.6 Heat Sink with Hole

The original heat sink used is modified to have some venting hole at the base plate of the heat sink. The dimension of the venting hole is 5 mm × 5 mm.

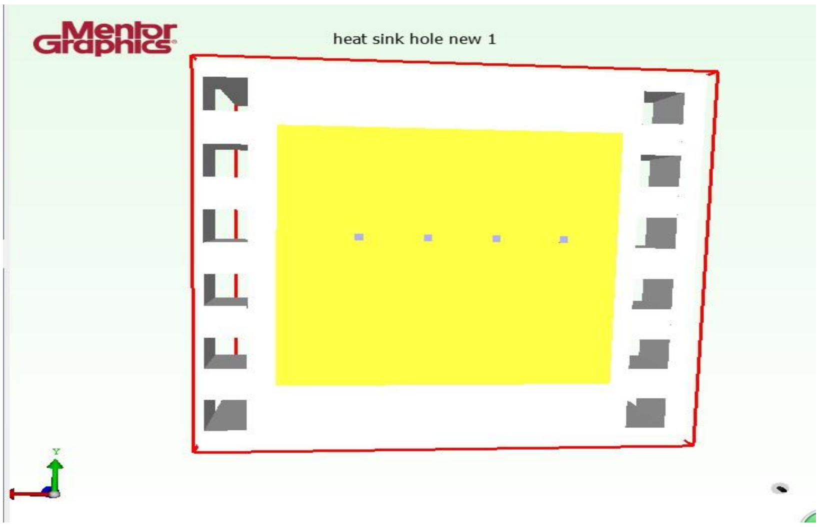


Figure 4.40: Heat Sink with Venting Holes

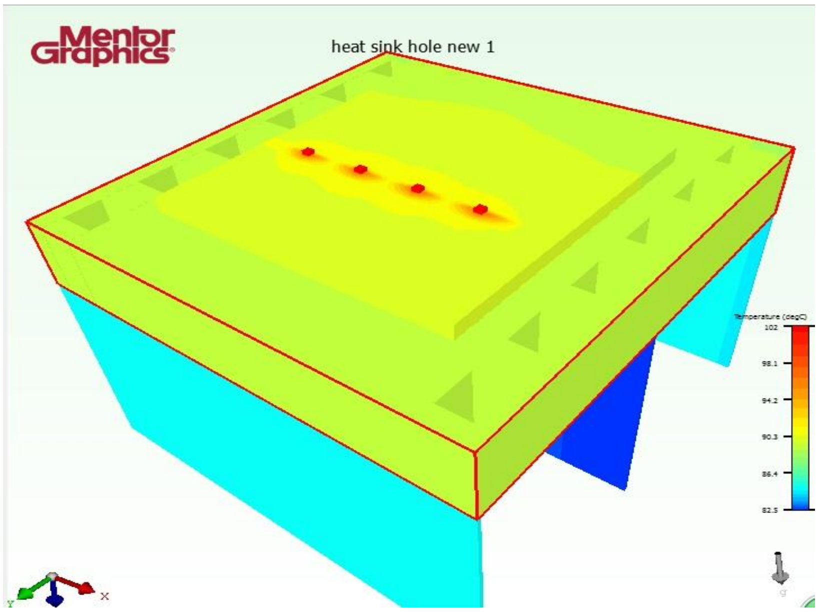


Figure 4.41: Result of LED Module with Venting Holes

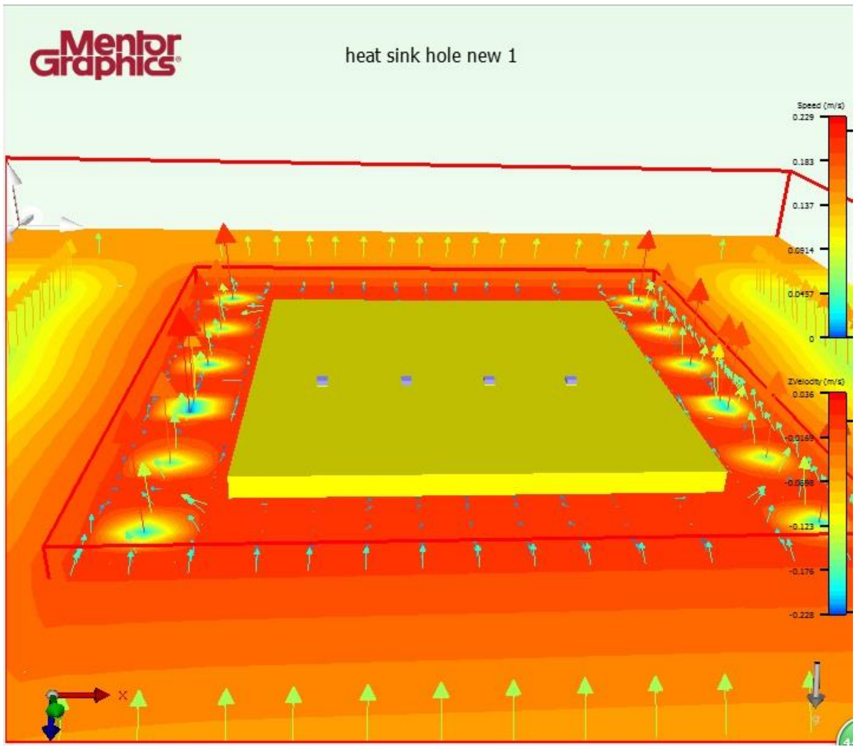


Figure 4.42: Velocity Map of the Heat Sink with Venting Holes

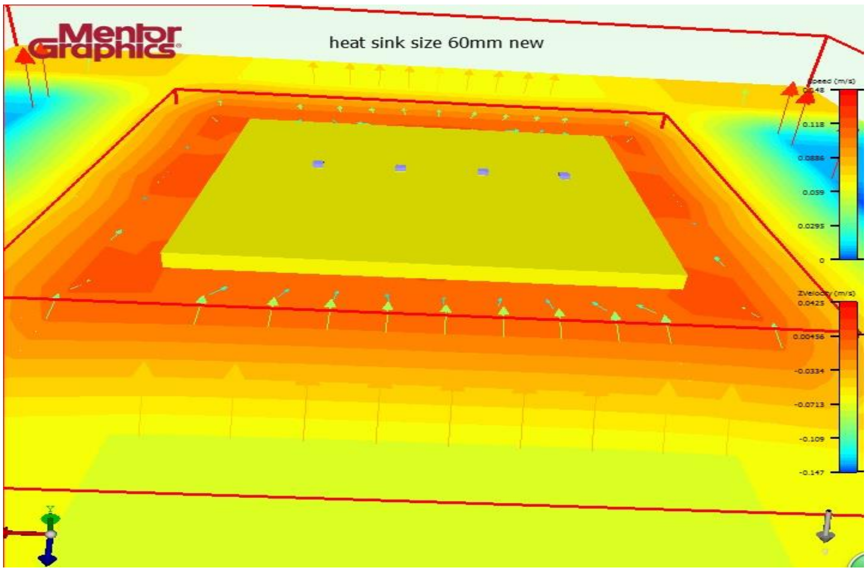


Figure 4.43: Velocity Map of the Original Heat Sink

The average temperature of the multiple-chip LED module with heat sink that has venting hole is 102 °C which is 35 °C lower than the original heat sink. By comparing the Figures 4.42 and 4.43, the maximum velocity of air flow of the heat sink with ventilation hole is 0.229 ms^{-1} while the maximum velocity of the air flow of the original heat sink is 0.148 ms^{-1}. Moreover, there are more arrows on the surface of heat sink shows in Figure 4.42, representing the air flows smoothly and frequently than the air flows in Figure 4.43. The higher air flow rate ventilate heat away effectively causes the efficient heat convection process and thus decrease in average junction temperature of the LED chips. This confirms that heat sink with ventilation hole is better since it provides good thermal management performance by smoothing the air flow around the heat sink. It is also cost effective and less dense as less material is required to manufacture it (Chu, Chang and Huang, 2015).

4.4 Optimization

After studying the factors that affect the thermal management performance of the multiple-chips LED module, the author designed an optimized multiple-chips LED module based on the analysis and experience of previous studies. The average junction temperature of the four LED chips is 64.5 °C which meets the requirement set by manufacturer. Figure 4.44 shows the optimized multiple-chips LED module designed and Figure 4.45 shows the thermal distribution map of the module. Table 4.11 shows the properties of the multiple-chips LED module.

