MODELLING OF THE LIGHT EMITTING DIODE (LED) HEATING/ COOLING PROCESS

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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

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

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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.

Signature : _________________________

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"MODELLING OF THE LIGHT EMITTING DIODE (LED) HEATING/ COOLING PROCESS"** was prepared by **LOO CHEE MENG** 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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Supervisor : Dr. Lai Koon Chun

Date : _______________________

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ABSTRACT

This research paper illustrated how LED modeling done using FloTHERM software. Different materials of heat sink will be tested, compared and discussed in the research. Next, designed heat sink will be analyzed for its heat dissipation and heat transferring toward the whole area of the heat sink through parametric studies. High power LED package will be modeled using CFD software and attached on heat sink to perform analyses to verify and observe the heat dissipation and heat transfer between LED towards heat sink. There are two main research objectives contribute toward this research which are; 1^{st} analyze the heat dissipation of the LED package and 2^{nd} improve design for the better cooling performance of the LED. Research will be contribute for the optimal and reliable operation with no catastrophic failure.

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LIST OF SYMBOLS / ABBREVIATIONS

P_{th}	heat power
R_{th}	thermal resistance
τ	thermal resistance *R* and thermal capacitance *C*
k	thermal conductivity, W/(m·K)
h	height, m
g	gravity, m/s^2
μ	viscosity, m^2/s
ρ	density, kg/m^3
ω	compressible flow parameter
v	specific volume, m^3
t	time, s
s	strain rate
T	temperature, K
P	pressure, kPa
PCB	printed circuit board
TIM	thermal interface material
GaN	gallium nitride
InGaN	indium gallium nitride
AIN	aluminium nitride
GaP	gallium phosphide
LED	light emitted diode
MCPCB	metal core printed circuit board
ALO	aluminium oxide

CHAPTER 1

INTRODUCTION

1.1 Background

Due to the influence of green technology, light bulb which commonly used in centuries has replaced by light emitting diode (LED) nowadays due to its power efficiency, power saving concern and longer lifespan. Since then, it was often manufactured as multi package module instead of single package due to the luminosity demand and cost concern. LED technologies has been seen applying in most applications where power efficiency is essential from household lighting, television display, car headlights to digital signage and more.

Nevertheless, the uniformity of temperature gradient may generate unbalanced stress along the multi package interface, resulting lifespan and output degradation. It is hence crucial to predict and model the thermal transfer performance of the LED module prior to the manufacturing process as to ensure output quality and prevent catastrophic failure. Despite the apprehensive grown and popularity of LED, today's LED applications present a complex design challenge. The challenge required such as current and voltage parameters, safety and power efficiency regulations, thermal management for better reliability and longer lifespan, limited circuit board space and the need to meet time-to-market deadlines must all be addressed simultaneously (Barb Schmitz, 2014).

Computational Fluid Dynamics is a methodology that allows engineers to predict the performance of their designs to simulate problems involving gases, liquids and solids and multi-phase problems. CFD is used in the design of almost every major product. Reducing uncertainty in the design process, increasing of the productivity and resulting in higher quality products and designs, with greater robustness to achieved customer's requirements. As such, CFD software are brought by experts to analyze the thermal spreading effect of the LED.

With the major advances of computational methods, CFD software has been used for modelling to reduce design time and cost. Due to the advances of the CFD software, CFD has now emerged as an effective tool towards simulation to measure and analyze temperature flows and heat transfer for better thermal management. By using CFD, suitable model of the LED can be generate and identify under various heating, cooling conditions and different environments before a various type of experimental done. Thus, it's able to reduce time consuming and period of designing a low power consumption LED.

Nevertheless in terms of heat dissipation, heat sinks are the most common hardware component in control of thermal management in electronics. The responsiveness and effectiveness of thermal control of electronic components which assemblies and modules by enhancing their surface area through the use of fins. Applications utilizing fins of the heat sinks for cooling purposes have increased significantly during the last few decades due to an increase in heat flux densities and product miniaturization. Today's advanced electronic circuits disperse substantially heavier loads of heat than ever before. At the same time, the premium associated with miniaturized applications has never been greater, and space allocated for cooling purposes is on the decline (R. Sam Sukumar, 2013). These factors have forced design engineers to seek more efficient heat sink technologies.

1.2 Problem Statements

Owing to the excellent color saturation and low power consumption, light emitting diode (LED) has become widely used in modern lighting applications such as flat-panel display, street lamps, advertising signage and decorative lighting. LED has drawn public attentions for its better reliability and lifespan, if compared to the traditional tungsten and florescence lighting. In order to enhance the luminosity performance of LED, the electrical driving current is crucial in producing more lumens. However, in real case most of the input power is lost as heat before transforming into useful light. The dissipated heat increases the temperature of the LED and affects its reliability and durability. The rise of temperature gradient can generate undesired stresses, eventually leads to light output degradation and catastrophic failure of the LED (Gavin Sullivan & Campbell Edmondson, 2008).

Recently, thermal distribution on multi package LED modules has become a new study. Modular LED is widely used as flat-panel and signage board as it generates more lumens at a lower cost. Nevertheless, the uniformity of temperature gradient may change and generate unbalanced thermal distribution along the module interface. In order to maintain the output light quality and performance reliability, thermal distribution analysis such as CFD was carried out to predict the thermal performance of LED module.

Since LEDs are negatively influenced by high temperature, the thermal management analysis for them is crucial for improved light quality, reliability and product lifespan. In this study, a thermal design of finned heat-sink with heat pipes as passive cooling was applied. the heat pipes can supply high thermal conductivity with much less weight and volume compared to copper or aluminium base and consequently less obstruction to air flow with enhanced natural convection. As the natural convection and radiation dominate heat transfer in this case, the optimum fin spacing was calculated by the most used empirical correlations.

Then, the design will be numerical investigated by computational Fluid Dynamics (CFD) to obtain best thermal performance. Meanwhile, the design will be evaluated experimentally as to consistently approve the thermal design compared to correlations and simulation. As the fin spacing is both optimized by correlations and modelling, the optimum thermal design can be eventually achieved.

1.3 Aims and Objectives

The objectives of the thesis are shown as following:

i) to study the thermal spreading effect

ii) to model the heat dissipation phenomenon

iii) to deduce the improved design for better thermal management of the LED

1.4 Outline of the Report

Basically in this final year project, since efficiency of light emitting diode (LED) is highly dependent on the operating current and junction temperature. Whereas in extreme conditions, high temperature also implies early degradation of the LED device. Therefore, thermal analyses for LED modules are to be carried out with the aid of Computational Fluid Dynamic (CFD) software (FloTHERM).

As for a starter, an example of heat sink was given by supervisor. Then measurements and analyze on heat sink will be carried out. Next, modelling will be done using FloTHERM software. Different materials of heat sink will be tested, compared and discussed further onwards. Next, the previously designed heat sink will be analyzed for its heat dissipation and heat transferring toward the whole area of the heat sink by using different environment for example: material of the heat sink, environment temperature, air density and more. The results obtained will be used as to prove the process of designing heat sink without any error occur. This is important because when the process brought to next procedure, any small mistake or careless in the process of designing heat sink will caused a problematic results, therefore process of designing of a heat sink is crucial and more details required.

Next, high power LED module will be modelled using CFD software. Then, it will be attached on heat sink to perform analyses to verify and observe the heat dissipation and heat transfer between LED towards heat sink. Besides that, experimental will be done to verify simulation versus real case are within the range with minor tolerance. There are two main research objectives contribute toward the project which are analyze the heat dissipation of the lighting element and improve design for the better cooling performance of the LED. Research will be contribute for the optimal and reliable operation with no catastrophic failure.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review

Siang Ling Oon 2010, using Computational Fluid Dynamic modeling technique to simulate LED package-on-substrate with a heat sink on top. The results shown details information of heat sink models with best possible results compared to actual measurements; however, a full details of heat sink model are very time consuming. The compact design version of heat sink model is only desired for fast analysis purposes. The result obtained for percentage error is justifiable for industrial applications and yet save more time.

Sridhar Narasimhan et al. 2003, reduced the computational method by creating heat sink using a compact “porous block” model, with a fine thermal conductivity and pressure loss co-efficient. From the study, parallel plate heat sinks which situated in laminar will imposed a convection. This methodology will determine thermal properties of compact heat sink models and thus provide a high level of accuracy. The results proved the data generated from using porous block compact model is legit. Other than that, porous-block representation can achieve outstanding acceptance to predict the thermal characteristics of a heat sinks.

Kevin R. Anderson et al. 2013, using CFD simulations to simulate heat and fluid flow performance in a electronic package through a large power dissipations of 1000 W/m2. A combination of thermal control using high thermal conductivity materials will forced convection cooling by using DC fans. While the internal forced convection heat transfer using a pumped fluid loop cold plate/heat exchanger system) to simulate the advantage of using COTS components to accomplish a thermal control solution. The results obtained are equivalent with previous studies which involving electronics cooling simulations.

Linton, R.L. et al. 1995, compared the results of a detailed CFD model of a heat sink with a set of experimental data. He use a his technique to represent the heat sink with a specific CFD model and compared with the detailed CFD model. Result indicated that his technique can be used when designing heat sinks for larger card or system models.

Mohammed H. S. Al Ashry 2015, made an attempt to prove the theoretical model by design a heat sink with a lower temperature gradient than PCB excess heat. The key of heat sink design is to sample the parts situated in central areas within the circuit board for better direct access to the heat source for better engagement. Experiments proved that increased convective air flow velocity will decreased conductive resistance on the surface of the heat sink. This feature is very persuasive and puts attention on the deploying forced convective air flow.

Dong Mei Li et al. 2009, designed a water miniature heat pipe to dissipate heat based on the LED packaging structure. Result is junction temperature of the source achieved below 70 ℃ at condition of natural convection. The result matched with the requirement of the LED working below 120 ℃ and result shows that heat pipe is the effective solution for the LED light application dissipation. Consideration for lower junction temperature are divided to three major requirement which are height, thickness and fin numbers. According to simulation results, the ideal scheme achieved when the lower junction temperature is 56.7 ℃ obtained by using few combination of optimization levels.

Bor Jang Tsai et al. 2011, simulated the temperature distribution under natural convection using numerical analysis and by introducing spherical coordinate system change in heat resistance. In addition to illuminating the heat dissipation of multi-chip LED modules, they attempts to identify the problems that affecting the temperature distributions of LEDs. Simulation results obtained and the temperature of a multi-chip LED module is slightly less than that of linear superposition. Thus, simulation result confirms the effectiveness, workable and accuracy of the proposed thermal resistance formula in the work.

Yan Lai et al. 2006, investigated an active liquid cooling solution to improve LED's application on automotive headlights. The investigation of thermal design completed from device to board to system level has been carried out throughout the research. Both methods of air cooling and passive liquid cooling are investigated and eliminated due to the methods unable to maintain temperature of LED junction under its maximum tolerated levels which unable to accept in the actual application. Therefore, only an active liquid cooling solution is nominated in terms of its suitable thermal management solution.

András Poppe et al. 2008, discussed about thermal characterization of packaged semiconductor devices by perform thermal simulations and measurements. Simulation is the priority to be done before production to be done. There are some difficulties to create an ideal simulation models since the actual time-constants of heat sink are small. They believe that combined thermal and radiometric measurements for power LEDs will become a standard some day.

Gábor Farkas et al. 2004, proved that the structure function approach is a powerful method for characterizing the heat conductance path and calculating junction-to-case thermal resistances. They also proposed to design a compact LED model with different complexity levels, where by experimental result able to describe some measured thermal effects and proceed to the electro-thermal simulation. The design model will reflects the changes of Rth at different currents and generate different temperature transients using the model of LED arrays with active components which allowed all transient junction temperatures and board temperature calculated and plotted.

Kai Lin Pan et al. 2014, studied the reliable thermal resistance calculation method by using theoretical mathematics calculation, experimental testing and finite element simulation based on the thermal resistance network model and the principle of steady state heat transfer. After that, she achieved experimental result with 9.2 %, and the error of total thermal resistance between the experimental result and finite element simulation with difference of -3.9 %.

2.2 Theoretical studies

2.2.1 Heat transfer

As previously mentioned in literatures, heat transfer characteristics of the LED package can be analyzed by the structure function method. It discusses the heat capacity parameters and thermal conductivity of the properties along the one-directional heat flow path. In order to derive the structure function, the thermal evaluations were firstly identified, followed by the heating or cooling curves. By transforming the curves, the structure function can be thus determined. The function relates to a time-constant system, in which the time constant, τ is a function of thermal resistance *R* and thermal capacitance *C*. According to (Székely 1991), detailed response of the structure function is calculated as:

$$\Delta T_j(t) = P_{th} \sum_{i=1}^{n} R_{thi} \cdot \left[1 - \exp\left(-t/\tau_i\right)\right] \tag{1}$$

where P_{th} is the heat power and R_{th} is the resistance. The function approaches infinity in a real distributed system, and Eq. (1) can be rewritten as:

$$\Delta T_j(t) = P_{th} \int_0^{\infty} R(\tau)\left[1 - \exp\left(-t/\tau\right)\right] d\tau \tag{2}$$

In relate to the time constant spectrum, Eq. (2) can be viewed as:

$$\frac{d}{dz} \Delta T_j(z) = P_{th} \int_{-\infty}^{\infty} R(\xi)\left[\exp\left(z - \xi - \exp\left(z - \xi\right)\right)\right] d\xi \tag{3}$$

where $z = \ln(t)$ and $\xi = \ln(\tau)$. The derivative of z is then expressed:

$$\frac{d}{dz}\Delta T_j(z) = P_{th} \cdot R(z) \otimes W(z) \tag{4}$$

where $W(z) = \exp[z - \exp(z)]$. The symbol $\otimes$ denotes the convolution operation. Besides, the structure function can be represented by a distributed RC thermal system, in which the sum of thermal capacitances and sum of thermal resistances are derived as Eqs. (5) and (6), respectively:

$$C_{\Sigma} = \int_0^x c(\xi)A(\xi)d\xi \tag{5}$$

$$R_{\Sigma} = \int_0^x \frac{d\xi}{\lambda(\xi)A(\xi)} \tag{6}$$

The differential structure function can be therefore determined:

$$Q(R_{\Sigma}) = \frac{dC_{\Sigma}}{dR_{\Sigma}} = c(x)\lambda(x)A^2(x) \tag{7}$$

where $c(x)$ is the volumetric heat capacitance, $\lambda(x)$ is thermal conductivity and $A(x)$ is cross sectional area of the heat flow.

2.2.2 Thermal resistance

In order to determine the thermal resistance (R_{th}), the schematic of LED package shown in Figure 1 can be transformed into the thermal circuit, as shown in Figure 2.

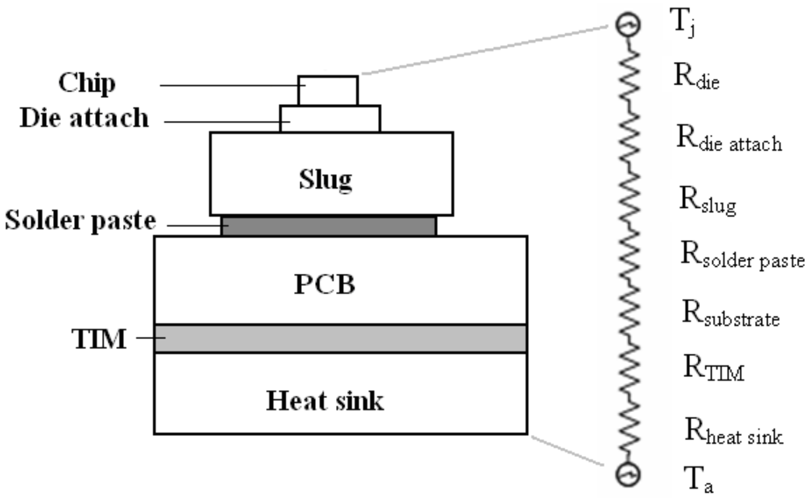


Fig. 2.1: Equivalent thermal circuit of LED package.

For the single chip LED package, the thermal resistance for the entire system can be estimated as:

$$R_{tot} = R_{die} + R_{die-attach} + R_{slug} + R_{solder-paste} + R_{substrate} + R_{TIM} + R_{heatsink} \quad (8)$$

If the low conductivity materials were used, i.e. silicon die attach, Ag solder paste and grease as TIM, Eq. (8) can be simplified as:

$$R_{tot} = R_{die} + R_{slug} + R_{substrate} + R_{heatsink} \quad (9)$$

By assuming a uniform heat flux on the top of chip, the thermal resistance of chip can be described with one-dimensional thermal resistance model for heat diffusion:

$$R_{die} = \frac{t_{die}}{k_{die} A_{die}} \quad (10)$$

where *t* is the thickness, *k* is the thermal conductivity and *A* is the cross sectional area. Similarly, thermal resistance of the slug can be expressed as:

$$R_{slug} = \frac{t_{slug}}{k_{slug} A_{slug}} \tag{11}$$

The structure model of the LED package with multiple chips is shown in Figure 3. The LED chip is with an area of $c \times d$ with center coordinate of (X_i, Y_i), mounted on the heat spreader measured in $a \times b$. In general, the heat spreader was insulated on all surfaces, except the bottom which left exposed to ambient.

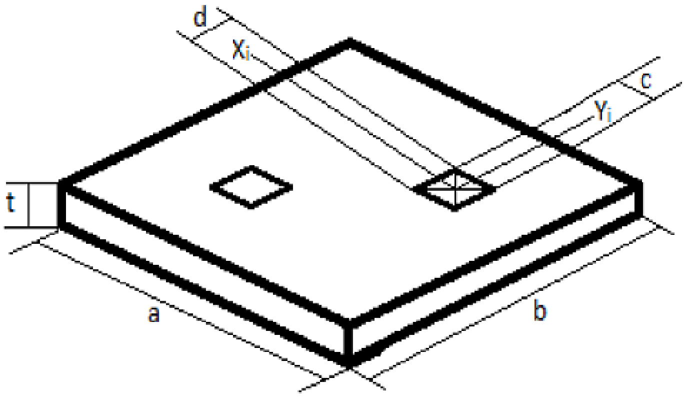


Fig. 2.2: Structure model of the LED package.

A general analytical solution based on separation variable method can be employed for temperature estimation on rectangular flux channels. The solution for the temperature distribution on the heat sink, which calculates the temperature of multiple chips LED package, was stated as (Cheng et al., 2010):

$$T(x, y, z) - T_f = \Delta T = \sum_{i=1}^{N} \theta_i (x, y, z) \tag{12}$$

where T_f is the ambient temperature, $T(x,y,z)$ is temperature of LED at the coordinate (x,y,z), N is the number of chip and θ_i measures the total temperature excess of the module. The following equation is to express the surface temperature distribution of LED module at $z = 0$:

$$\theta i(x, y, 0) = A_0^i + \sum_{m=1}^{\infty} A_m^i \cos(\lambda x) + \sum_{n=1}^{\infty} A_n^i \cos(\delta x) + \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} A_{mn}^i \cos(\lambda x)\cos(\delta x) \tag{13}$$

Several Fourier coefficients, i.e. A_m, A_n and A_{mn} must be determined in order to obtain the temperature excess. A_0 is the value for the coefficient in uniform flow and calculated by:

$$A_0 = \frac{Q}{ab}\left(\frac{t}{k} + \frac{1}{\gamma}\right) \tag{14}$$

where γ indicated the heat transfer coefficient of the LED to base, k is the thermal conductivity of heat spreader and Q is the dissipation power. The Fourier coefficients can be determined by:

$$A_m^i = \frac{2Q\left[\sin\left(\lambda_m\left(2X_i + c_i\right)/2\right) - \sin\left(\lambda_m\left(2X_i + c_i\right)/2\right)\right]}{abc_i k \lambda_m{}^2 \phi(\lambda_m)} \tag{15}$$

$$A_n^i = \frac{2Q\left[\sin\left(\delta_n\left(2Y_i + d_i\right)/2\right) - \sin\left(\delta_n\left(2Y_i - d_i\right)/2\right)\right]}{abd_i k \delta_n{}^2 \phi(\delta_n)} \tag{16}$$

$$A_{mn}^i = \frac{16Q\cos\left(\lambda_m X_i\right)\sin\left(\lambda_n c_i / 2\right)\cos\left(\delta_n y_i\right)\sin\left(\delta_n d_i / 2\right)}{abc_i d_i k \beta_{m,n} \lambda_m \delta_n \phi\left(\beta_{m,n}\right)} \tag{17}$$

where $\lambda = m\pi/a$, $\delta = n\pi/b$ and $\beta = (\lambda^2 + \delta^2)^{0.5}$. For the multiple chip LED package, says $N \times N$ array, the total thermal resistance can be determined by using the following equation:

$$R_{tot} = R_{die} + R_{slug} + R_{substrate} + N \times R_{heatsink} \tag{18}$$

The last term in Eq. (18) can be obtained by considering the innermost LED which gives a maximum junction temperature:

$$N \times R_{heatsink} = \frac{T(x,y,0)}{NQ} \tag{19}$$

2.2.3 Simulation

Simulation study of the LED package can be made with the professional thermal analysis software. The software Flotherm can be utilized to perform the thermal modeling work. With the embedded CFD solver, Flotherm is able to solve the Navier-Stokes equations for mass, momentum and energy conservation with the finite volume technique (Panton, 1996). The equation for mass can be expressed as:

$$\left[\frac{\partial \rho}{\partial t} + v \cdot \nabla \rho\right] = -\rho \nabla \cdot v \tag{20}$$

where ρ is the density, t is the time and v is the velocity vector. Momentum is another vector measurement which is in the same direction as velocity and calculated as:

$$\rho\left[\frac{\partial v}{\partial t} + v \cdot \nabla v\right] = -\nabla p + \rho g - 0.67 \cdot \nabla(\mu \nabla \cdot v) + 2\nabla \cdot \mu S \tag{21}$$

where p is the pressure, g is the gravity, μ is the viscosity and S is the strain rate tensor. The thermal energy is presented as follows:

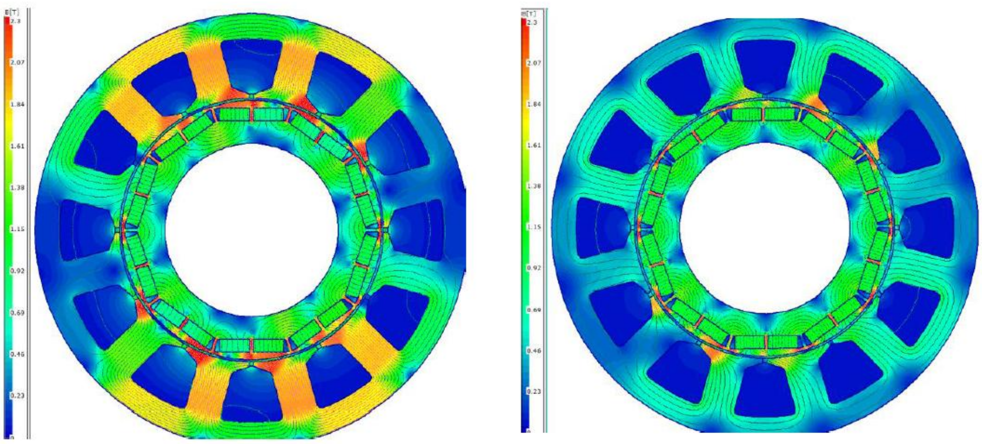
$$\rho c_P\left[\frac{\partial T}{\partial t} + v \cdot \nabla T\right] = \nabla \cdot (k \nabla T) - 0.67 \cdot \mu(\nabla \cdot v)^2 + 2(\mu S : S) + \beta T \cdot \left[\frac{\partial p}{\partial t} + (v \cdot \nabla) p\right] \tag{22}$$

where T is the absolute temperature, k is the thermal conductivity and β is the expansiveness. A number of simulation software could be used to perform the thermal analysis, e.g. Star CCM+ and ANSYS. STAR-CCM+ performs thermal modelling of electric machines and calculates the temperature transient of the system. STAR-CCM+ is able to solve engineering problems involving fluid flow, conjugate heat transfer and solid stress. On the other hand, ANSYS allows the design and optimization of new equipment and to troubleshoot existing installations. Furthermore, it contains modelling capabilities to model flow, turbulence, heat transfer, and reactions for real case industrial applications.

