International Journal of Advanced Technology & Engineering Research (IJATER)
www.ijater.com

HEAT SINK DESIGN FOR HIGH LED POWER APPLICATIONS

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Abstract

This article observes a research on different variations of heat sinks suitable for SMD LED's, which are mounted on a metal core PCB. Heat sinks with different number of fins and made of different materials are observed. Additionally analysis on the factors and the components which have the greatest influence on the transmitting of heat of the construction to the environment has been conducted.

Introduction

It is of critical importance in LED designing how the heat will be dissipated, and how the heat losses should be transmitted as efficiently as possible. Only in this way can provide a lower junction temperature and reliable and stable performance over a long period of time. The control of heat transfer processes in high power LEDs depends of the environmental conditions and current application. In practice there is no universal approach of optimum thermal design. Always heat transfer and management should be tailored to the specific requirements of the entire LED light system [1].

Various types of heat sinks suitable for SMD LEDs with power of 1W, mounted on a metal core boards (MCPCB) are studied from the position of optimum heat dissipation. Simulation tests were performed using CFD (Computational Fluid Dynamics) software Flotherm, which offers tools for predicting heat transfer. By this way thermal impact of heat sink on the design of the LED can be estimated. In result a heat sink to dissipate heat efficiently can be chosen that fit the specific requirements for the final product packaging. Different number of heat sinks and fins made of different materials were tested. Comparisons were made between them and factors and components were analyzed that have the greatest influence on the heat dissipation of the LED structure.

Determining heat sink capability requirement

Before we start planning the thermal management of power LED heat sink working conditions must be taken in consideration such as:

A) The maximum ambient temperature - T_{ambmax}. This temperature depends on the specific operating parameters under which we plan to operate the LED and the specific application, and installation of the final product.

B) Maximum temperature of junction - T_{jmax}. This is the maximum junction temperature at which the LED can operate without occurrence of irreversible changes in the semiconductors, which may lead to damage. However, to ensure reliable and continuous operation, manufacturers usually recommend a lower maximum junction temperature in the catalogue literature. For example, if the catalogue T_{jmax} = 125^{0}C, the recommended operating temperature is 85^{0}C.

C) The maximum power dissipation of the LED - P_{LEDmax}.

The maximum power for each LED can be found by the following equation:

$$P_{LED\max} = I_{f\max} \times U_{f\max} \quad (1)$$

where:

I_{fmax} is the maximum value of the current through the diode in the forward direction;

U_{fmax} is the maximum voltage value in the forward direction, which can run LEDs.

Usually the maximum junction temperature (T_{jmax}), the maximum power dissipation P_{LEDmax}, and maximum values for I_{fmax} and U_{fmax} of LED are given in the catalog data with the specifications of the manufacturer [2]. Other important parameters that are needed for the calculation of the thermal characteristics of LEDs are: the thermal resistance of the junction to case $R_{\theta j\text{-}c}$, the thermal resistance between the junction and the board $R_{\theta j\text{-}pcb}$, when the LED is mounted on a printed circuit board. These parameters are also usually given in the catalog information by the LED manufacturer.

Heat sink design

Usually powerful LEDs are mounted on a metal core PCB (MCPCB) that is attached to the heat sink. Thus heat release from the junction of the LED passes through the MCPCB board, which has good thermal conductivity and reaches the heat sink by conduction. While the heat transfer from the heat sink to the ambient is done by free convection.

The total thermal resistance $R_{\theta j\text{-}a}$ of LED, mounted on MCPCB board with heat sink, can be represented as thermal resistances connected in series between the junction and the solder point to PCB $R_{\theta j\text{-}sp}$, from the solder point to bottom of the board $R_{\theta sp\text{-}pcb}$, from the circuit board to the heat sink

$R_{\theta pcb\text{-}hs}$ and from the heat sink to the environment $R_{\theta hs\text{-}amb}$. Fig. 1 shows a thermal model of LED heat sink [2, 3].