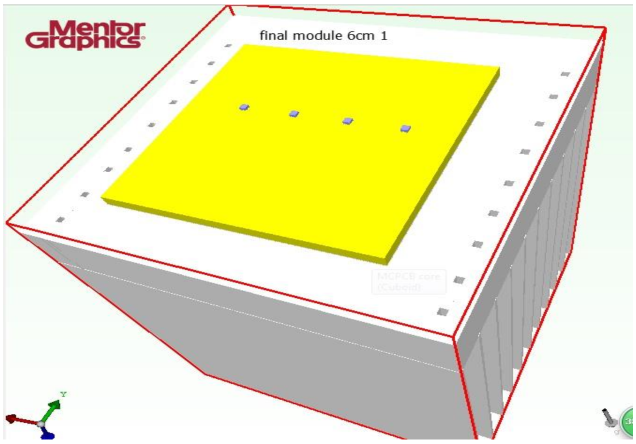


Figure 4.44: Optimized Multiple-Chips LED Module

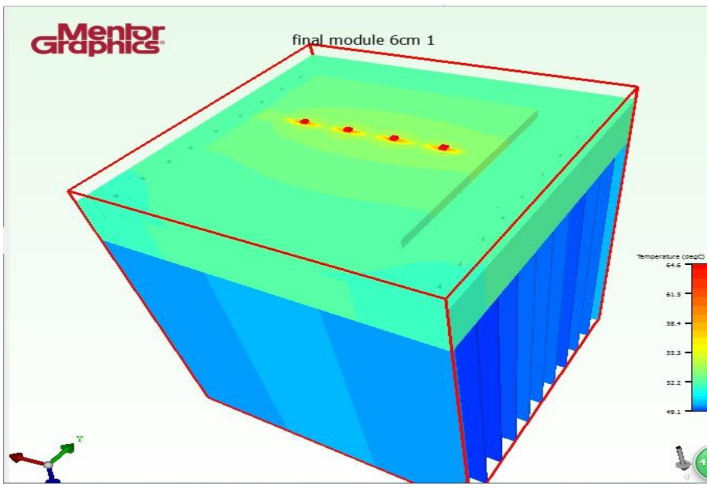


Figure 4.45: Thermal Distribution Map of the Optimized Multiple-Chips LED Module

Table 4.11 Properties of the Optimized Multiple- Chips LED Module

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED x4	Gallium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	1 × 1	0.1	385
MCPCB				
core	Copper	40 × 40	2	385
dielectric	FR4,IT-180	40 × 40	0.07	0.88
conductor	Copper	40 × 40	0.035	385
TIM	Dow coning TC-5022	40 × 40	0.025	4
Heat sink Number of fin=11 Fin height=60 mm Fin width=0.7 mm Size of ventilation hole=1mm × 1mm	Aluminum	60 × 60	10	201

In the optimized module, GaN LED chips are selected due to their high thermal conductivities and high luminous output. MCPCB substrate which has better thermal dissipation performance is used to replace the original FR4 substrate. Moreover, the heat sink used has optimized area for dissipate heat. With thickness of 10 mm, the spread resistance is minimized and the heat can spread evenly. From Figure 4.45, the entire base of the heat sink is 52 °C and represent in light green color. This shows that the heat has spread evenly to every corner of the base of heat sink. Moreover, the number of fin, fin height and wide are optimized to increase the total surface area for the heat dissipation without reduce the air flow velocity. Ventilation holes are also added to increase the air flow rate.