2.3 Software Implemented CFD

2.3.1 STAR CCM+

STAR-CCM+ showed new methods of thermal modelling of electric machines using the combination of an electromagnetic analysis tool to determine the performance and the temperature transient of the system. STAR-CCM+ able to run engineering process by solving problems involving fluid flow, conjugate heat transfer and solid stress. Figure 3 shows the different flux density distributions for the two load cases with the highly saturated parts in red



a) load point 1000.0 rpm b) load point 6000.0 rpm

Fig. 2.3: Flux density distribution, PC-FEA running the *i*-*Ψ*-GoFER for a certain rotor position

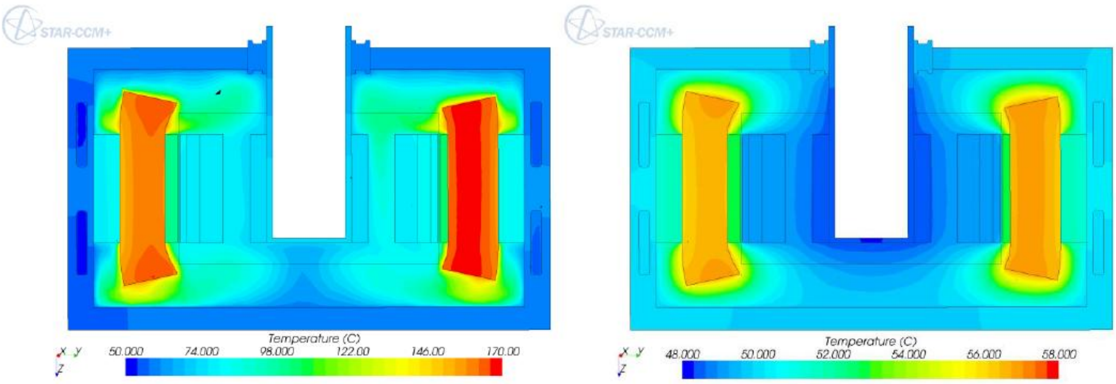


Fig. 2.4: Temperature distribution for both load case 1000 rpm and 6000 rpm

For 1000 rpm load case, the winding is hotter than on the left hand side as the water is already pre heated from the right half. For the 6000.0 rpm load case the cooling with the minimum temperature drops below the 50 ℃ of the coolant inflow temperature.

2.3.2 SolidWorks

With SolidWorks Flow Simulation, the designer able to define the system to be used and select the desired result resolution by meshing all level. The design engineer defines the project objectives of the analysis and required information to achieve the ideal result thus monitor those values during the calculation and create a table of the computed values when the analysis has been completed.

Heat sink without shield

Heat sink with shield

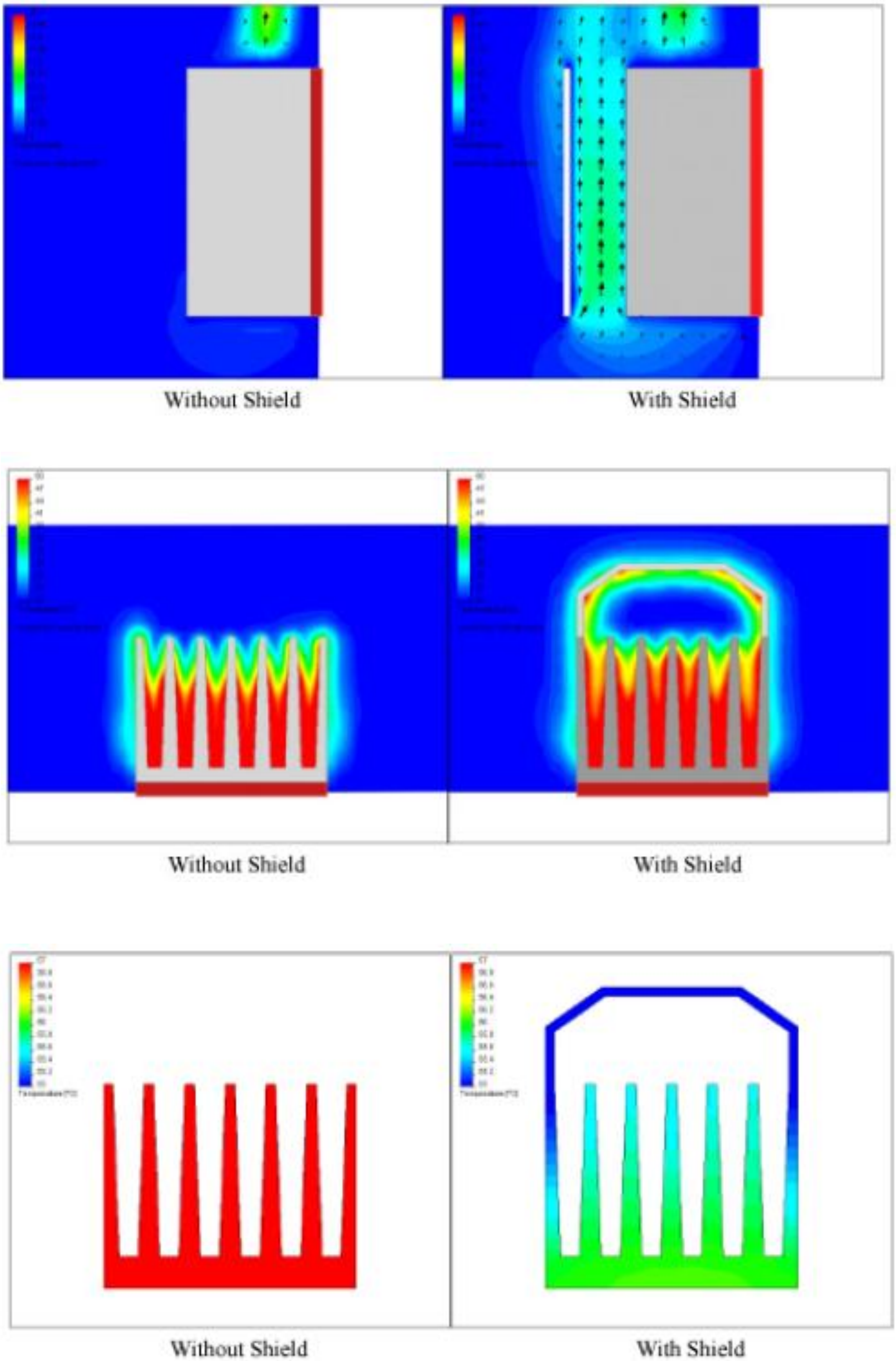


Fig. 2.5: Simulations using SolidWorks CFD software

2.3.3 Mentor Graphic

With Mentor Graphics FloEFD is a proven thermal simulation software environment that speeds and simplifies the task of LED luminaire and system design. Engineers test new ideas with "what-if" simulations rather than expensive hardware prototypes. And important issues like internal and external temperatures and heat flows can be evaluated quickly and accurately.

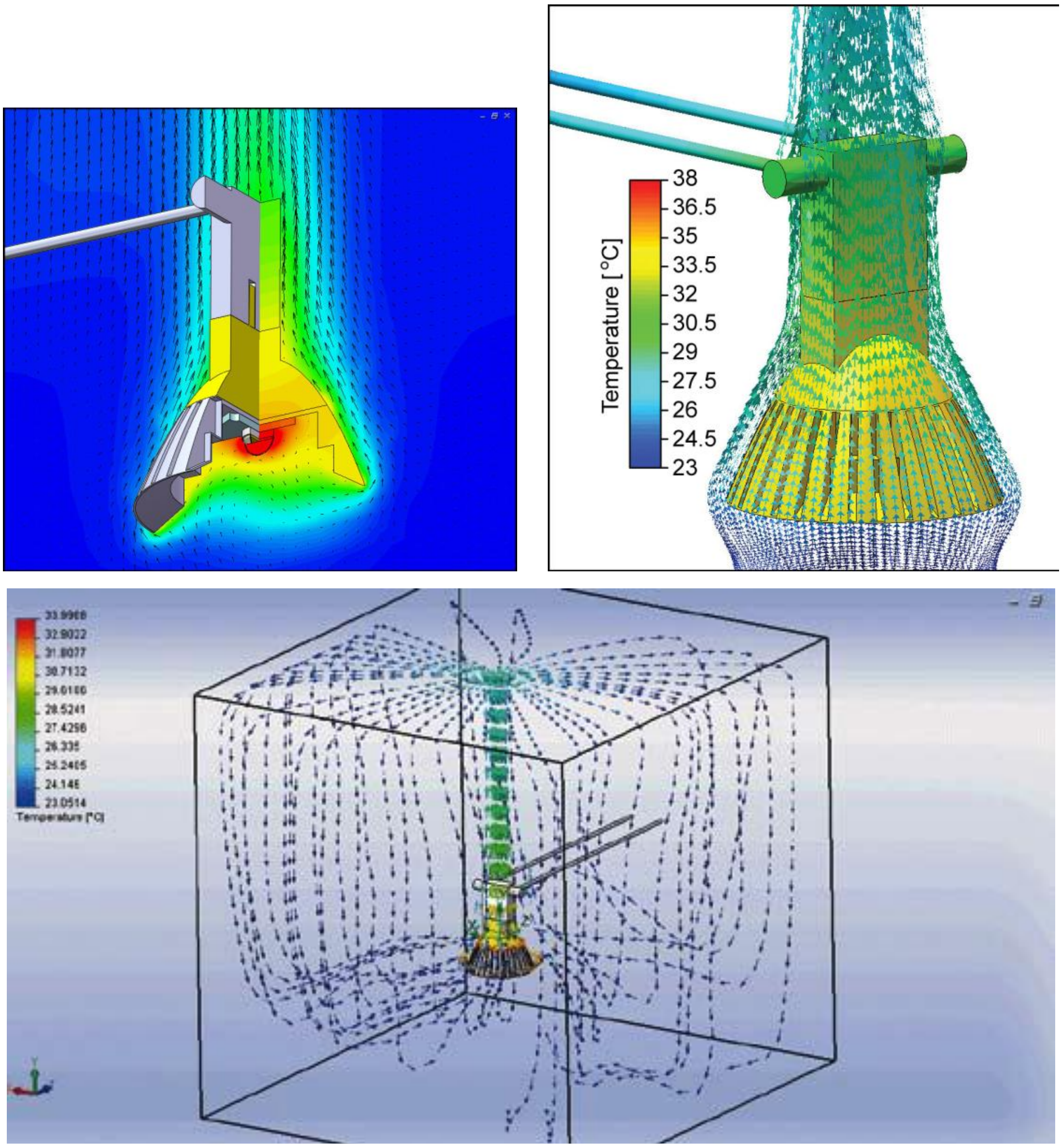
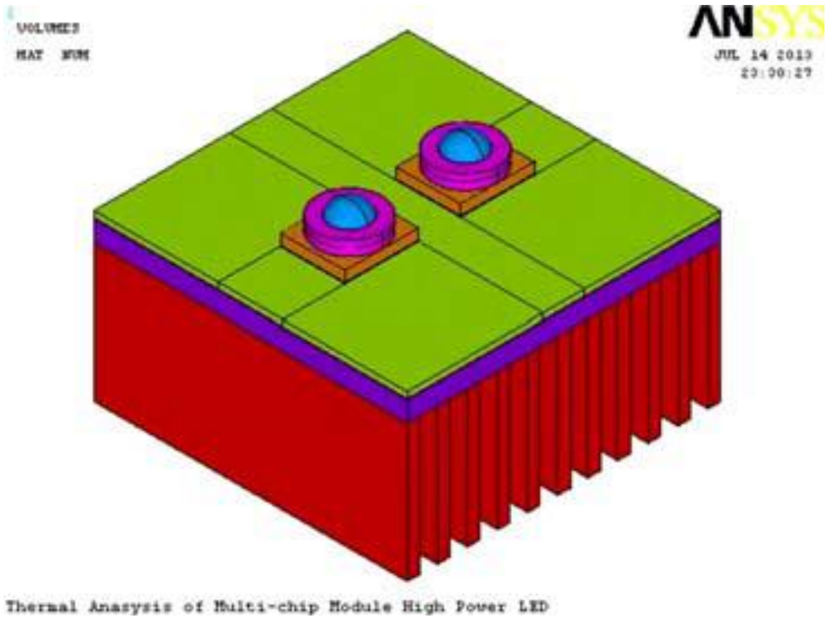
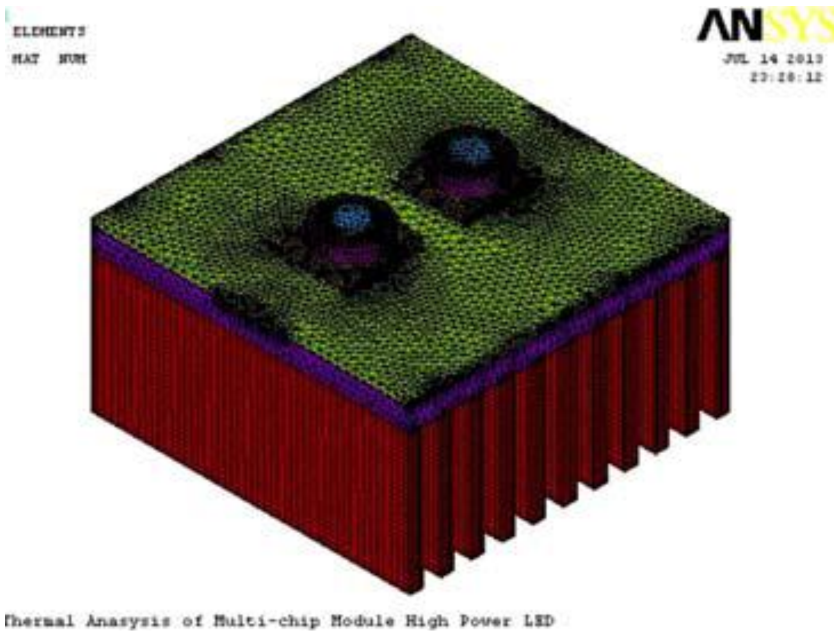


Fig. 2.6: The Mentor Graphics MicReD T3Ster Thermal Measurement System characterizes critical LED thermal parameters.

2.3.4 ANSYS

ANSYS allows design engineer to predict an engineering process with confidence by input details of information to a user friendly interface before manufacturing process began. This software has the analysis capabilities to design and optimize new equipment and to troubleshoot existing installations. Furthermore, it contains modeling capabilities to model flow, turbulence, heat transfer, and reactions for real case industrial applications. Figures below showed that CFD software simulate simulation of heat dissipation from LED package throughout heat sink





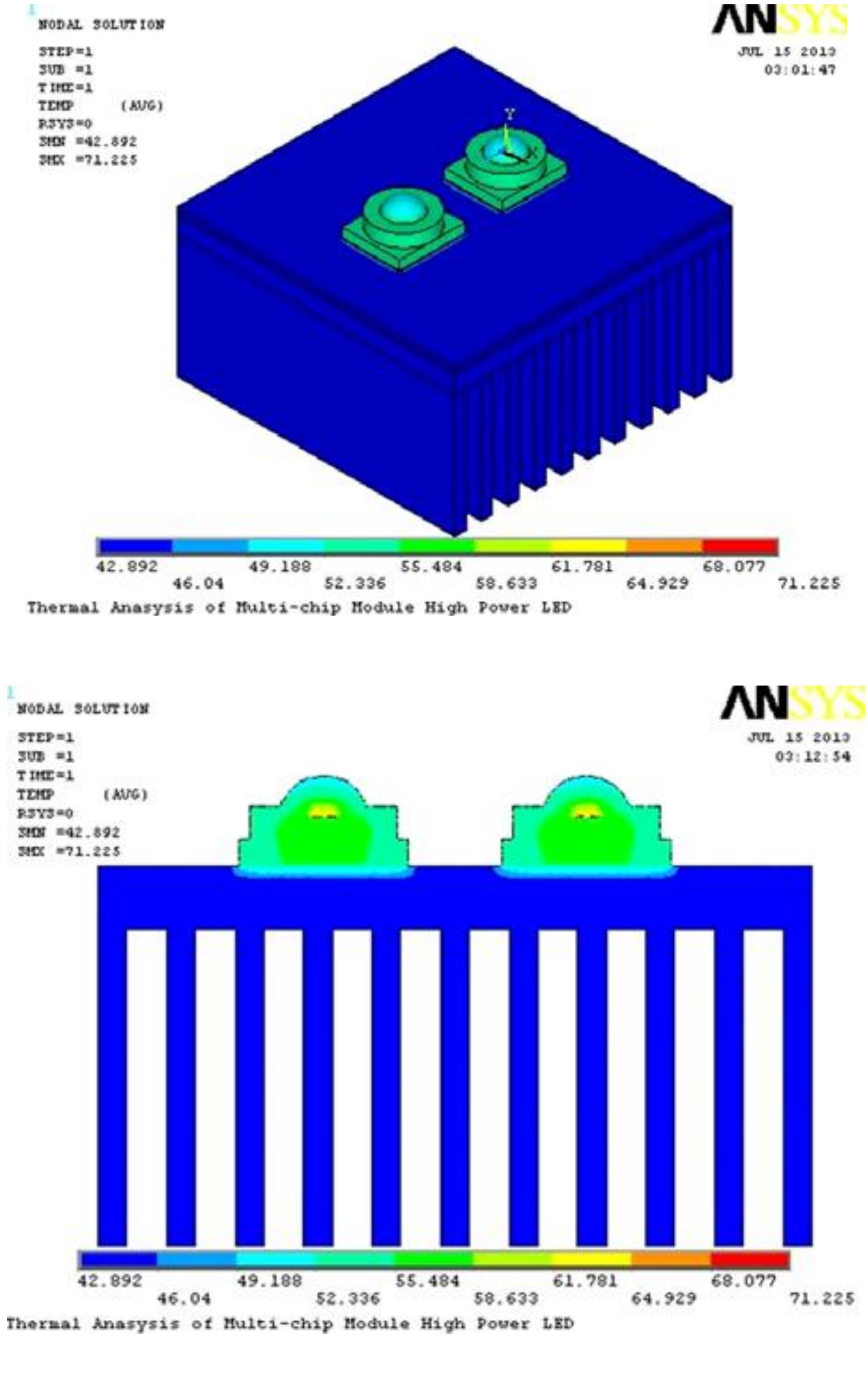


Fig. 2.7: Temperature distribution of finite element simulation.