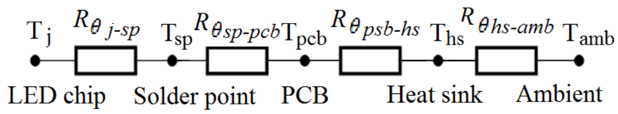


Figure 1. Thermal resistance model of LED with heat sink

Total thermal resistance is expressed by the following equation:

$$R_{\theta j-amb} = R_{\theta j-sp} + R_{\theta sp-pcb} + + R_{\theta pcb-hs} + R_{\theta hs-amb} \quad (2)$$

In the design of the heat sink it is essential to calculate the thermal resistance $R_{\theta hs\text{-}amb}$, which supports the junction temperature below the maximum permissible even under the worst operating conditions. Junction temperature T_j of the LED is given by:

$$T_j = T_{amb} + R_{\theta j-amb} \times P_{LED} \quad (3)$$

where: T_{amb} is ambient temperature; $R_{\theta j\text{-}amb}$ is thermal resistance from junction to the ambient; P_{LED} - is the power scattered by the LED.

The following thermal simulations by CFD software FloTherm are made, aiming to show the effectiveness of the different designs of heat sinks and materials applicable to power SMD LEDs mounted on MCPCB board.

A. Thermal design of the LED system with heat sinks of different materials

The most common LED applications are used heat sinks from aluminum and copper. In most cases the use of aluminum heat sinks it is preferred, because they are easily handled and have a low weight and price of copper. Copper heat sinks are used primarily in powerful LED applications because it has a large coefficient of thermal conductivity and can dissipate heat more efficiently than aluminum. For the manufacture of heat sinks various aluminum or copper alloys with good thermal conduction properties and lower cost are used very often.

For the purposes of this study simulations of powerful white LED model HPA8-44KYx mounted on MCPCB aluminum plate attached to the standard square heat sink were made. The standard square aluminum heat sink is used to evaluate the effectiveness of other materials for making heat sinks - 5052 aluminum, 6061 aluminum, pure copper, brass. Fig. 2 shows the construction of the LED HPA8-44KYx without heat sink, and Fig. 3 shows the structure of the underlying heat sink, which are modelled in Flotherm for the purposes of the study. The LED system that will be heat modelled consists of the following: LED 1W, thermal tape with thermal conductivity 1,2W/m·K to attach the LEDs to the contact plate sites of the MCPCB and heat sink. For thermal modelling of LED compact model is created, where the geometry is simplified and presented as a cube with dimensions 7.9 mm x 7.25 mm x 6.4mm.

Figure 2. View of LED HPA8-44Kyx, 1W on MCPCB

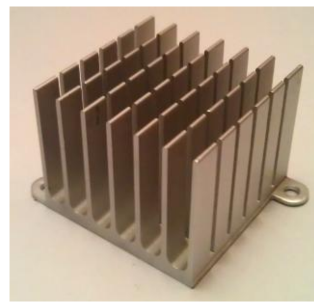


Figure 3. View of Heat Sink

Table 1 describes the details of modeling MCPCB board and thermal conductivity relevant sections taken from the library of Flotherm:

Table 1. Details for modeling of MCPCB

Layer	Thermal Conductivity	Thickness
Aluminum	150 W/m·K	1,6 µm
Dielectric Layer	2,3 W/m·K	100 µm
Copper (Top)	398 W/m·K	50 µm

The geometry and dimensions of the underlying heat sink used to establish the numerical model are shown in Fig. 4(a) and Fig. 4 (b).

The results of the thermal simulation of the LED system with heat sinks of different materials and thermal characteristics used in the simulations are shown in Fig. 5 (a÷e).

All simulations were performed at ambient temperature of 25^0C. In the simulations the thermal conductivity of different materials for a heat sink are taken from the standard Flotherm library.