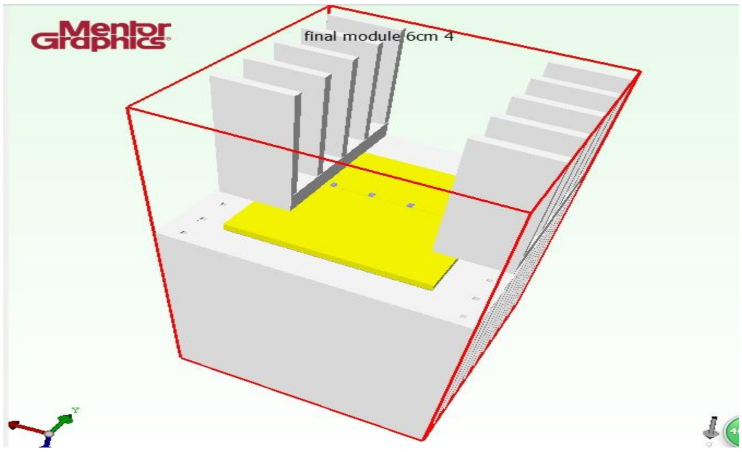


Figure 4.46: Optimized Multiple- Chips LED Module with Additional Heat Sink

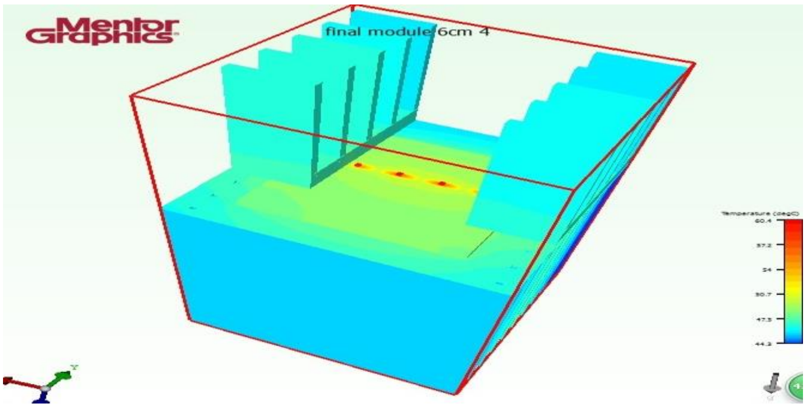


Figure 4.47: Thermal Distribution Map of Optimized Multiple-Chips LED Module with Additional Heat Sink

Table 4.12 Properties of the Optimized Multiple- Chips LED Module with Additional Heat Sink

Component	Material	Dimension (mm)	Thickness (mm)	Conductivity (W/mK)
LED x4	Gallium Nitrate (GaN)	1 × 1	0.5	130
Slug	Copper	50 × 1	0.1	385
MCPCB				
core	Copper	40 × 40	2	385
dielectric	FR4,IT-180	40 × 40	0.07	0.88
conductor	Copper	40 × 40	0.035	385
TIM	Dow coning TC-5022	40 × 40	0.025	4
Heat sink Number of fin=11 Fin height=60mm Fin width=0.7mm Size of ventilation hole=1mm × 1mm	Aluminum	60 × 60	10	201
Additional heat sink Number of fin=5 Fin height=30mm Fin width=2mm	Aluminum	15 × 40	5	201

Figure 4.46 shows two additional heat sinks are attached directly at the edge of the copper slug. These two heat sinks are used to dissipate some of the heat that conducts from the copper slug to the atmosphere directly. As a result, the thermal dissipation ability of the multiple-chips LED module has improved and the average junction temperature of the LED chips is 59.52 °C. However, this design is not recommended to the devices which emphases on mobility such as mobile phone and

laptop. This is because increase in number of heat sinks causes increase in the mass and size of the module. Besides, total cost to manufacture the module also increase too.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Multiple-chips LED module development and thermal management performance of the chips were studied in this project. The main objectives of the project were accomplished and concluded in this section. Besides, the recommendation and future work are discussed in this chapter.

5.1.1 Development and Simulation of Multiple-Chips LED Module using Computational Fluid Dynamic Software

Multiple-chips LED module was developed successfully using CFD software in this project. It consists of LED chips, copper slug, substrate and heat sink. The LED chips used throughout the project are $1 \times 1 \times 0.5$ mm. The forward voltage across the LED chips are 3V and the current flow through is 0.95 A. The thermal coefficient of the chips is 70% and the calculated thermal power dissipation is 2 W. The copper slug is used to attach the LED chips to the substrate. The substrate is a PCB board containing the circuit to provide electric to the LED chips to light up and control the brightness of the LED chips. Besides, it also provides mechanical support and helps in heat dissipation. After that, the LED module is attached to a heat sink. The heat sink plays an important role in thermal management performance of the multiple-chips LED module because it increases the total surface area of the module and this greatly improves the heat dissipation performance of the module.