CHAPTER 3

METHODOLOGY

3.1 Heat sink Design

Fig.3.1: Front view of Heat sink

Fig.3.2: Side view of Heat sink

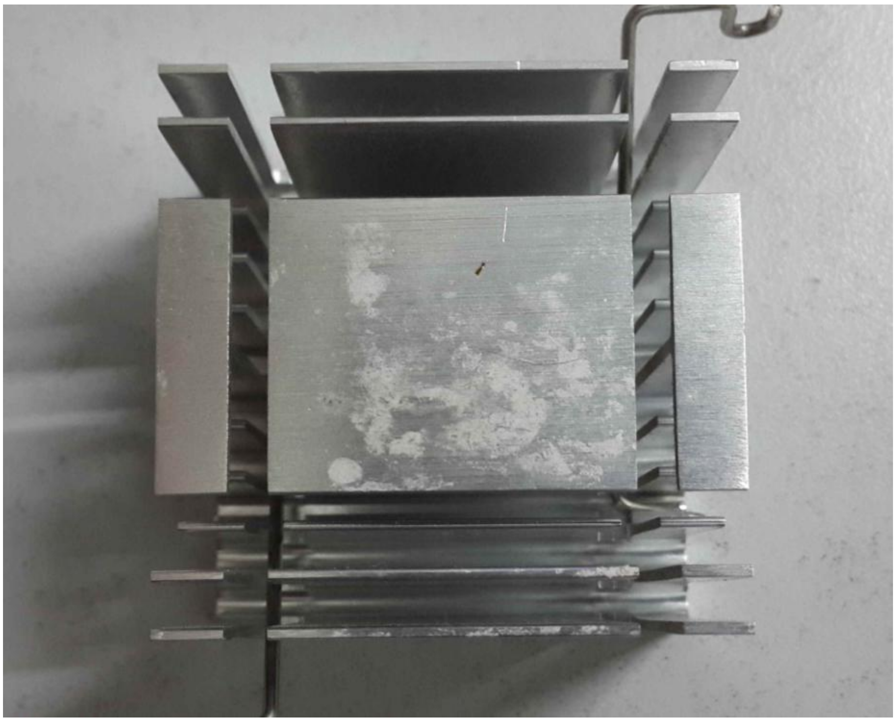


Fig.3.3: Top view of Heat sink

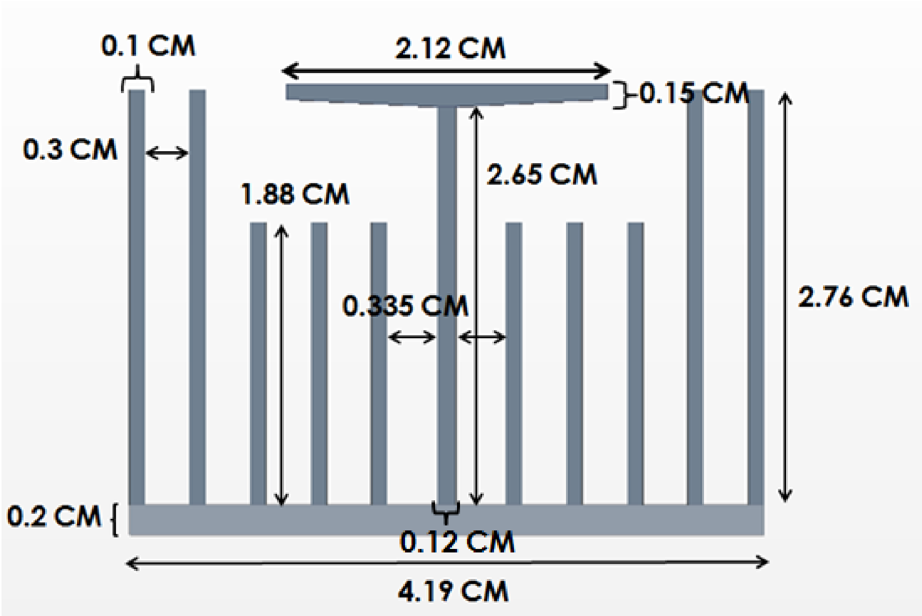


Fig.3.4: Actual measurement for front view

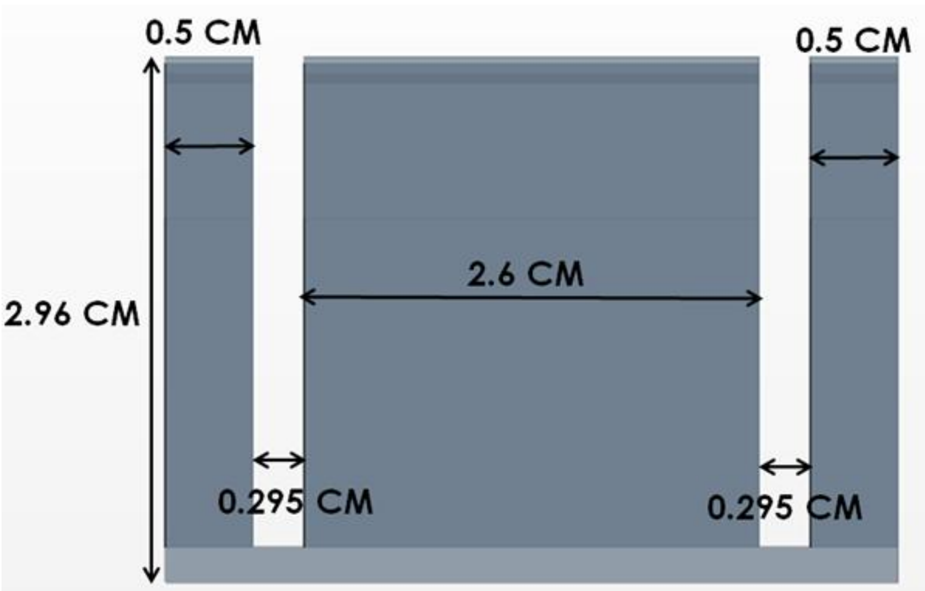


Fig.3.5: Actual measurement for side view

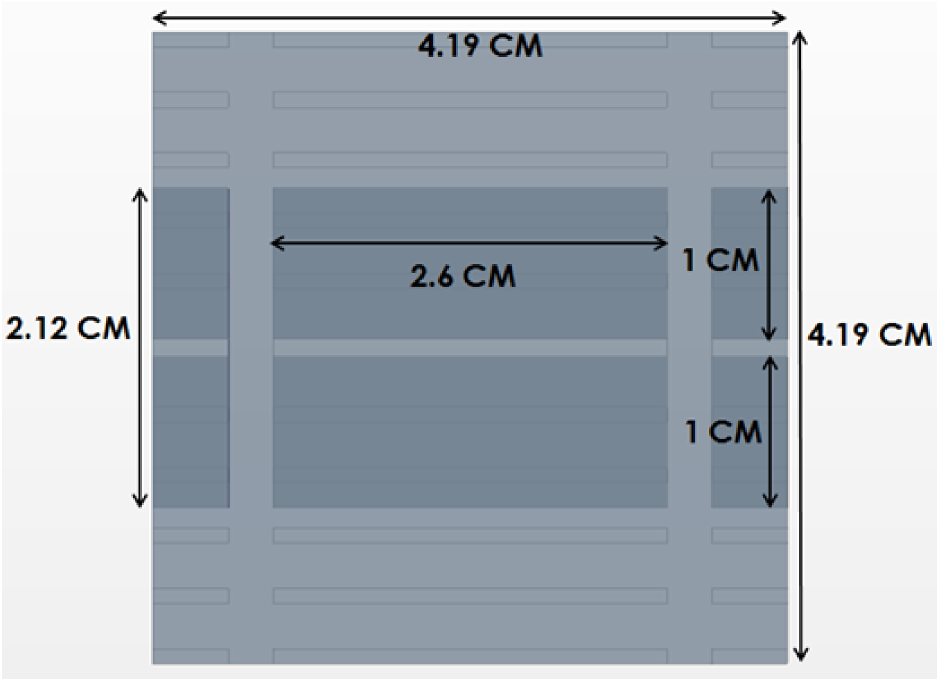


Fig.3.6: Actual Measurement for top view

3.2 Using FLOTHERM

3.2.1 Heat sink design

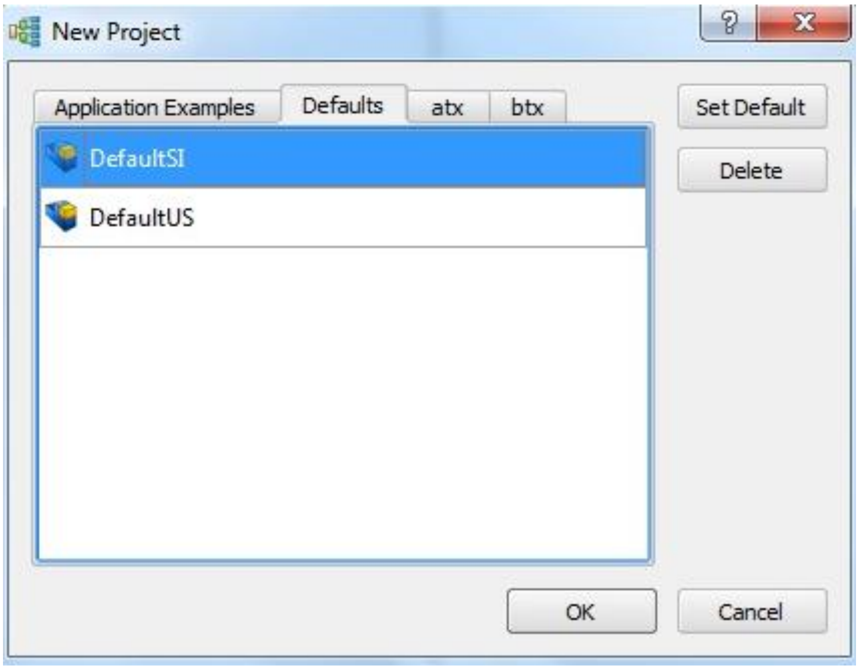


Fig.3.7: Create a new project from FLOTHERM user interface

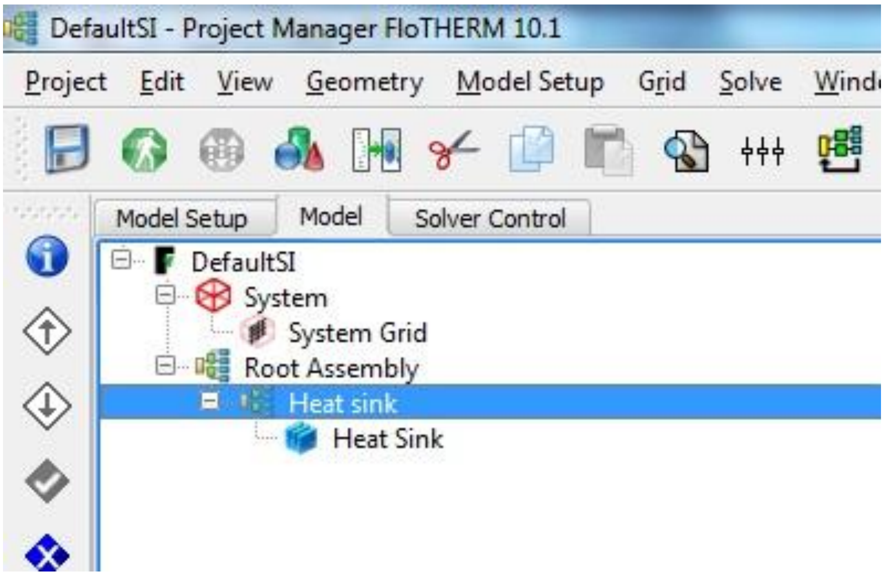


Fig.3.8: Select "Assembly" from the panel and then select "Heat sink"

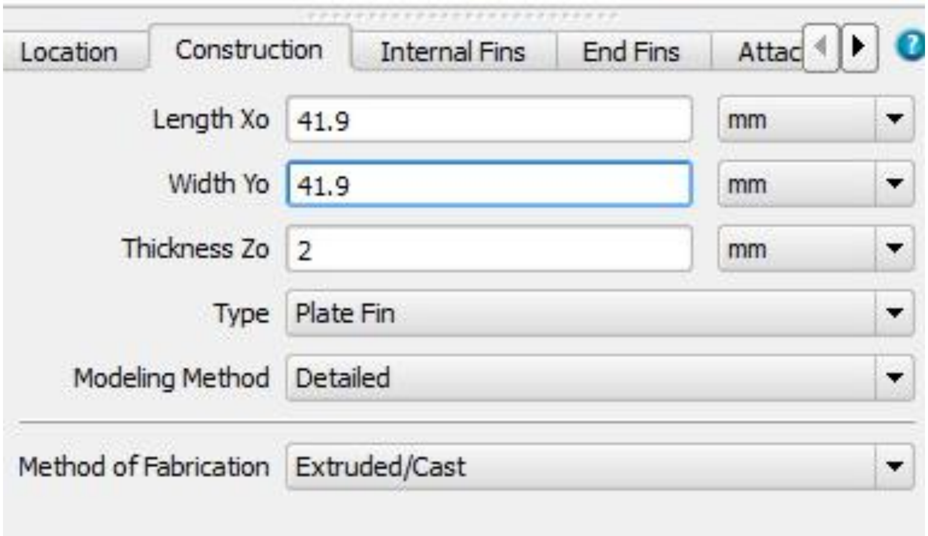


Fig.3.9: Select the dimension for the Heat sink

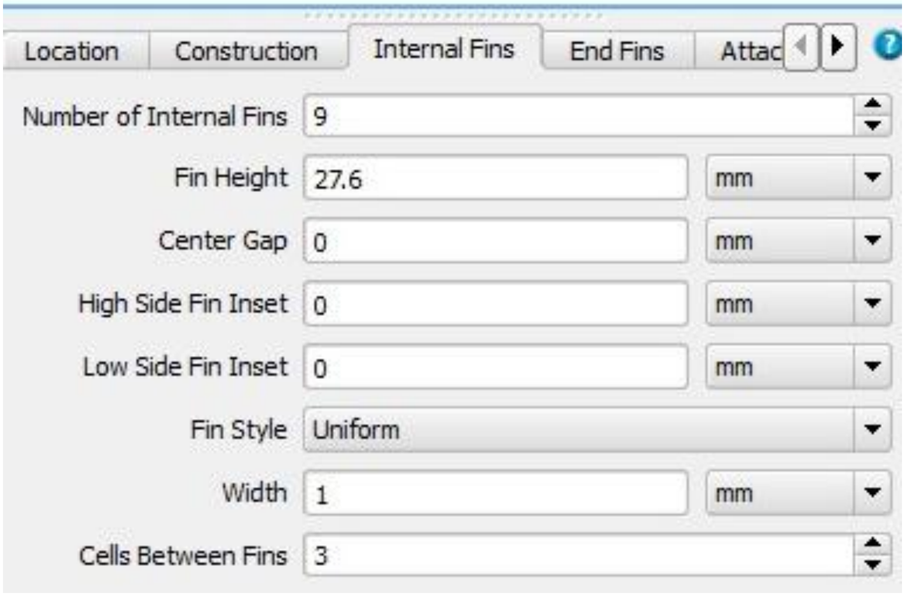


Fig.3.10: Select the requirement for fins of the Heat sink

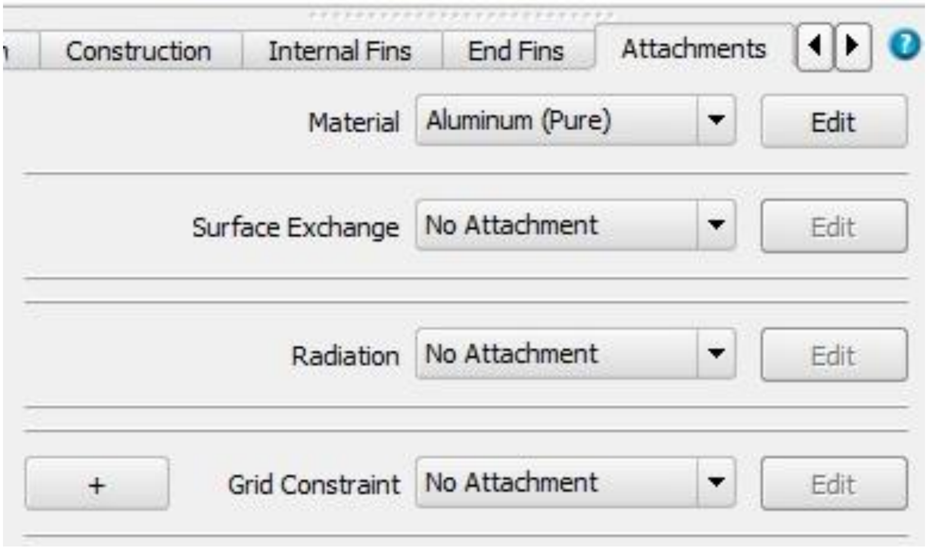


Fig.3.11: Select the material for the Heat sink

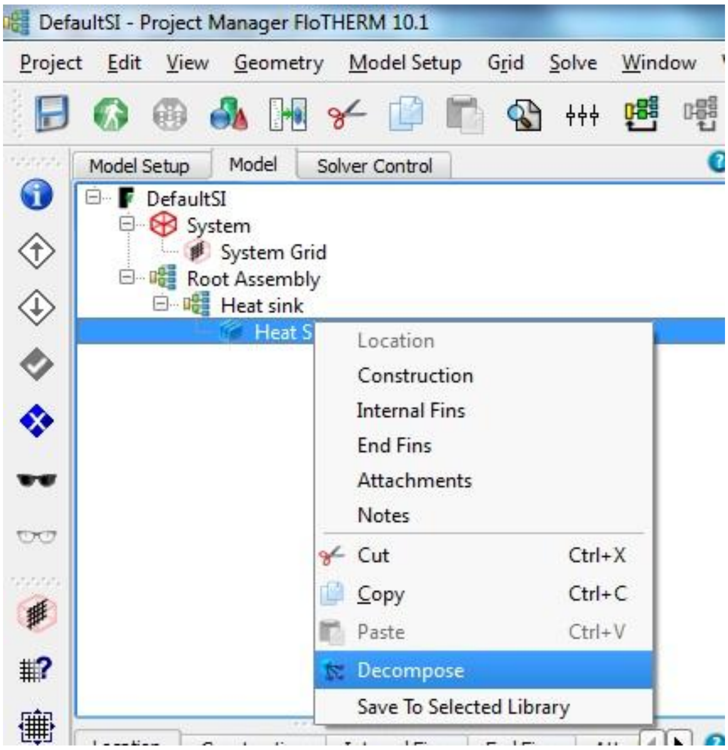


Fig.3.12: Decompress the Heat sink for further details setting

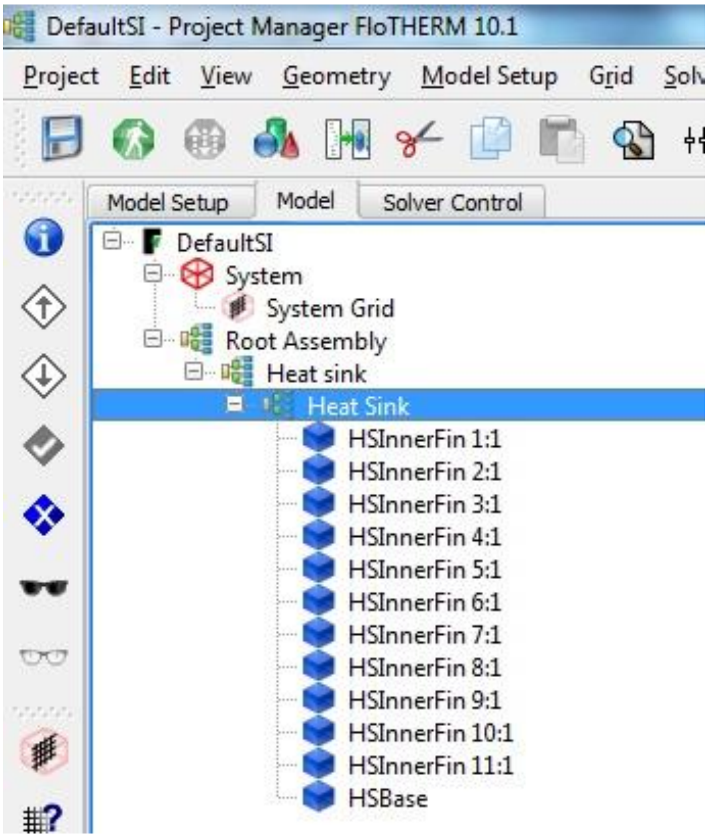


Fig.3.13: After decompression for the Heat sink

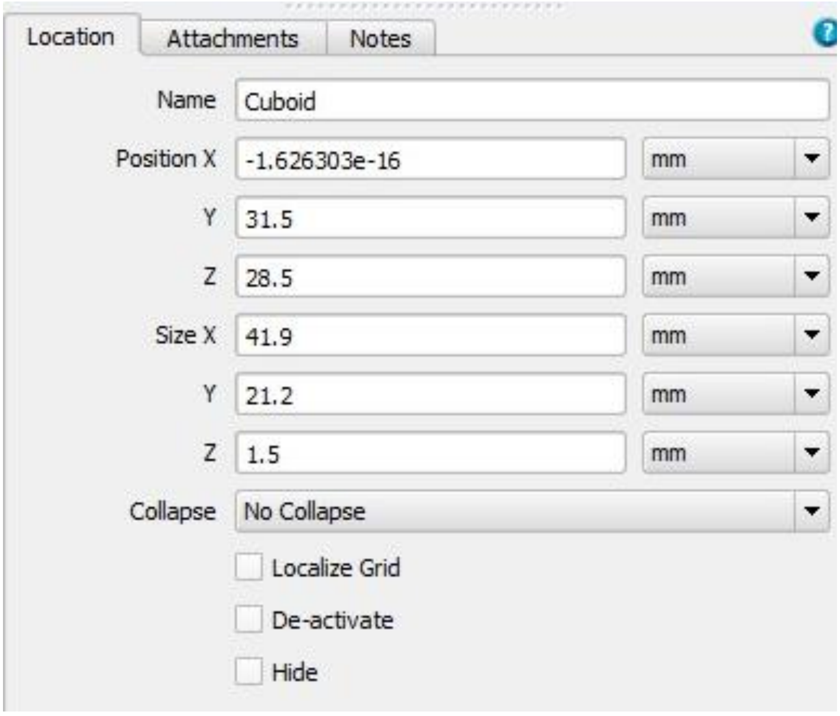


Fig.3.14: Adding a cuboid to the Heatsink

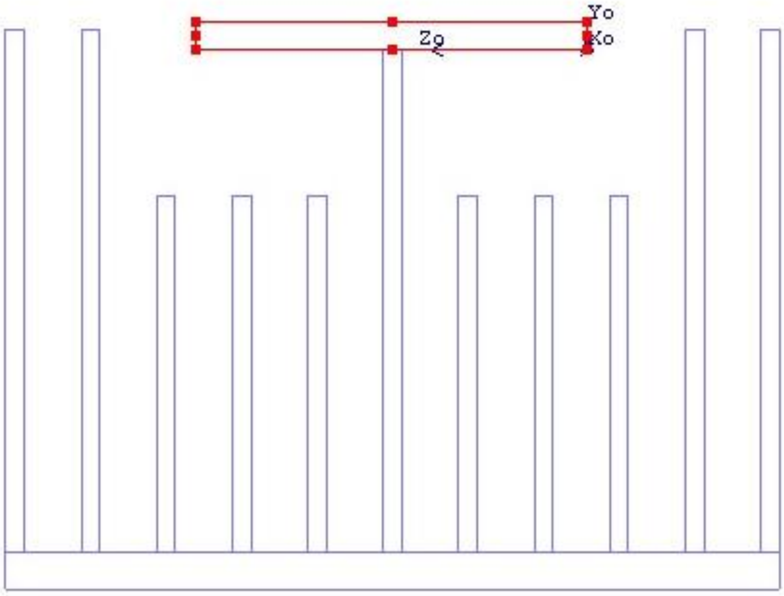


Fig.3.15: Compact Heat sink design is completed

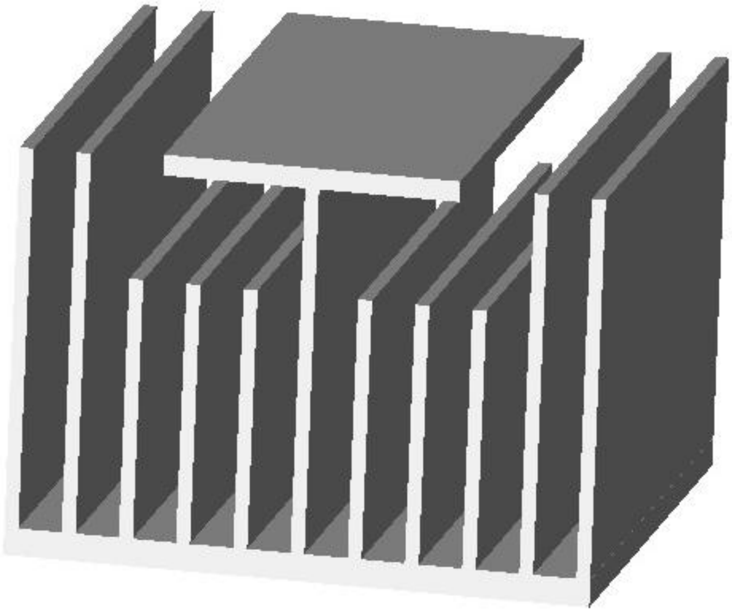


Fig.3.16: Compact Heat sink layout

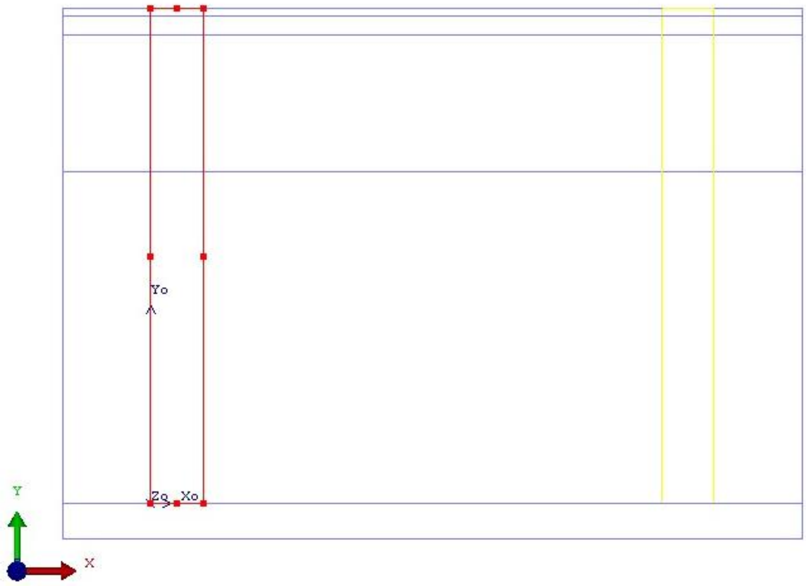


Fig.3.17: Create cut off for the Heat sink

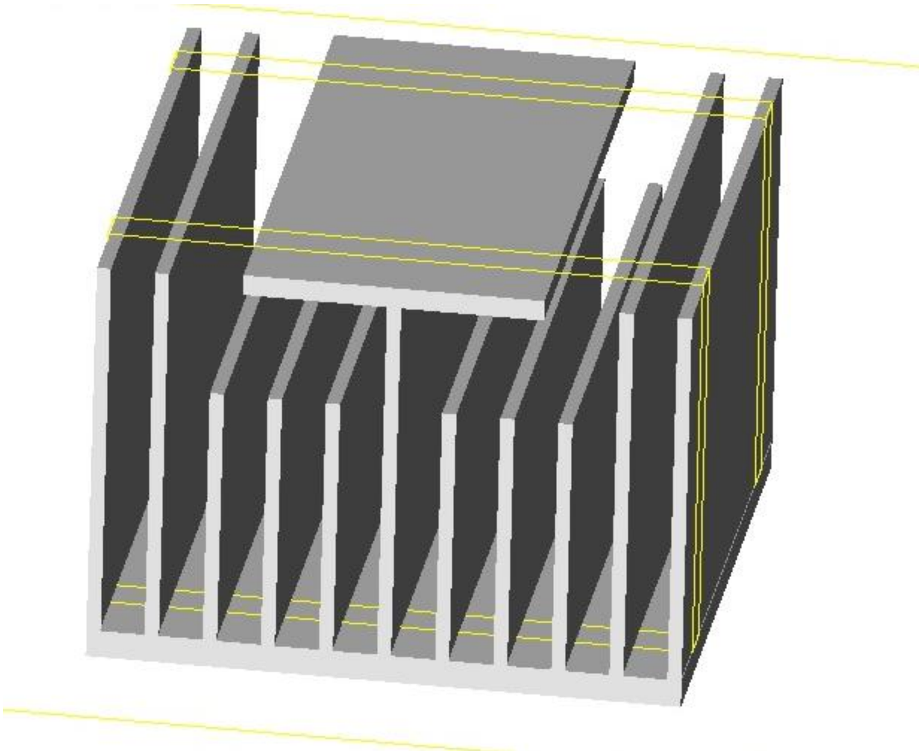


Fig.3.18: The outline of the cut off for the Heat sink

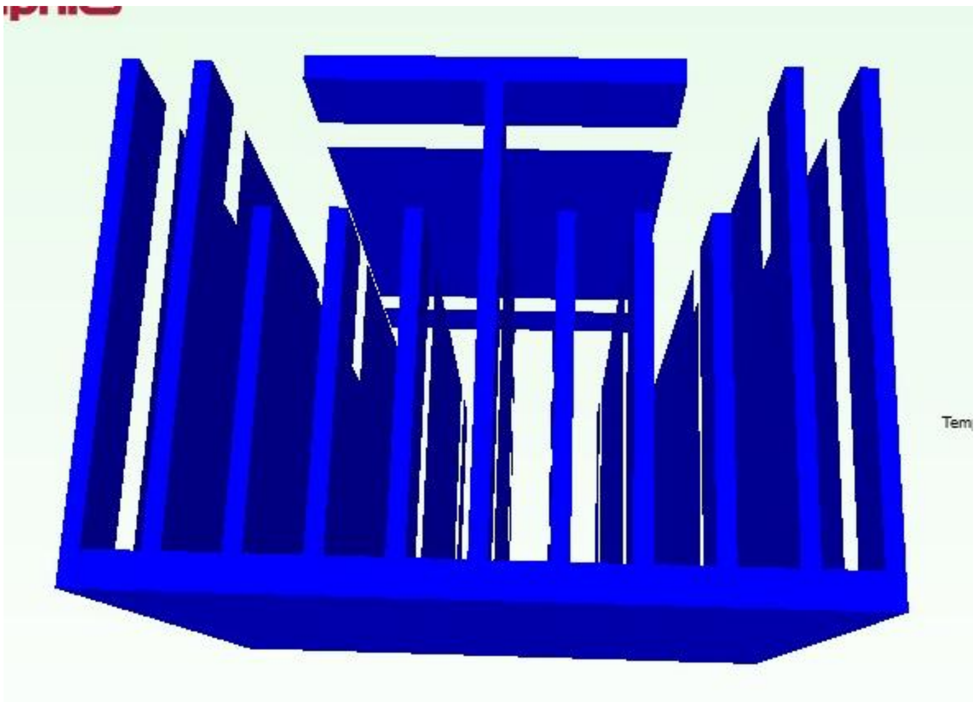


Fig.3.19: After cut off for the Heat sink

3.2.2 LED DESIGN

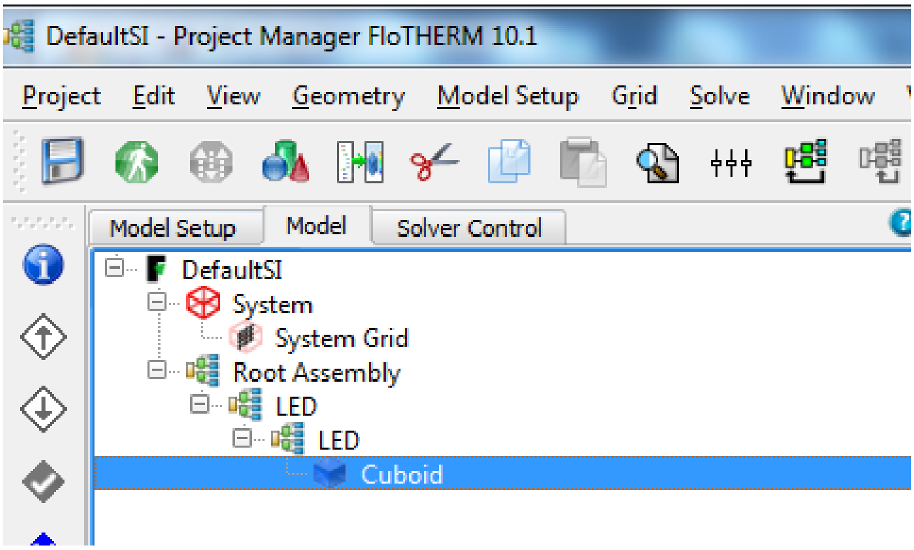


Fig.3.20: Create LED package

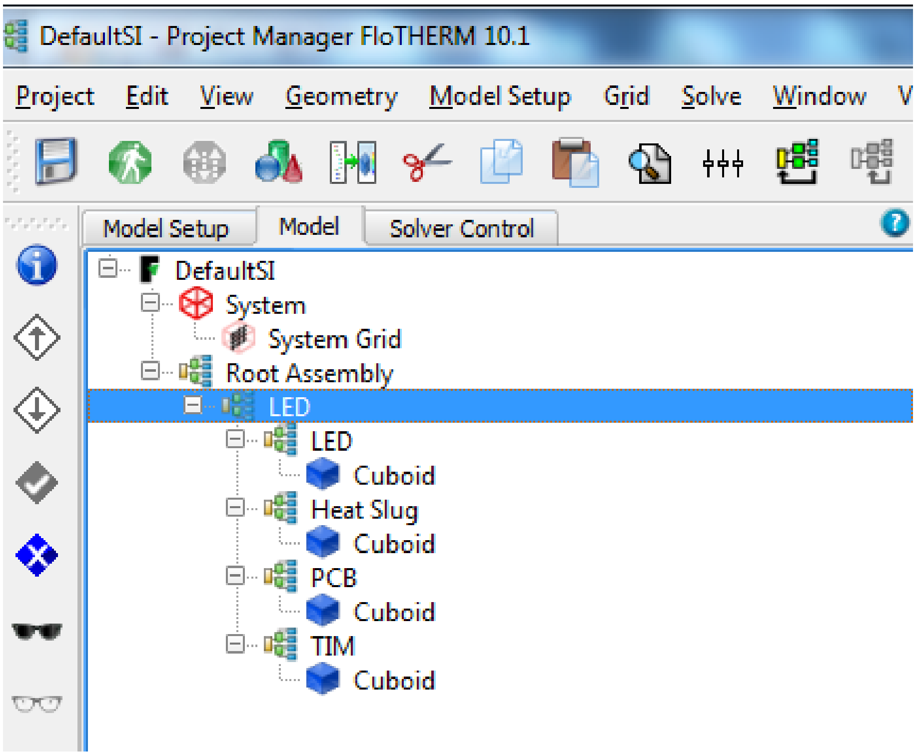


Fig.3.21: Create layers for LED package

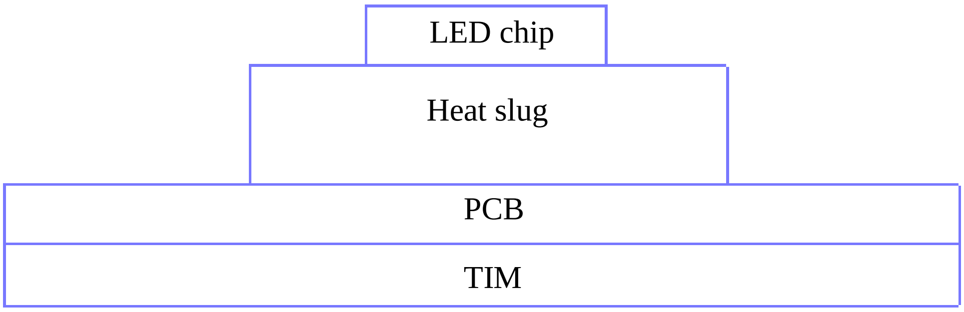


Fig.3.22: completed layers for LED package

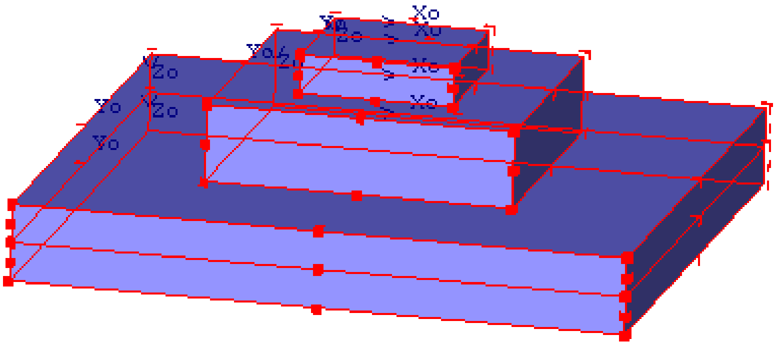


Fig.3.23: Compact LED package design layout

Table.3.1: Material list for LED package

Type	Materials	(W/m.K)
LED	GaN/InGaN	130
LED	AIN	285
LED	GaP	110
Substrate	Heat Slug	386
PCB	FR-4	0.3
PCB	MCPCB	201
TIM	Grease	4.1
TIM	ALO	25
TIM	Film	3
TIM	Tape	0.6

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 LED PARAMETRIC STUDIES

4.1.1 PCB materials

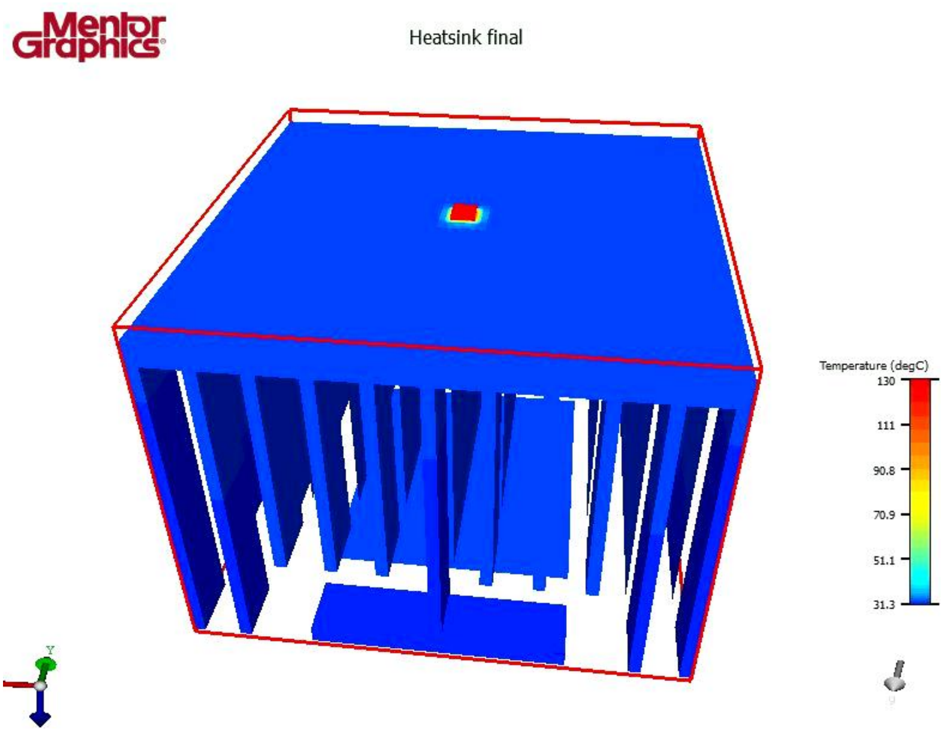


Fig.4.1: Result of 1 mm^2 GaN single chip LED package with FR-4 PCB material and ALO for TIM of 0.5 W

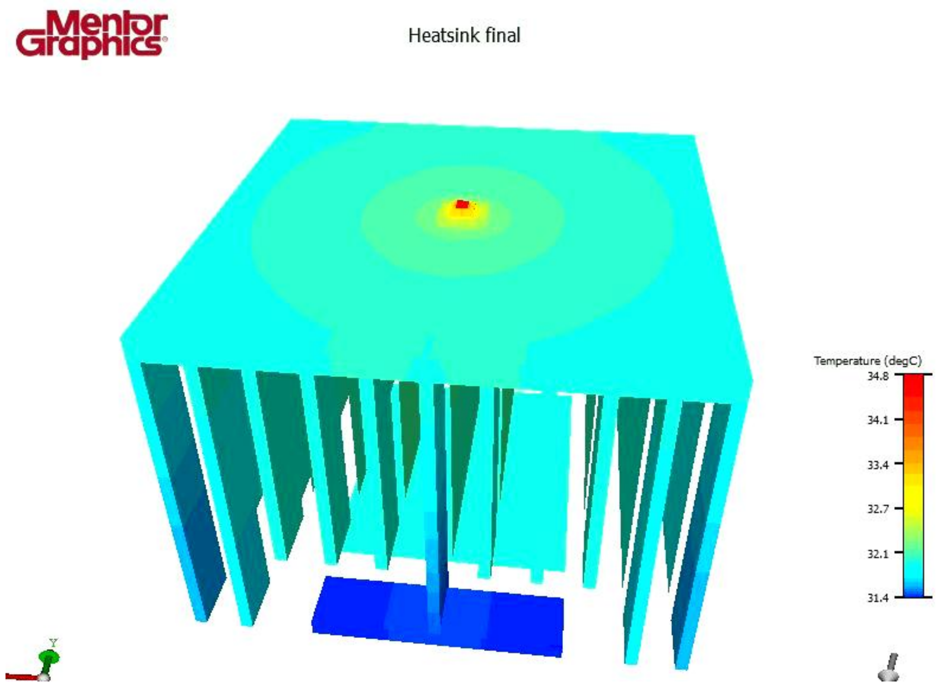


Fig.4.2: Result of 1 mm^2 GaN single chip LED package with MCPCB PCB material and ALO for TIM of 0.5 W

Table.4.1: Result of two PCB materials compared

Chip	Size	CHIP	PCB	TIM	Power	Temperature	
No.	W X L	Material	Material	Material	Watt	Min	Max
1	1 x 1 mm^2	GaN	FR-4	Grease	0.5	31.3	135
				ALO	0.5	31.3	130
				FILM	0.5	31.3	141
				TAPE	0.5	31.3	166
			MCPCB	Grease	0.5	31.4	36.6
				ALO	0.5	31.4	34.8
				FILM	0.5	31.4	38.6
				TAPE	0.5	31.4	47.6

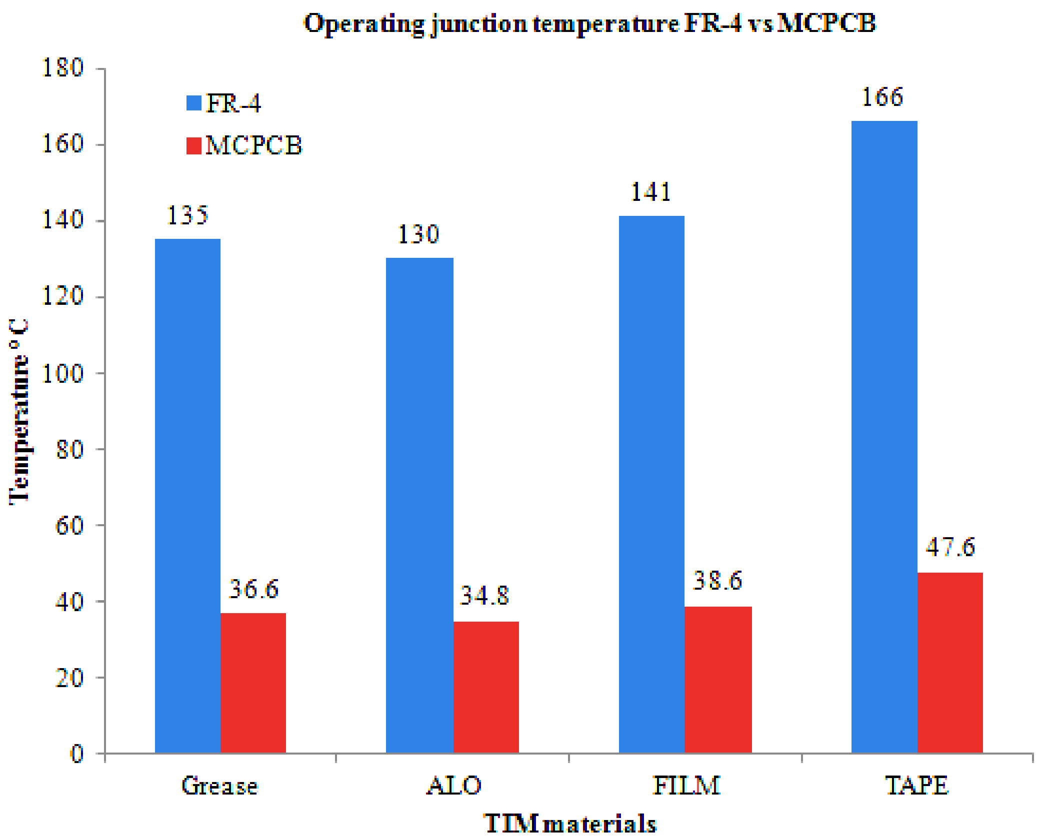


Fig.4.3: Operating junction temperature FR-4 vs MCPCB for different types of TIM of 0.5 W

Figure 31 shown the result of implementing 1 x 1 mm^2 GaN/InGaN single LED package with FR-4 as PCB material and as well as ALO for TIM (Thermal interface material). From table 2 and graph 2, the result obtained when using FR-4 as PCB material which maximum operating junction temperature achieved is 130 ℃. Since the optimum operating junction temperature for LED package must not exceed 90-120 ℃, therefore FR-4 material omitted. MCPCB (metal core PCB) material adopted for the PCB and simulation verified that MCPCB done a better job for heat dissipation compared to FR-4 where the result obtained is 34.8 ℃ by implementing ALO material for TIM layer compared to 130 ℃ from FR-4.

Based from the comparison of the result for different types of TIM layer, ALO for TIM layer perform the better task for heat dissipation which yield 34.8 ℃ while grease material yield 36.6 ℃, film material yield 38.6 ℃ and tape material yield

47.6 ℃. To put it in a nutshell, ALO is suitable for better thermal conductivity compared to other materials..