After studying the structure and the physical properties of the multiple-chips LED module, the author has modeled the module using the CFD software. After the model development, simulation was performed in order to produce the thermal distribution map of the module. Moreover, the junction temperature of the LED chips was measured.

5.1.2 Study the Factors that Affect the Thermal Management Performance of Multiple-Chips LED Module

Three main factors are studied in this project namely, thermal conductivity of the material, LED arrangement and hear sink design.

In the first criteria, three different types of LED chips (GaAs, GaP and GaN chips) are used to study the effect of thermal conductivity of material to the thermal management performance of the module. The result shows that GaAs which has thermal conductivity of 52 W/mK has average junction temperature of 1230 °C, whereas GaP and GaN chips that have thermal conductivity of 110 and 130 W/mK, respectively, have junction temperature of 266 °C. From the result, the author concluded that thermal conductivity is an important factor in the thermal management performance of the module. High thermal conductivity material gives high thermal dissipation performance and greatly enhances the thermal management performance of the module. Next, the FR4 substrate used in the GaN module is replaced with copper MCPCB and DBC. The simulation result shows that module with MCPCB and DBC module have better thermal management performance compared to the FR4 substrate. Besides, MCPCB and DBC substrate also provide better mechanical support and improve the sustainability of the module. Although the MCPCB and DBC have good thermal dissipation ability, MCPCB is preferred because DBC has lower mechanical reliability and lack in flexibility in design. In this criterion, the author also found that adding TIM layer between the substrate and heat sink does not improve the thermal management performance of the module. This is because there is no air gap between the substrate and heat sink if the module was developed using the software. Adding the TIM layer is just to increase the thermal resistance between the substrate and the heat sink. However, the author decided to use the TC-5022 which is a good TIM material that proven by other designer in all the modules developed to make the modules operate like a real module.

In addition, effect of number of LED chips and LED layout to the thermal management performance of the module is studied. It is found that increase in the number of LED chips will greatly increase the average junction temperature of the LED chips. This is because the total thermal power loss increases with the increase in number of the LED chips. As a result, the heat sink used fail to dissipate the large amount of heat to the surrounding leading to increase in the average junction temperature of the LED chips. Besides, the distance between the LED chips also affects the thermal management performance of the module. The distance between the LED chips must be wide enough to prevent heat influence between the LED chips during the dissipation of heat. However, the distance between the LED chips cannot be too wide because it will cause the size of the module increase. The author found that 8 mm is the optimum distance because it can reduce the heat influence between the LED while maintaining the overall small size of the module. Moreover, different orientations of LED chips are studied so as to determine the orientation that can improve the thermal management performance of the module. The straight line and the circle orientation are better compared to triangle and rectangle orientation. The author considered the straight line orientation is suitable as it gives the best thermal management performance. If the size of the module is a limiting factor, circle orientation can be chosen because it occupies less space although the thermal management performance is poorer compared to the straight line orientation.

The last criterion involves the study of the heat sink design that affect the thermal management performance of the multiple-chips LED module. Heat sink with larger area and longer heat fin height is found to has better heat dissipation ability. This is because large surface area and long fin height provide additional surface area with the atmosphere which helps to dissipate heat to atmosphere easily. Next, the thickness of the heat sink is also an important factor and it is related to the spreading resistance of the heat sink. The thicker heat sink has low spreading resistance. When the heat sink thickness is set to optimum value which is 10 mm, the spreading resistance is very low and heat can spread evenly throughout the heat sink. The heat sink is fully utilized and the thermal dissipation performance is improved. Beyond the optimum thickness, the thermal resistance of the heat sink increases and causes heat to accumulate at the base of heat sink. As a result, the heat cannot dissipate and cause rise in junction temperature of the LED module. Moreover, increase in fin number and fin width also improved the thermal dissipation performance of the module because the total convection surface area of the heat sink has increased. When the fin number and fin width exceed the optimum number, the excessive fins and the fins are too thick to reduce the air flow around the fins. This causes hot air stagnant around the fins and heat cannot be conducted from the heat sink to the air easily. This greatly reduces the thermal dissipation performance of the heat sink. The author decided to use 11 fins although the optimum number of heat sink is 15. This is because the thermal dissipation performance of the heat sink with 11 fins and 15 fins is almost the same. Heat sink with 11 fins is selected as heat sink with 15 fins requires a different manufacturing method and the cost is very expensive compared to heat sink that has 11 fins. Furthermore, heat sink with ventilation hole has high thermal dissipation performance. The ventilation hole improved the air flow rate around the fins of the heat sink. With higher air flow rate, more heat can be ventilated through convection and this improves the thermal dissipation performance of the heat sink.