4.1.2 LED chip and TIM materials

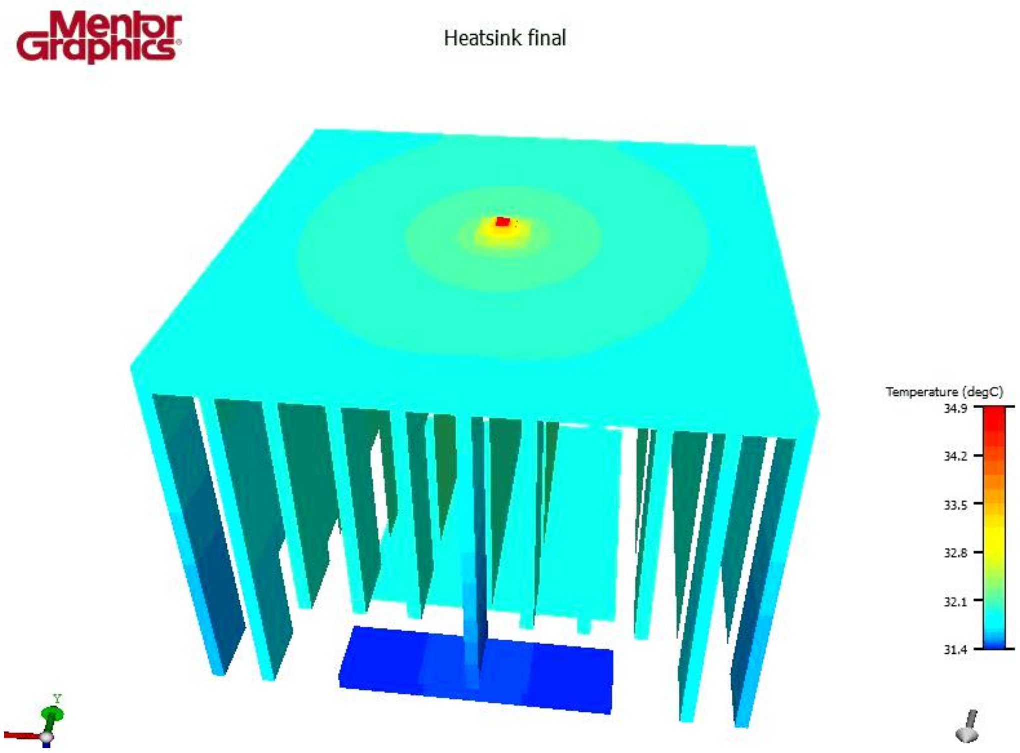


Fig.4.4: Result of 1 mm^2 GaP single chip LED package with MCPCB PCB material and ALO for TIM of 0.5 W

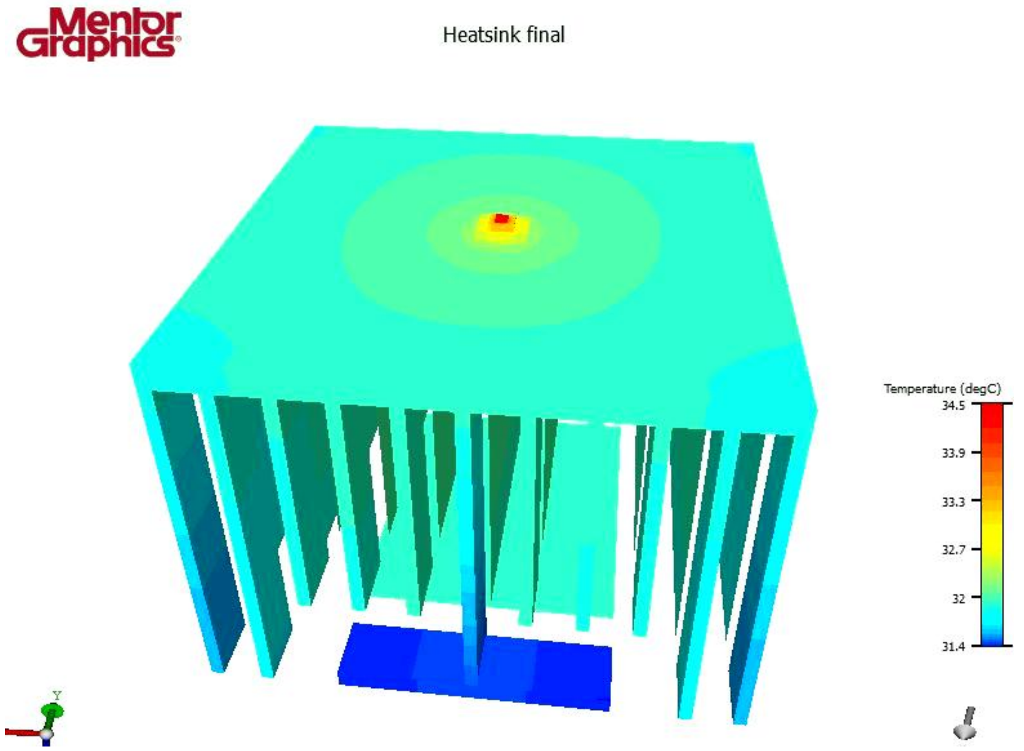


Fig.4.5: Result of 1 mm^2 AIN single chip LED package with MCPCB PCB material and ALO for TIM of 0.5 W

Table.4.2: Comparison of maximum operating junction temperature for GaN, GaP and AIN materials for LED Chip

	Temperature ℃		
TIM Materials	LED Chip materials		
	GaN	GaP	AIN
Grease	36.6	36.7	36.3
ALO	34.8	34.9	34.5
FILM	38.6	38.7	38.4
TAPE	47.6	47.7	47.4

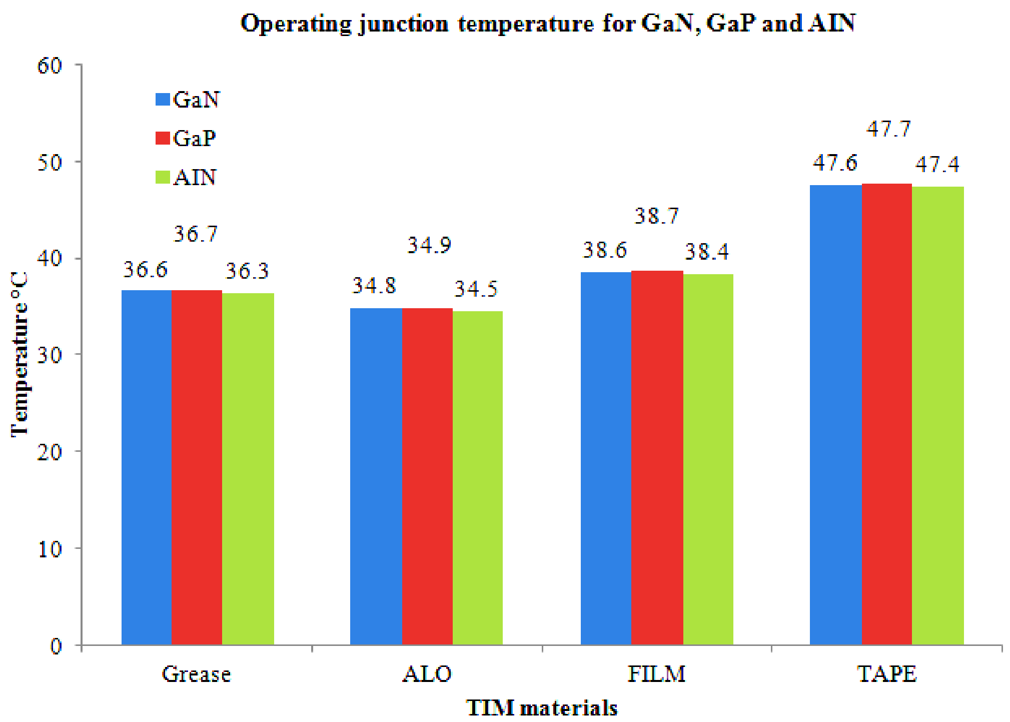


Fig.4.6: Maximum operating junction temperature for GaN, GaP and AIN materials

From table 2, the result shown that AIN material perform the best operating junction temperature which yield 36.3℃ for Grease material, 34.5℃ for ALO material, 38.4℃ for Film material and 47.4℃. Throughout the comparison, the actual result for three types material induced a similar result therefore GaN and AIN material were chosen to proceed for next task since GaN material is widely used by semiconductor industrial to develop LED chip due to its stability and convenient of implementation while AIN material is new to market which is expensive and due to its complicated process thus perform an excellent thermal conductivity. GaN/InGaN and AIN materials, heat slug, MCPCB and ALO is finalized as good thermal conductivity LED package.

4.1.3 Sizes of LED Chip and total power

4.1.3.1 Single LED chip package

Table.4.3: Result of maximum operating junction temperature of single LED chip package for two types of LED chip materials

Chip Materials	Sizes (mm^2) 1		1.5		2	
	0.5 W	1 W	0.5 W	1 W	0.5 W	1 W
GaN	34.8	44.6	34	42.9	33.7	42.5
AIN	34.8	44.1	33.9	42.7	33.7	42.4

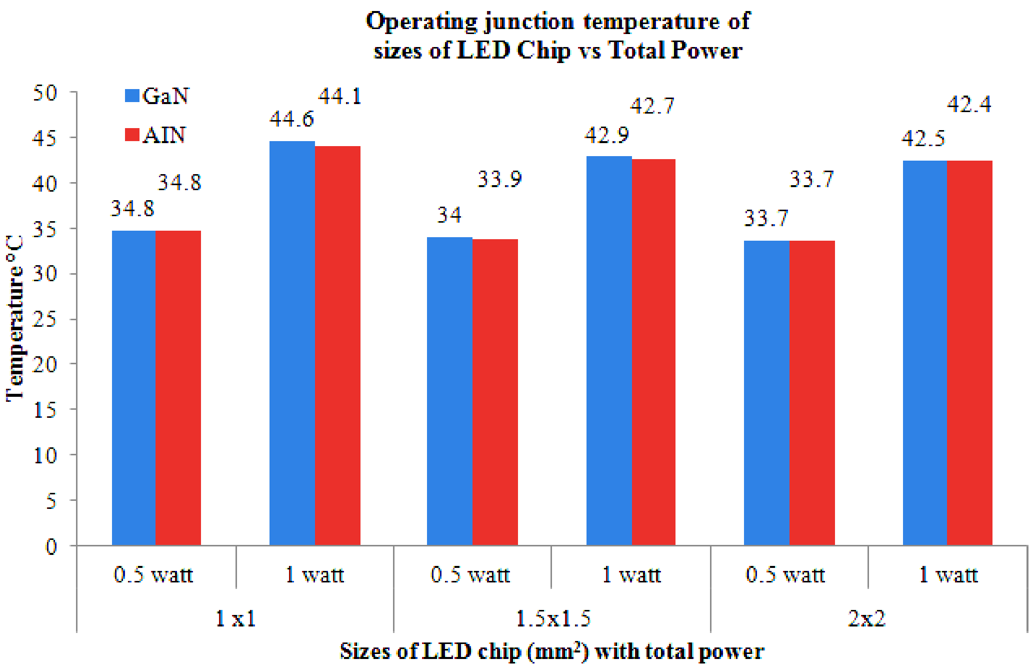


Fig.4.7: Maximum operating junction temperature for single LED chip for different dimension (1, 1.5 and 2) mm^2 of heat sink ranging total power from 0.5W to 1W

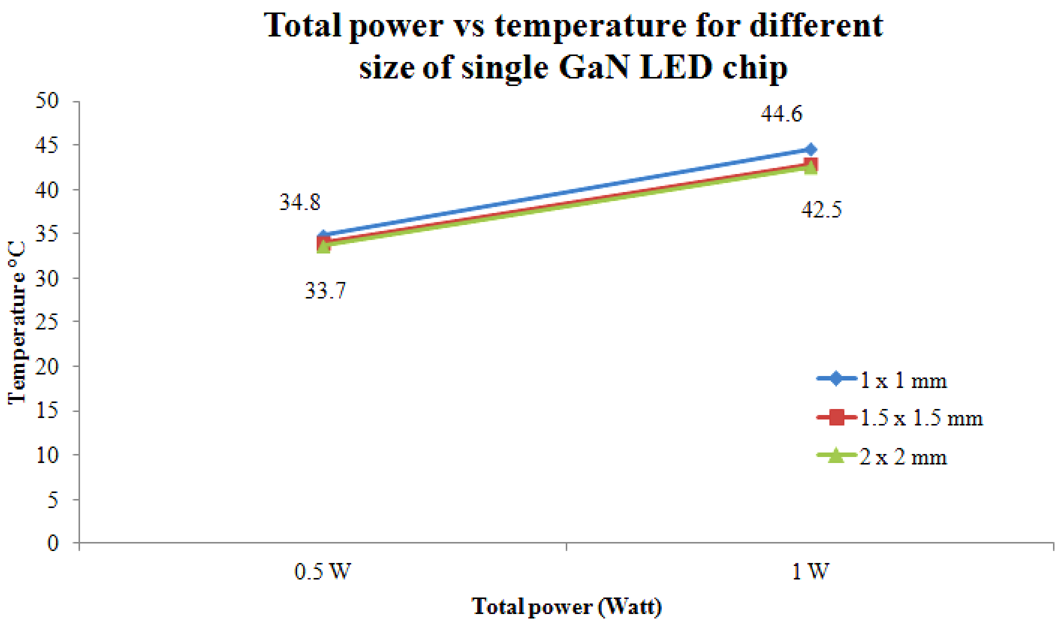


Fig.4.8: Graph of total power vs temperature for different sizes of single GaN LED Chip

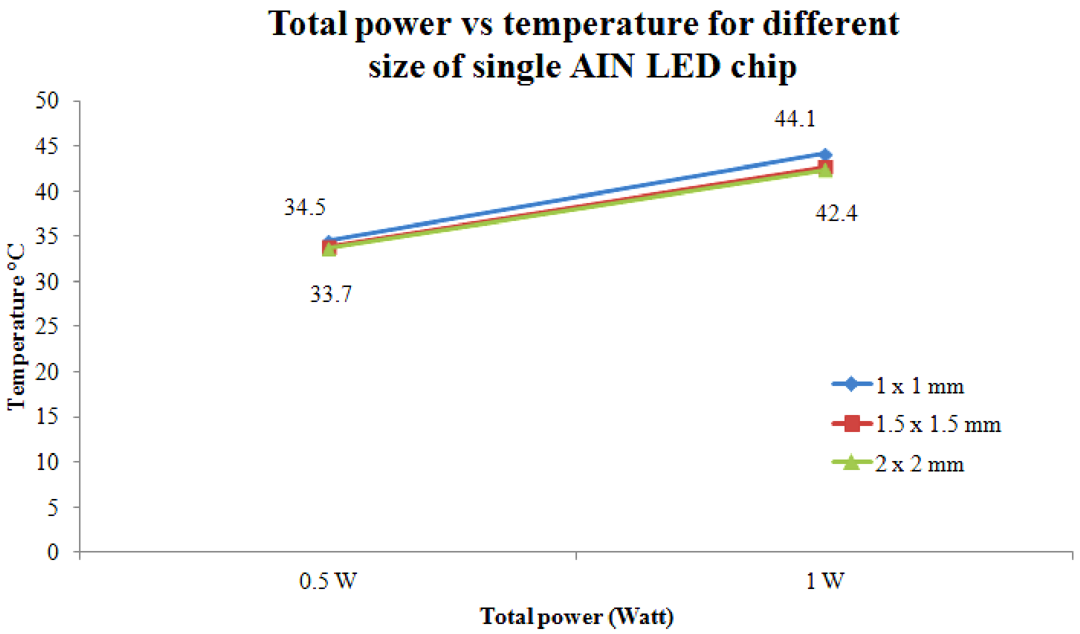


Fig.4.9: Graph of total power vs temperature for different sizes of single AIN LED Chip

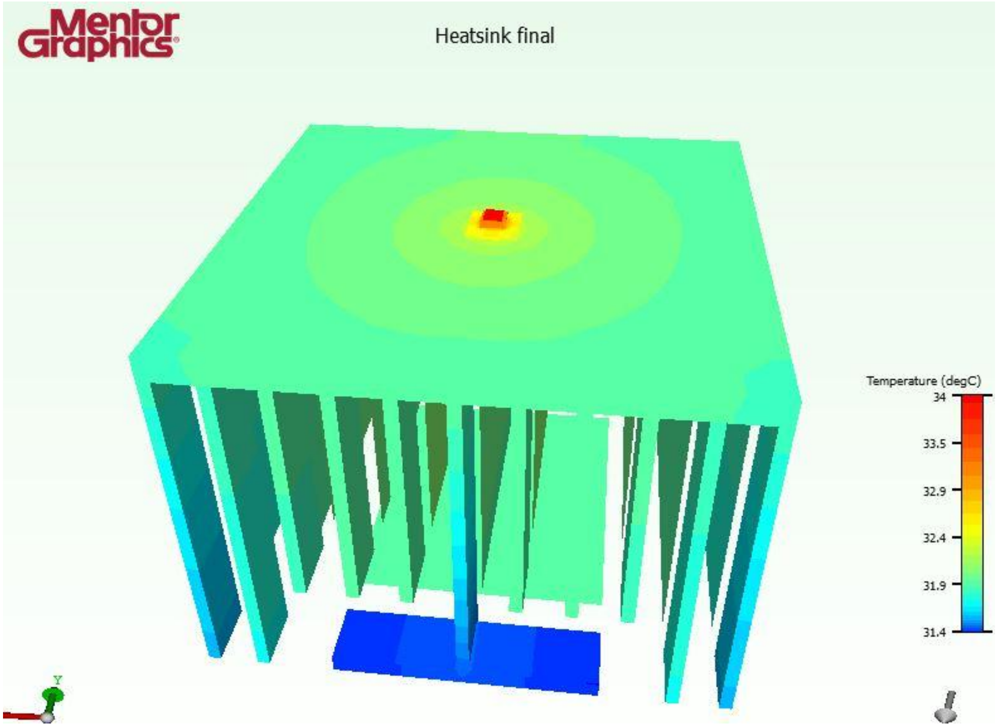


Fig.4.10: Result of 1.5 mm^2 GaN single chip LED package with MCPCB PCB material and ALO for TIM for 0.5 W

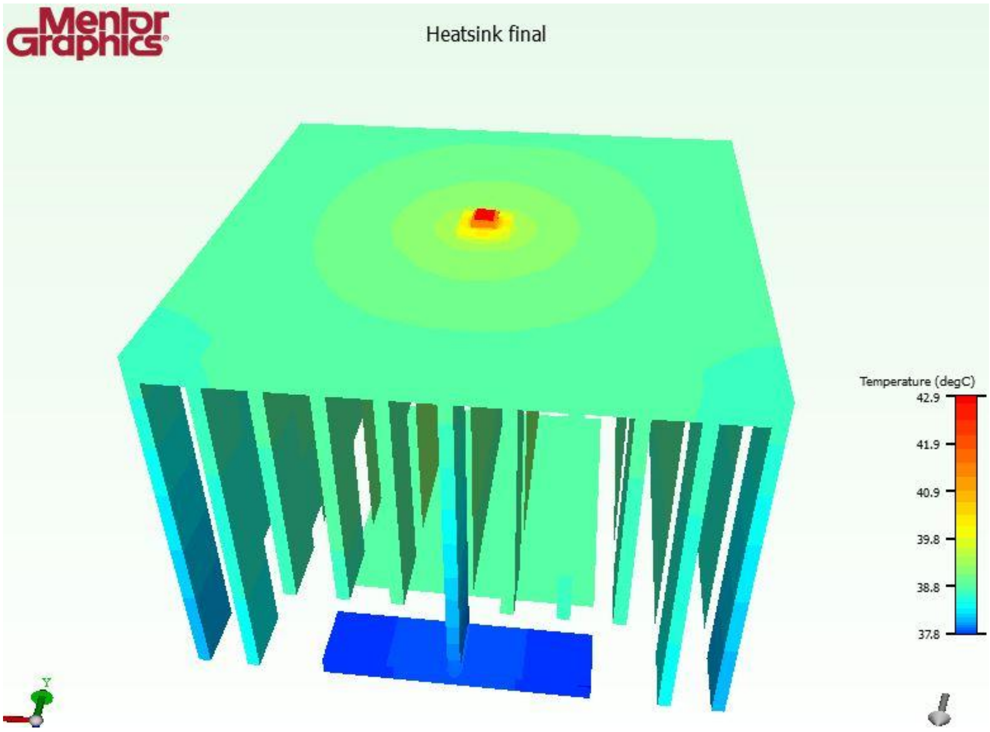


Fig.4.11: Result of 1.5 mm^2 GaN single chip LED package with MCPCB PCB material and ALO for TIM for 1 W

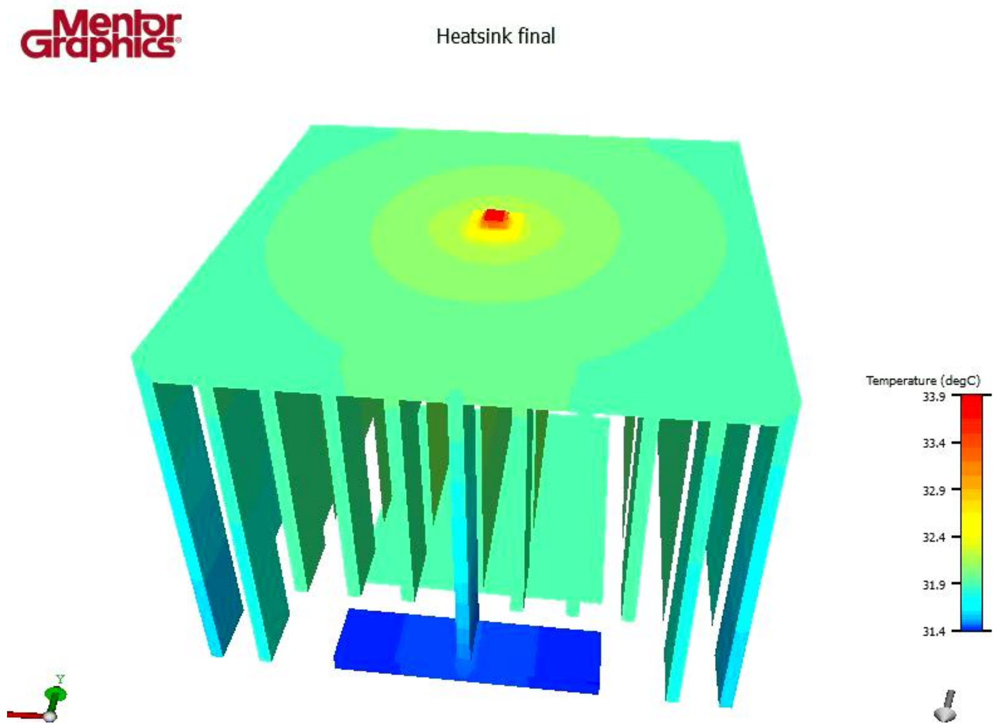


Fig.4.12: Result of 1.5 mm^2 AIN single chip LED package with MCPCB PCB material and ALO for TIM for 0.5 W

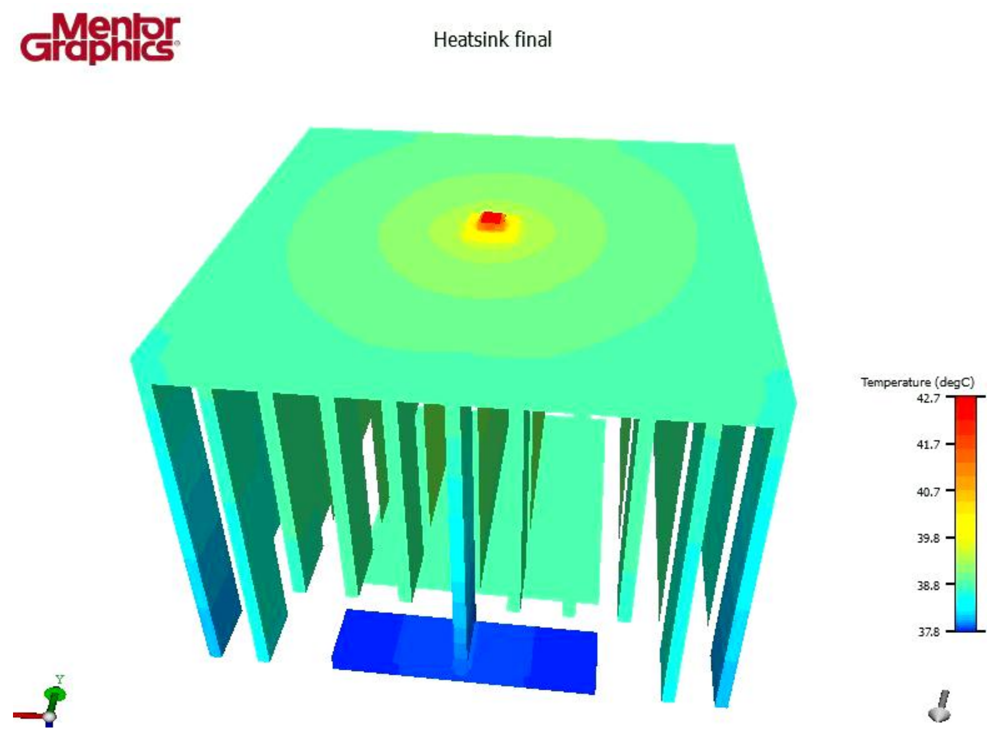


Fig.4.13: Result of 1.5 mm^2 AIN single chip LED package with MCPCB PCB material and ALO for TIM for 1 W

From the result of table 3 and Graph 3, two materials GaN and AIN for LED chip were tested for different chip sizes ranging from 1 to 2 mm^2 and total power ranging from 0.5 to 1 watt. From the comparison at both material, the outcome is almost the same, therefore both material can be adopted. From the comparison at three different sizes, 2 mm^2 outcome a better result than the other two sizes while 1.5 mm^2 perform a similar result as 2 mm^2. From the comparison of two total power of 0.5 W and 1 W for three different sizes, size of 2 mm^2 perform the best result 33.7 ℃ for 0.5 W and 42.4 ℃ for 1 W while 1.5 mm^2 outcome a similar result as 2 mm^2 which are 34 ℃ for 0.5 W and 42.9 ℃ for 1 W.

4.1.3.2 2 LED Chip package

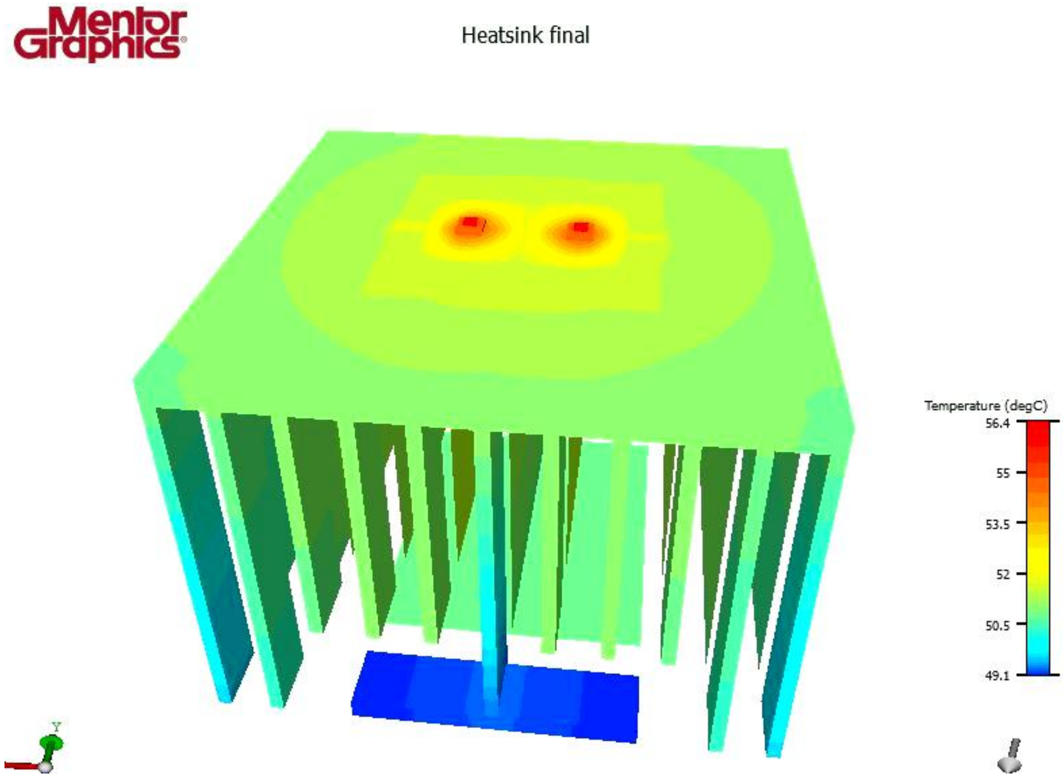


Fig.4.14: Result of 1 mm^2 AIN 2 chip LED package with MCPCB PCB material and ALO for TIM for 2 W

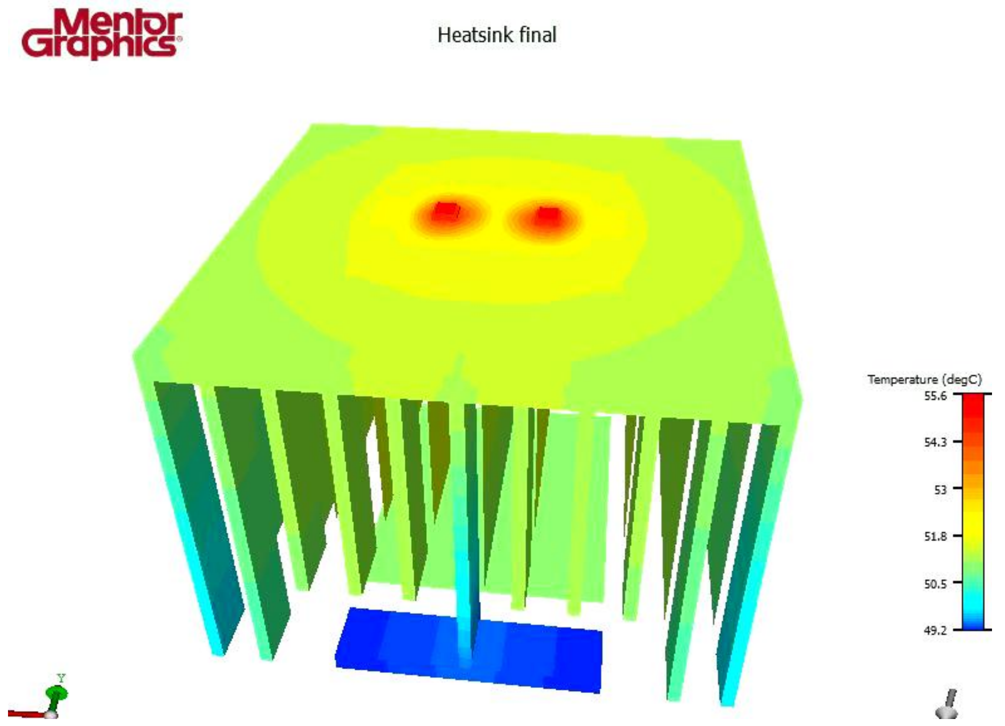


Fig.4.15: Result of 1.5 mm^2 AIN 2 chip LED package with MCPCB PCB material and ALO for TIM for 2 W

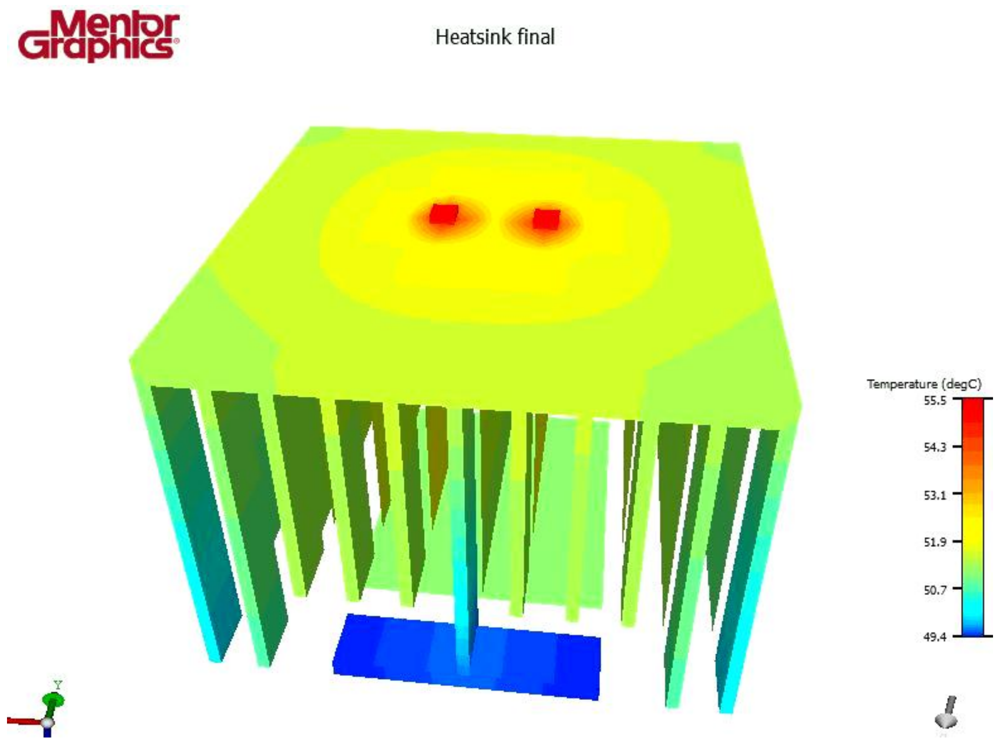


Fig.4.16: Result of 2 mm^2 AIN 2 chip LED package with MCPCB PCB material and ALO for TIM for 2 W

Table.4.4: Result of maximum operating junction temperature of 2 LED chip package for two types of LED chip materials

Chip Materials	Sizes (mm^2)					
	1		1.5		2	
	1 W	2 W	1 W	2 W	1 W	2 W
GaN	41.7	56.5	41.1	55.8	41.2	55.7
AIN	41.4	56.4	41	55.6	41.1	55.5

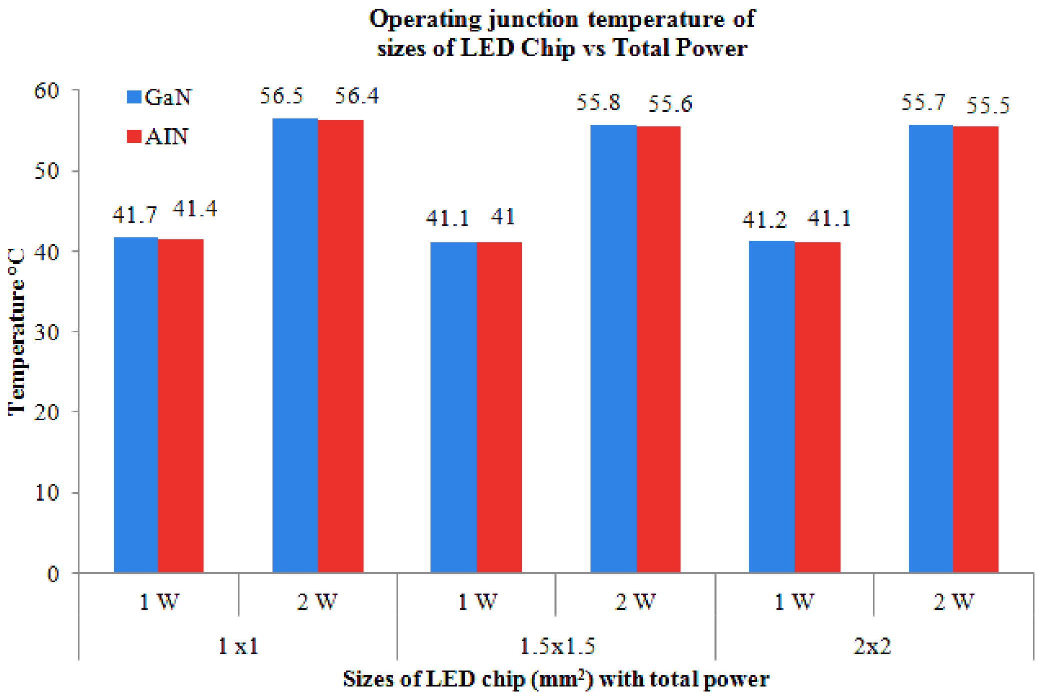


Fig.4.17: Maximum operating junction temperature for 2 LED chip for different dimension (1, 1.5 and 2) mm^2 of heat sink ranging total power from 1W to 2W

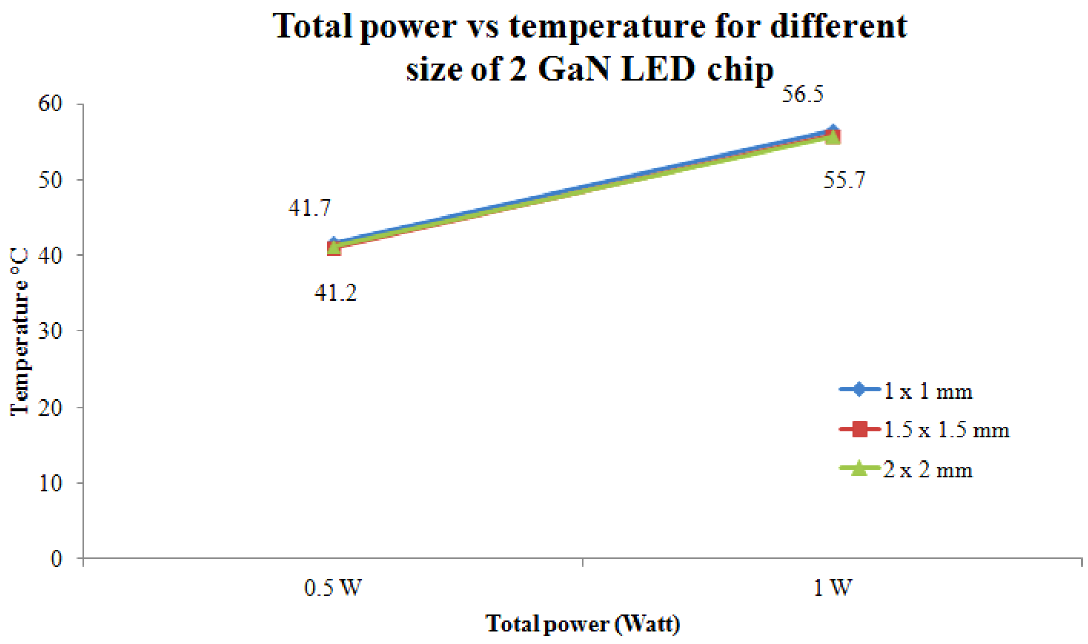


Fig.4.18: Graph of total power vs temperature for different sizes of 2 GaN LED Chip

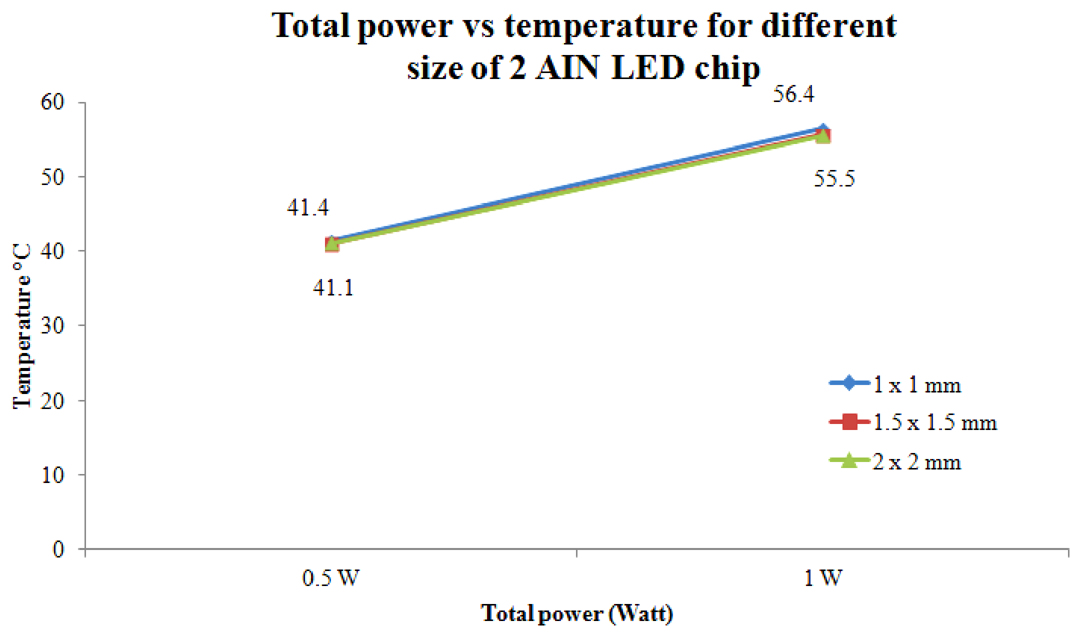


Fig.4.19: Graph of total power vs temperature for different sizes of 2 AlN LED Chip

From the result of table 4 and Graph 4, two materials GaN and AIN for LED chip were tested for different chip sizes ranging from 1 to 2 mm^2 and total power ranging from 1 to 2 watt. From the comparison at both material, the outcome is almost the same, therefore both material can be adopted. From the comparison at three different sizes, 2 mm^2 outcome a similar result as 1.5 mm^2. From the comparison of two total power of 1 W and 2 W for three different sizes, size of 2 mm^2 and 1.5 mm^2 perform the best same result 41.1 ℃ for 1 W and 55.7 ℃ for 2 W while 1 mm^2 perform a similar result of 41.7 ℃ for 1 W and 56.4 ℃ for 2 W.

4.1.3.3 4 LED Chip package

Table.4.5: Result of maximum operating junction temperature of 4 LED chip package for two types of LED chip materials

	Temperature ℃					
Chip Materials	1(mm^2)		1.5(mm^2)		2(mm^2)	
	2 W	4 W	2 W	4 W	2 W	4 W
GaN	54.5	78.9	53.7	77.5	53.7	77.4
AIN	54.2	78.5	53.4	77.4	53.4	77.4

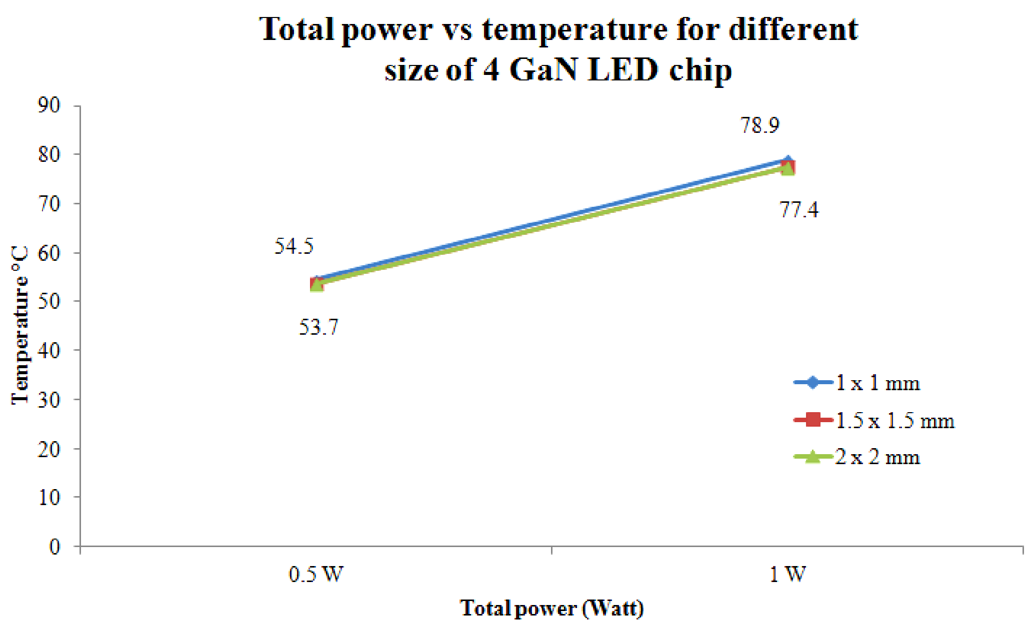


Fig.4.20: Graph of total power vs temperature for different sizes of 4 GaN LED Chip