5.1.3 Model a Multiple Chips LED Module that Has High Luminous Output and Good Heat Dissipation Performance.

After studying the factors that affect the thermal management performance of the LED module, optimized four LED chips module is developed. The GaN chips used operate in 3V which gives high luminous output. Besides that, blue color light generated by GaN can be combined with phosphor to generate white color light that has high luminosity which suitable to be used in many industry fields that require bright working environment. Copper MCPCB is used as substrate because it has good thermal dissipation ability and can provide mechanical support to enhance the sustainability of the module. The module is then attached to an optimized aluminum heat sink. The heat sink has dimension of 60 mm × 60 mm × 10 mm. The heat sink has 11 fins which have height of 60 mm and fin width of 0.7 mm. Moreover, ventilation holes are added to improve the air flow rate around the fins. The average junction temperature of the four LED chips is 64.5 °C and it meets the requirement set by manufacturer.

5.2 Recommendation and Future Work

This project has an extremely large potential to be improved in a few ways. The optimized module has been developed successfully but many additional features can be added to improve the thermal management performance of the module. All the additional features are discussed in this section.

The main weakness of the optimized module is the size of the heat sink. The 6 cm^2 heat sink is quite large and not suitable to be used in device that emphasis on mobility. In order to reduce the size of the heat sink but also to maintain it good thermal dissipation performance, thermal via can be introduced in the module. Figure 5.1 shows the implementation of the thermal via in a LED module. The thermal via can reduce the thermal resistance of the module by providing an effective path for the heat conduction from the LED chips to the heat sink directly.

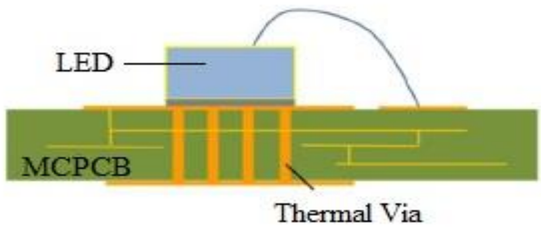


Figure 5.1: LED Module with Thermal Via

Another method to improve the thermal management performance of the heat sink is by introducing heat pipe. The heat pipe can be embedded in the base of the heat sink to reduce the spreading resistance. As a result, the heat can distribute evenly across the base of the heat sink base causing the base has high temperature. Effective convection cooling can be achieved at the heat fins because more heat can be conducted from the base to the heat fins due to larger temperature gradient between the base and fins of the heat sink. Figure 5.2 shows two types of heat pipe that can be embedded to the heat sink. With heat pipes added, the thickness and size of the heat sink can be reduced while improving the thermal management performance of heat sink.

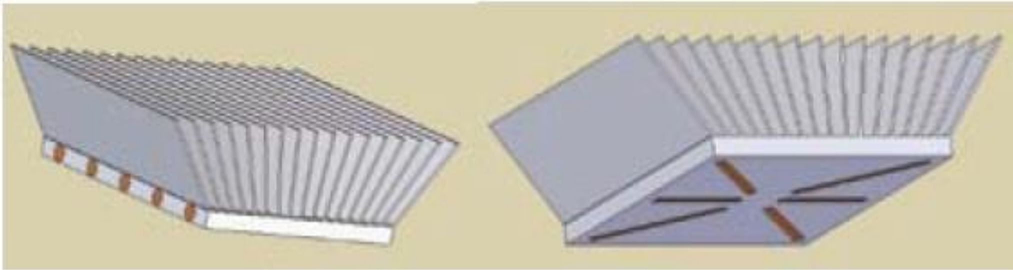


Figure 5.2: Embedded and Surface Embedded Heat Pipe Heat Sinks

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