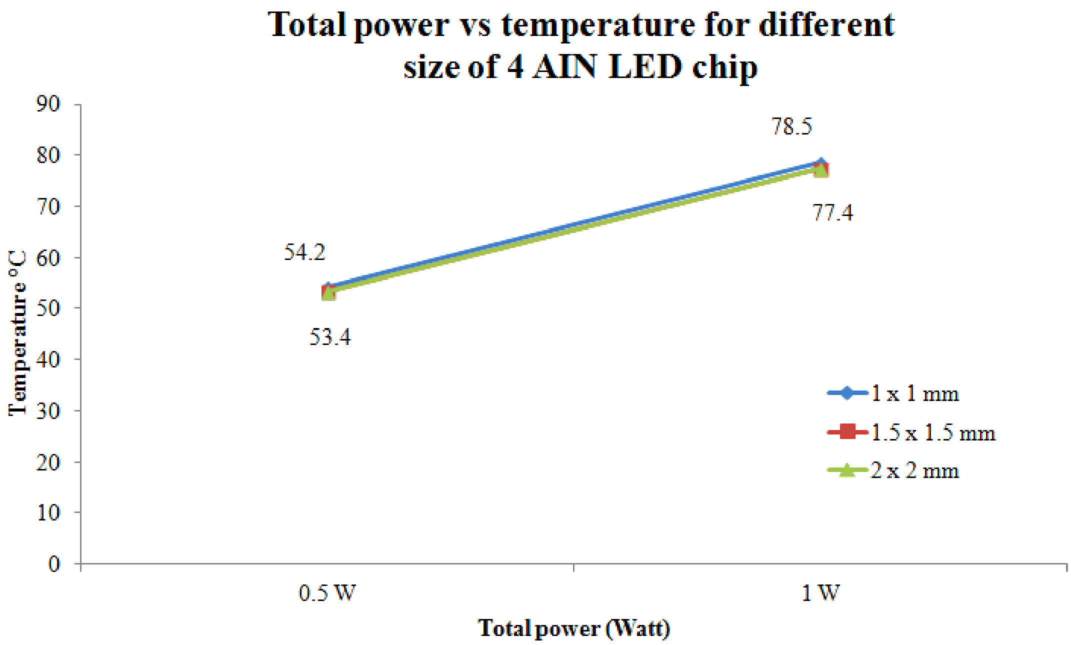


Fig.4.21: Graph of total power vs temperature for different sizes of 4 AIN LED Chip

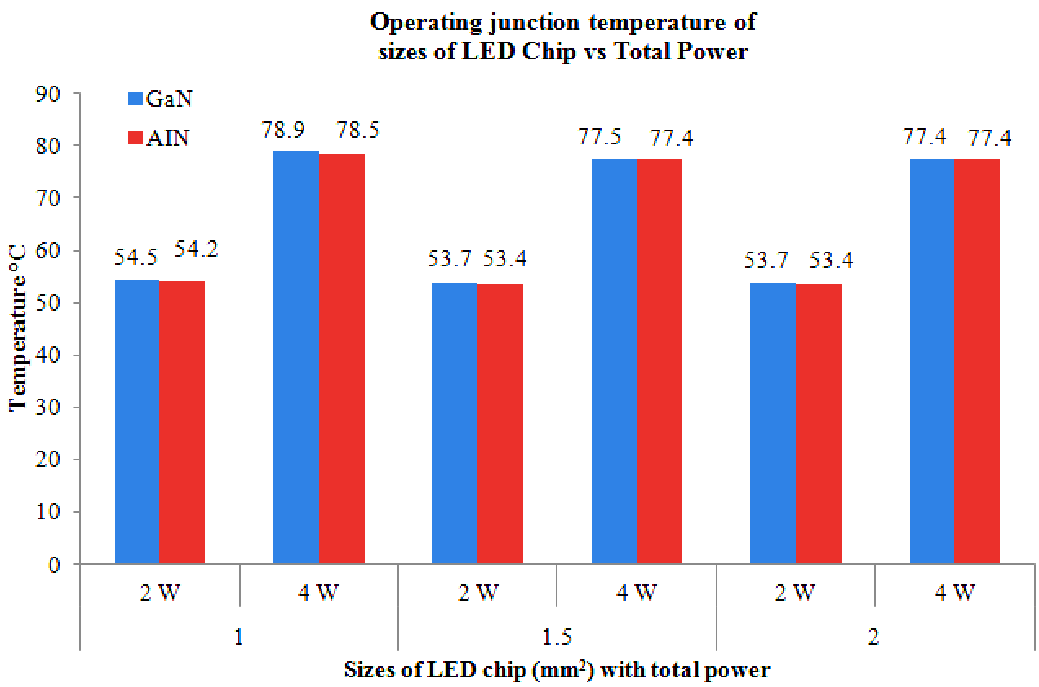


Fig.4.22: Maximum operating junction temperature for 4LED chip for different dimension (1, 1.5 and 2) mm^2 of heat sink ranging total power from 2W to 4W

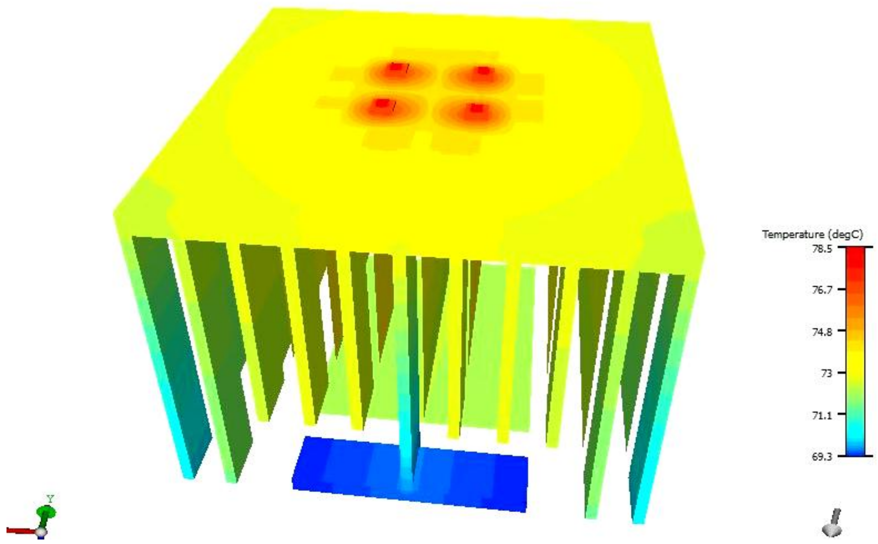


Fig.4.23: Result of 1 mm^2 AIN 4 chip LED package with MCPCB PCB material and ALO for TIM for 4 W 78.5 ℃

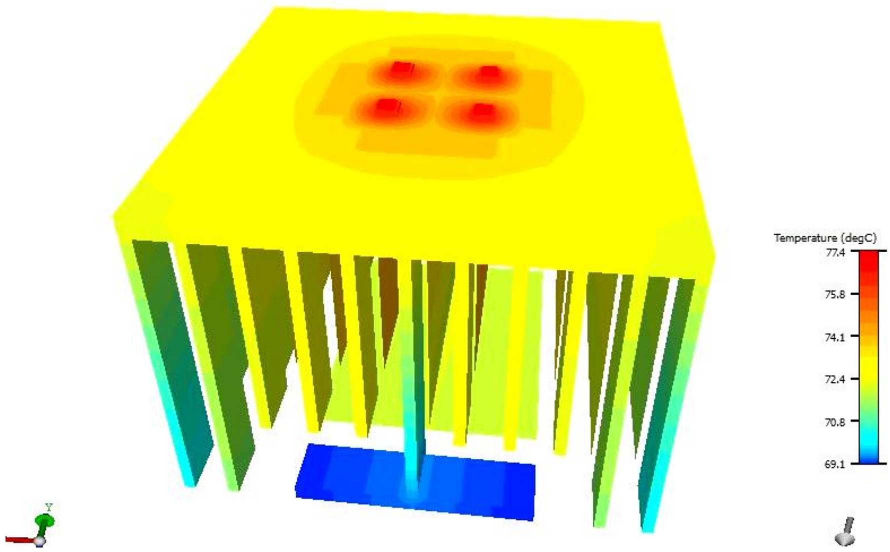


Fig.4.24: Result of 1.5 mm^2 AIN 4 chip LED package with MCPCB PCB material and ALO for TIM for 4 W 77.4 ℃

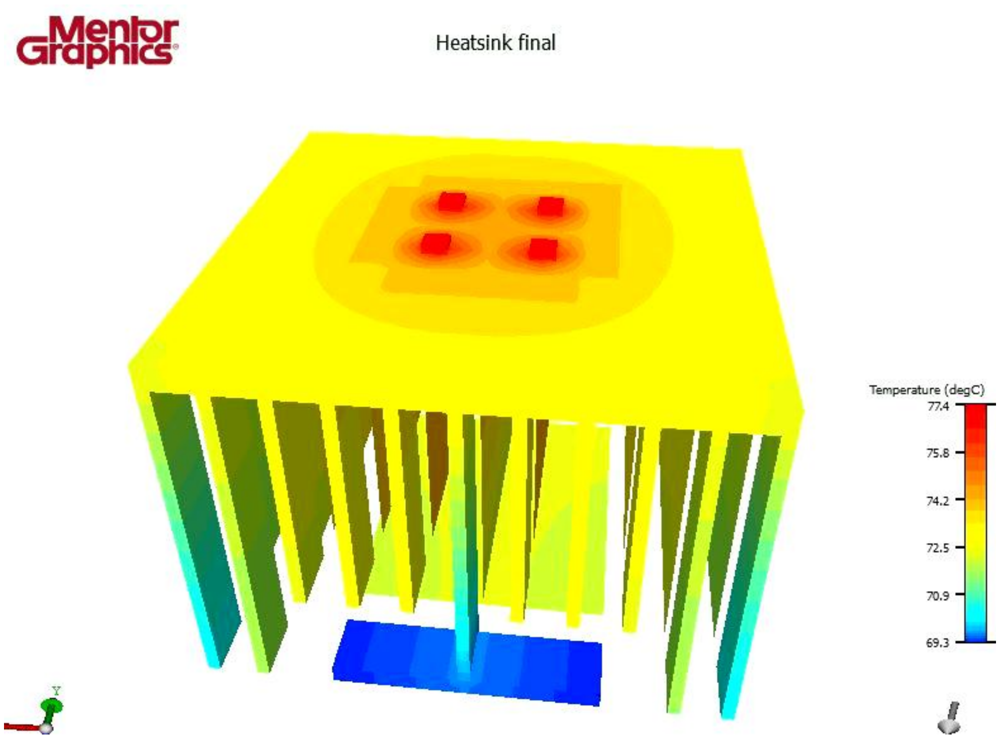


Fig.4.25: Result of 2 mm^2 AIN 4 chip LED package with MCPCB PCB material and ALO for TIM for 4 W 77.4 ℃

From the results, two materials GaN and AIN for LED chip were tested for different chip sizes ranging from 1 to 2 mm^2 and total power ranging from 2 to 4 watt. From the comparison at both material, the outcome is almost the same, therefore both material can be adopted. From the comparison at three different sizes, 2 mm^2 outcome a similar result as 1.5 mm^2. From the comparison of two total power of 2 W and 4 W for three different sizes, size of 2 mm^2 and 1.5 mm^2 perform the best same result for both total power of 53.7 ℃ for 2 W and 77.4 ℃ for 4 W while 1 mm^2 perform a similar result 54.5 ℃ for 2 W and 78.9 ℃ for 4 W with 1 ℃ tolerance.

4.1.4 Heat sink design

Table.4.6: Parametric studies for Heat sink's base thickness 0.15cm

Base thickness	Fin Height	Fin Thickness	Base size 3cm^2	4cm^2	5cm^2
cm	cm	cm	Temperature °C		
0.15	2.56	0.1	47	34.6	34.9
		0.15	50.2	40.1	35.4
		0.2	54	42.7	36.6
	2.76	0.1	46.3	34.2	34.4
		0.15	49.4	39.3	34.8
		0.2	49.2	41.7	35.9
	2.96	0.1	46.8	33.8	33.4
		0.15	49.3	37.6	33.7
		0.2	51.1	39.3	35.4

Table.4.7: Parametric studies for Heat sink's base thickness 0.2cm

Base thickness	Fin Height	Fin Thickness	Base size 3cm^2	4cm^2	5cm^2
cm	cm	cm	Temperature °C		
0.2	2.56	0.1	46.9	34.3	34.7
		0.15	49.9	39.9	35.2
		0.2	51.9	42.5	36.4
	2.76	0.1	46.2	34	34.2
		0.15	49.2	39.1	34.6
		0.2	48.9	41.5	36.1
	2.96	0.1	46.6	33.6	33.2
		0.15	49.1	37.4	33.6
		0.2	55.4	39.1	35.4

Table.4.8: Parametric studies for Heat sink's base thickness 0.25cm

Base thickness	Fin Height	Fin Thickness	Base size		
			$3cm^2$	$4cm^2$	$5cm^2$
cm	cm	cm	Temperature °C		
0.25	2.56	0.1	46.8	34.2	34.6
		0.15	49.9	39.8	35.1
		0.2	53.6	42.4	36.4
	2.76	0.1	46.1	33.9	34.1
		0.15	49.3	39.1	34.5
		0.2	48.9	41.4	36.1
	2.96	0.1	46.6	33.5	33.2
		0.15	48.8	37.4	33.5
		0.2	55.2	39.1	35.3

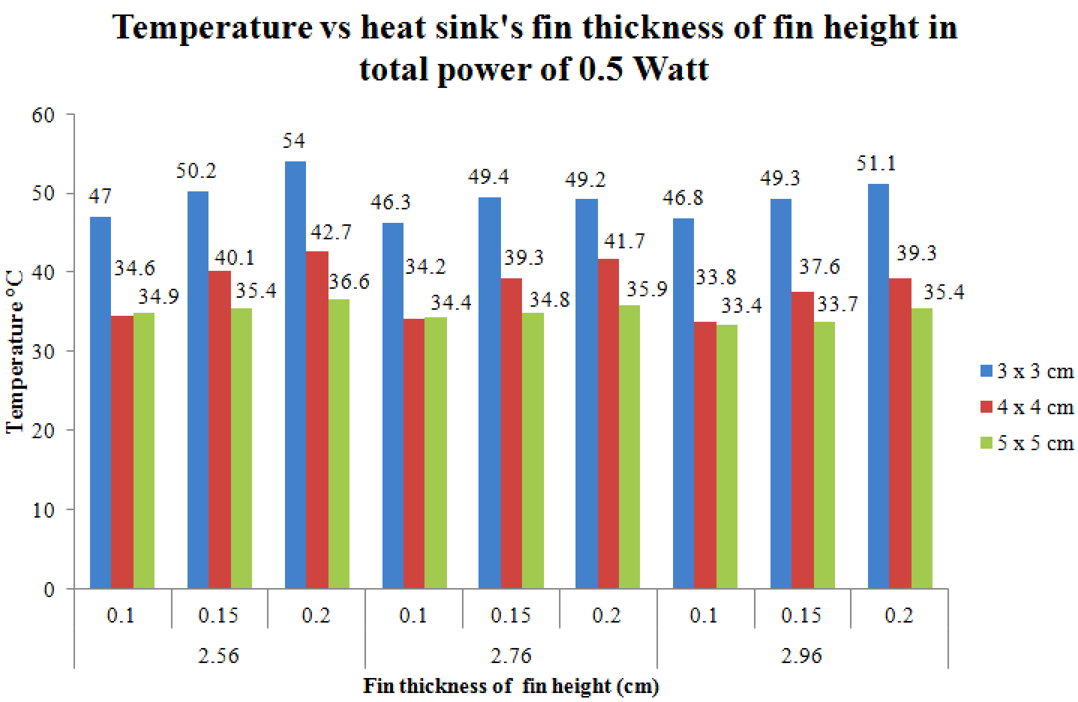


Fig.4.26: Maximum operating junction temperature for single $2mm^2$ LED chip for different heat sink size (3, 4 and 5) cm^2, heat sink's fin thickness and height and heat sink's base thickness 1.5mm of total power 0.5 Watt

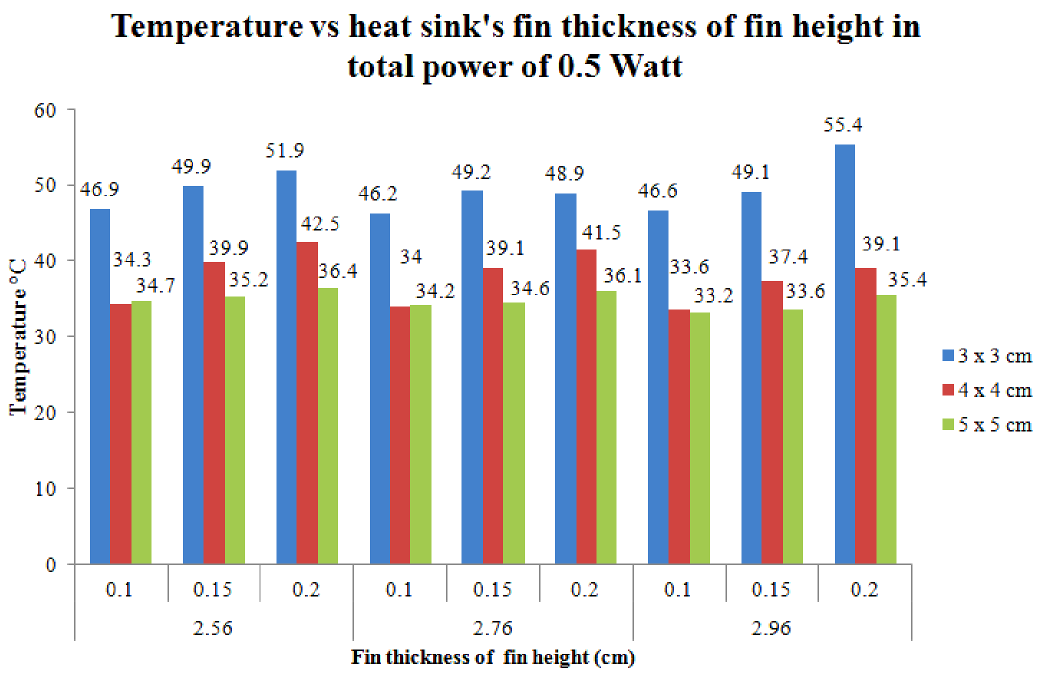


Fig.4.27: Maximum operating junction temperature for single 2mm^2 LED chip for different heat sink size (3, 4 and 5) cm^2, heat sink's fin thickness and height and heat sink's base thickness 2mm of total power 0.5 Watt

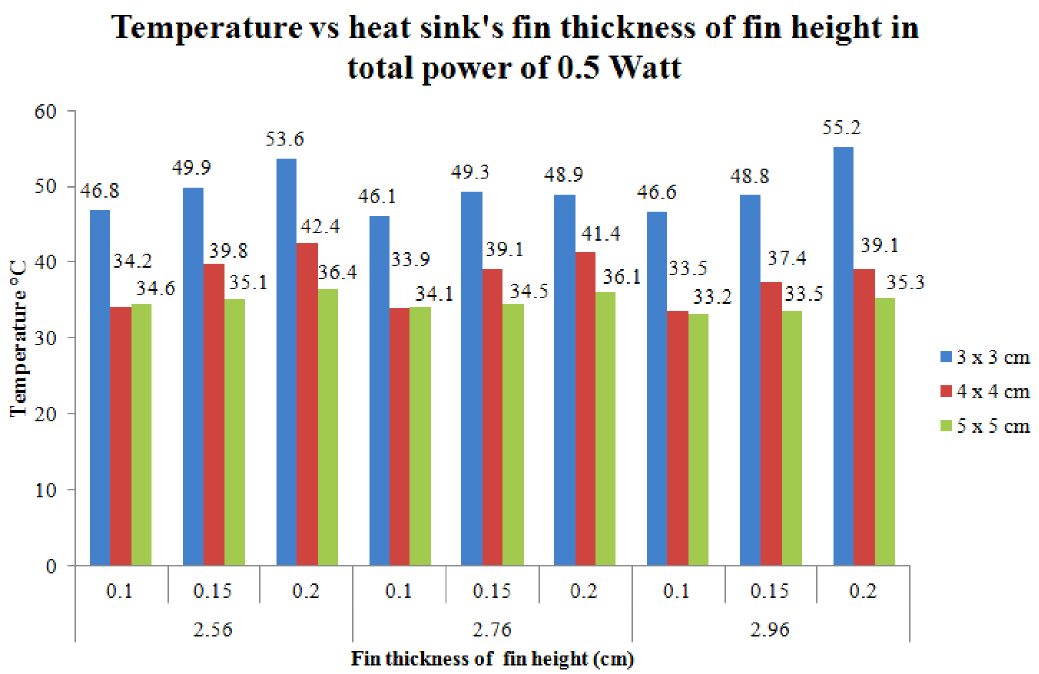


Fig.4.28: Maximum operating junction temperature for single 2mm^2 LED chip for different heat sink size (3, 4 and 5) cm^2, heat sink's fin thickness and height and heat sink's base thickness 2.5mm of total power 0.5 Watt

The result simulation is based on 2mm^2 AIN single LED chip with MCPCB and ALO. Based on the result from table 6,7 and 8, increasing or decreasing the heat sink's base thickness does not affect the temperature. However, the result show a better heat dissipation when increasing the height of heat sink's fin. Next by comparing to the results, the best heat dissipation obtained when the heat sink's fin thickness is 0.1cm. The result proved that when the heat sink's fin thickness increased, the heat dissipation become worse. Besides that, the results also showed that the best heat dissipation when the size of heat sink increased to 5cm^2 . The overall best result obtained 33.2 ℃ when heat sink's fin height is 2.96cm, heat sink's fin thickness is 0.1cm and heat sink's base size is 5cm^2 .

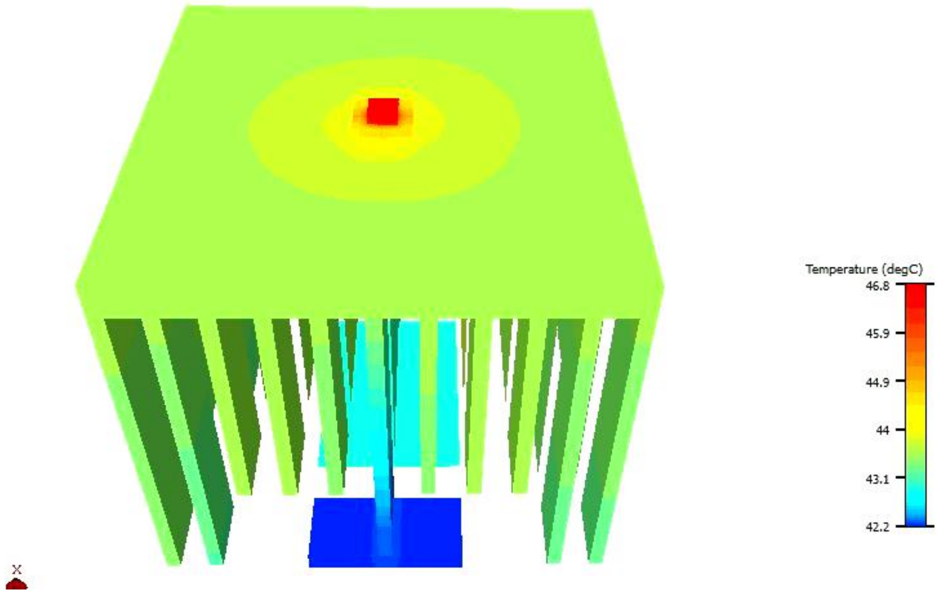


Fig.4.29: Result of 2 mm^2 AIN single chip LED package on 3cm^2, 2.56cm height and 1mm thickness heat sink for 0.5 W 46.8 ℃

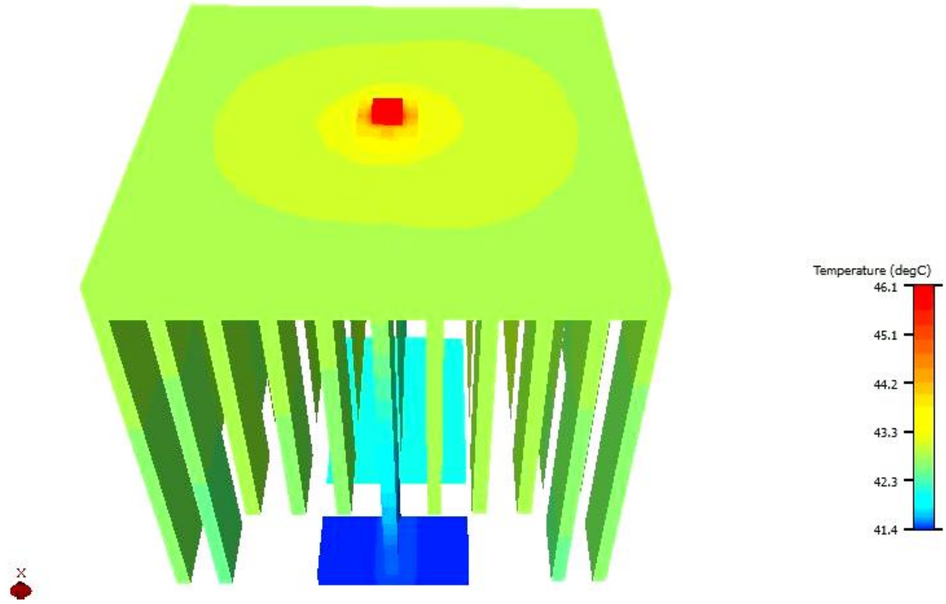


Fig.4.30: Result of 2 mm^2 AIN single chip LED package on 3cm^2, 2.76cm height and 1mm thickness heat sink for 0.5 W 46.1 ℃

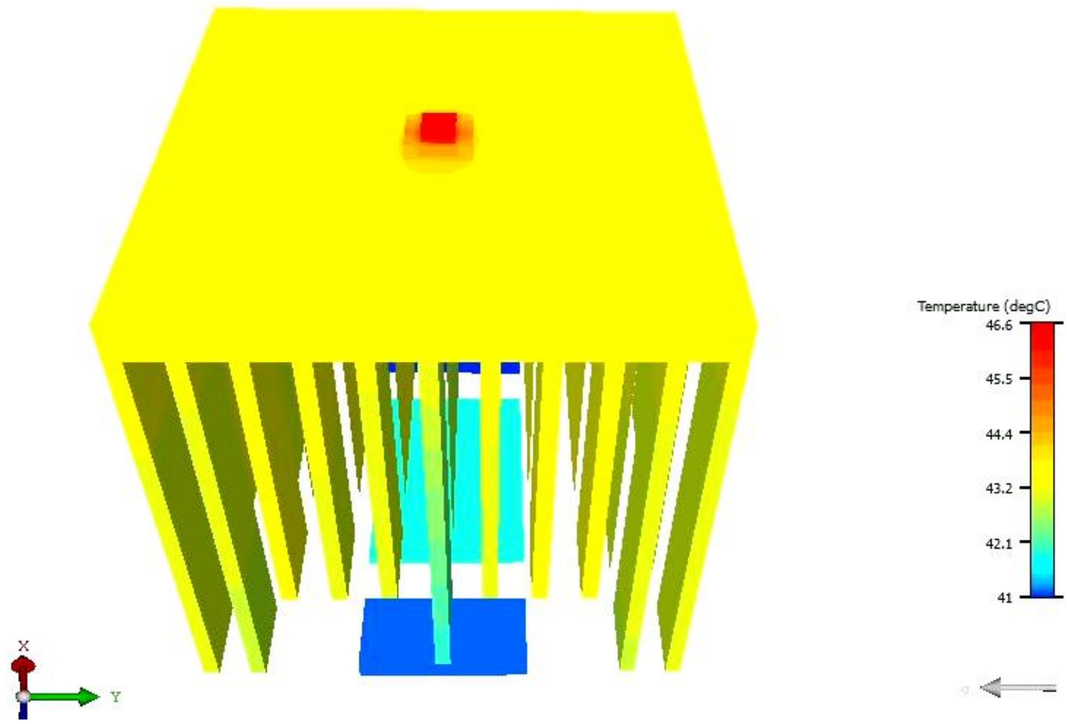


Fig.4.31: Result of 2 mm^2 AIN single chip LED package on 3cm^2, 2.96cm height and 1mm thickness heat sink for 0.5 W 46.6 ℃

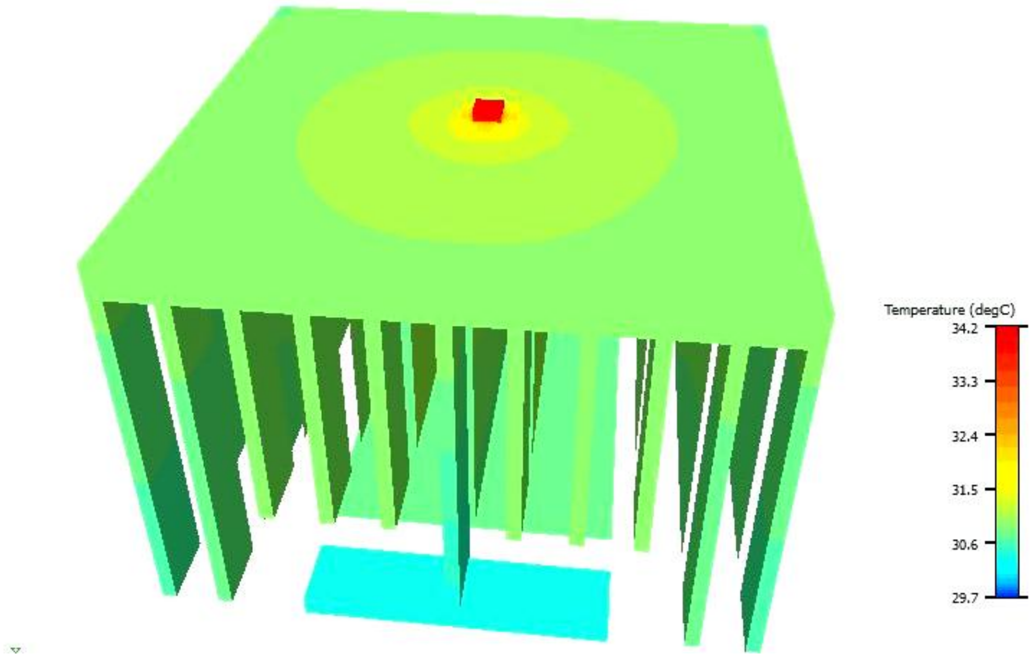


Fig.4.32: Result of 2 mm^2 AIN single chip LED package on $4cm^2$, 2.56cm height and 1mm thickness heat sink for 0.5 W 34.2 ℃

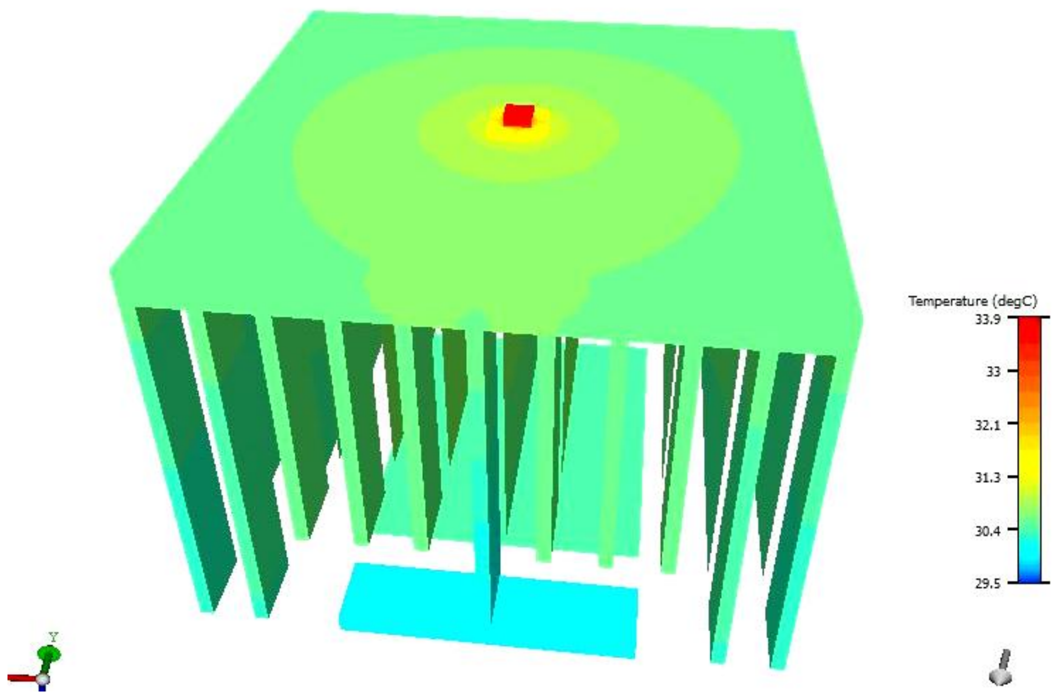


Fig.4.33: Result of 2 mm^2 AIN single chip LED package on $4cm^2$, 2.76cm height and 1mm thickness heat sink for 0.5 W 33.9 ℃

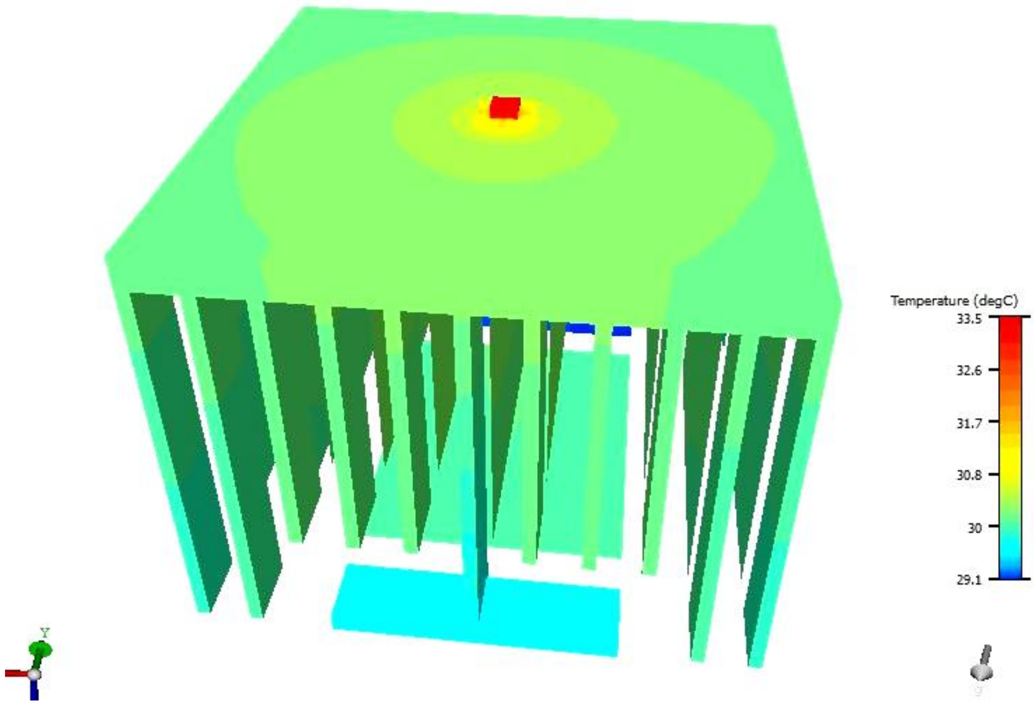


Fig.4.34: Result of 2 mm^2 AIN single chip LED package on 4cm^2, 2.96cm height and 1mm thickness heat sink for 0.5 W 33.5 ℃

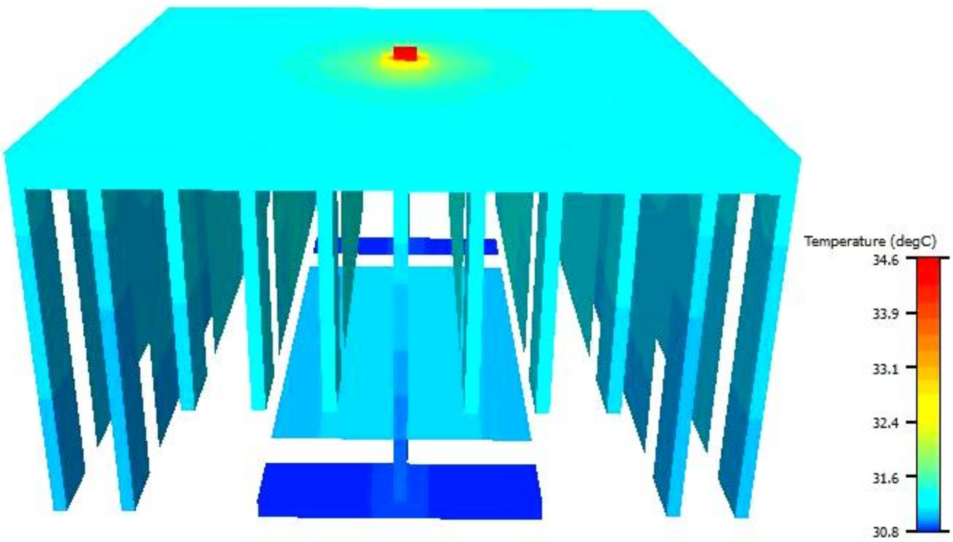


Fig.4.35: Result of 2 mm^2 AIN single chip LED package on 5cm^2, 2.56cm height and 1mm thickness heat sink for 0.5 W 34.6 ℃

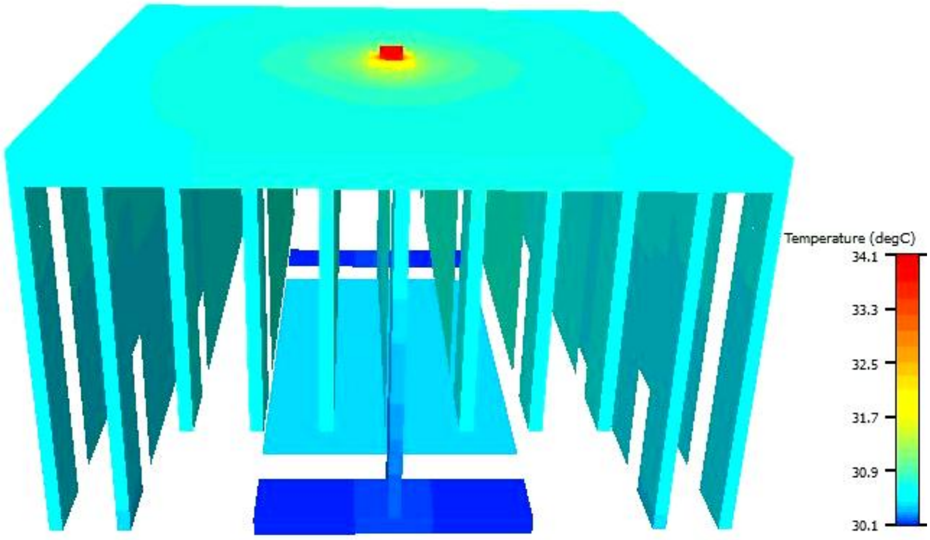


Fig.4.36: Result of 2 mm^2 AIN single chip LED package on $5cm^2$, 2.76cm height and 1mm thickness heat sink for 0.5 W 34.1 ℃

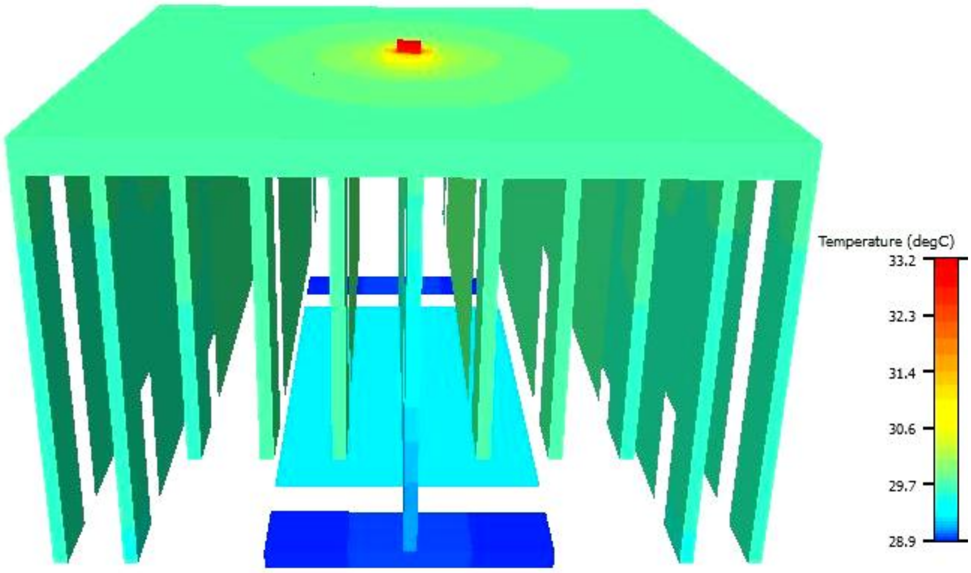


Fig.4.37: Result of 2 mm^2 AIN single chip LED package on $5cm^2$, 2.96cm height and 1mm thickness heat sink for 0.5 W 33.2 ℃

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the research, there are mainly focused on two parts which are LED design and heat sink design. Based on both designs, a parametric studies done to investigate the cooling and heating process of LED modeling.

For the LED design, the simulation result shows that PCB materials FR-4 thermal conductivity of 0.3W/m.K and MCPCB thermal conductivity of 201W/m.K. MCPCB material is the most effective solution for thermal conductivity where FR-4 return 130 ℃ which is incompatible for industrial use because exceeded optimum operating temperature of 90 ℃ while MCPCB return 34.8 ℃ for total power 0.5Watt, single 1mm x 1mm GaN LED chip and ALO TIM material. Therefore, the material of FR-4 for PCB omitted.

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Next, comparison of simulation results for three types of LED chip material for InGaN/GaN, GaP and AIN. For InGaN/GaN material of thermal conductivity of 130 W/m.K, the maximum temperature yield 34.8 ℃; For GaP material of thermal conductivity of 110 W/m.K, the maximum temperature yield 34.9 ℃; For AIN material of thermal conductivity of 285 W/m.K, the maximum temperature yield 34.5 ℃. Thus, AIN is the best material to be used for develop LED chip.

Other than that, among all the Thermal interface materials of grease, ALO, film and tape, ALO is out perform than other materials by 34.8 ℃ while grease achieved 36.6 ℃, film achieved 38.7 ℃ and tape achieved 47.7 ℃. Thus, ALO proved to have better thermal conductivity for heat dissipation, therefore ALO is the best material to be used for develop TIM.

For single chip LED by changing total power in range of 0.5 W to 1 W with LED chip sizes; 1.5mm^2 and 2mm^2 yield a similar result by 33.9 ℃ and 33.7 ℃ for 0.5 W while 42.7 ℃ and 42.4 ℃ for 1 W. For 2 chip LED by changing total power in range of 1 W to 2 W; 1.5mm^2 and 2mm^2 yield a same result by 41 ℃ for 1 W and 55.5 ℃ for 2 W. For 4 chip LED by changing total power in range of 2 W to 4 W, 1.5mm^2 and 2mm^2 yield a same result by 53.4 ℃ for 2 W and 77.4 ℃ for 4 W. This proved that 1.5mm^2 and 2mm^2 yield the best result compared to 1mm^2; Other than that, the overall simulation results is acceptable since the maximum operating junction temperature yield 78.5 ℃ which is under 90 ℃.

For heat sink design, a combinations of sizes of heat sink, heat sink's fin thickness and height and heat sink's base thickness done for parametric studies. From the result and placement of LED chip on heat sink also play an important role for heat dissipation. The best result obtained when LED chip placed exactly closed to the fin of heat sink. Base size of the heat sink is one of the factor that influence the operating junction temperature, compared to the base sizes of 3cm^2 to 5cm^2 by fin height of 2.96cm and fin thickness 1mm, each yield 46.6 ℃, 33.6 ℃ and 33.2 ℃. 5cm^2 yield the better result of 33.2 ℃ while 4cm^2 's result is acceptable since both result is similar.

Next, heat sink's base thickness does not affect much to operating junction temperature however heat sink's fin thickness and fin height does make difference to the temperature. For fin thickness 1mm to 2mm, fin thickness of 1mm yield better thermal dissipation; For fin height of 2.56cm to 2.96cm, fin height of 2.96cm yield the better thermal dissipation. Therefore, combination of heat sink's base size of 5cm^2, fin thickness of 1mm and fin height of 2.96cm yield the best result of 33.2 ℃ among all the results.

5.2 Recommendations

For better thermal spreading or heat dissipation, LED package's material and heat sink design played an important role. Therefore, any combinations of design that varied better thermal conductivity is made into consideration. Table below illustrated all the recommendations to improved heat dissipation for LED package.

Table.5.1: LED package's material recommendation

LED package's layer	Recommendations material	Acceptable
Chip	AIN	GaN/ InGaN
Heat slug	fixed	-
PCB	MCPCB	-
TIM	ALO	Grease

Table.5.2: LED package's size recommendation

LED package's layer	Recommendation size	Acceptable
Chip	$2mm^2$	$1.5mm^2$
Heat slug	Same as chip size	-
PCB	2 times larger than chip size	-
TIM	Same as PCB size	-

Table.5.3: Heat sink's design recommendation

Heat sink	Recommendation size	Acceptable
Size	$5\ cm^2$	$4mm^2$
Base thickness	Any in 1.5 mm to 2.5mm	-
Fin thickness	1mm	1.5mm
Fin height	2.96cm	2.56cm and 2.76cm

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