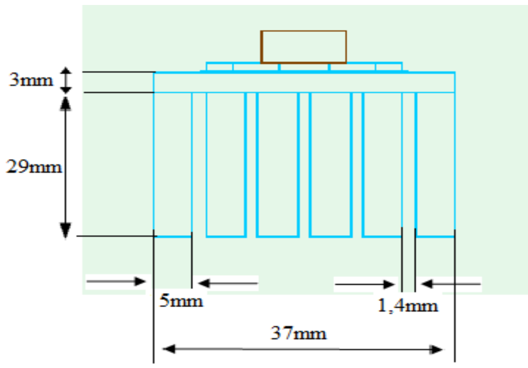


Figure 4(a). The geometry of the heat sink in the Z axis (full face)

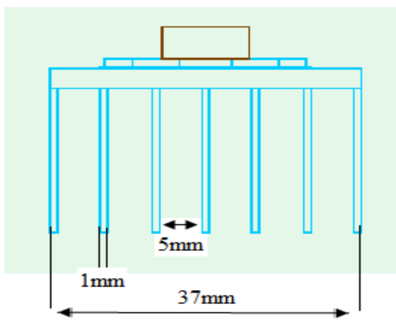
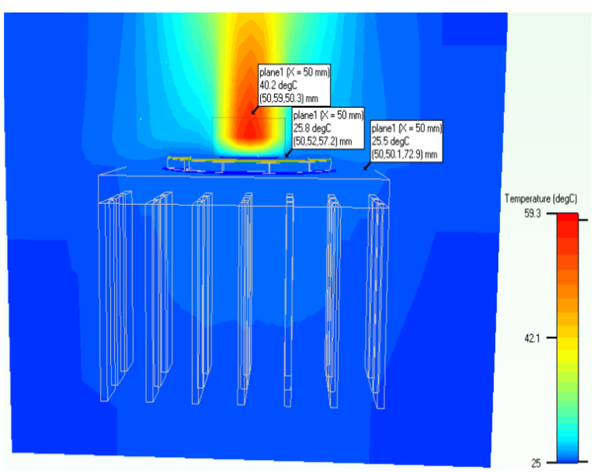
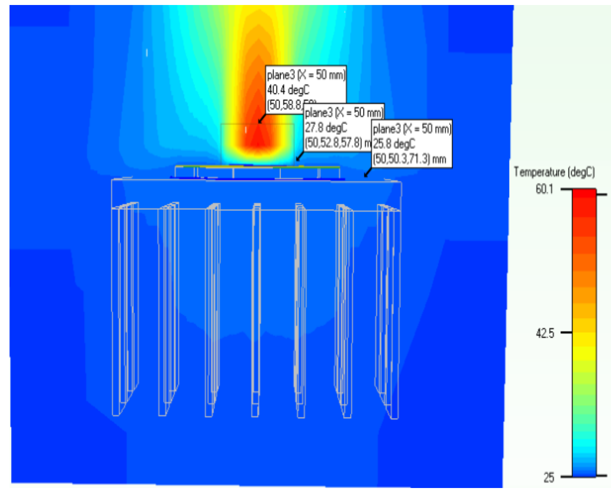


Figure 4(b). The geometry of the heat sink in the Z axis (profile)

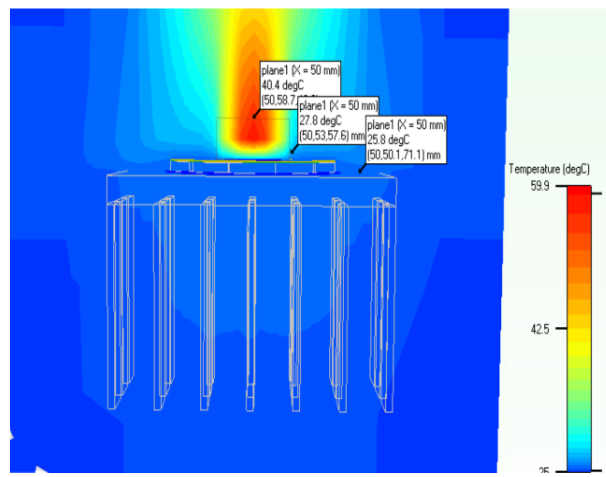
In Fig. 6(a), (b) and (c) are shown graphic results of LED temperature T_{LED}, the temperature at the solder point T_{sp}, the heat sink temperature T_{hs} obtained from simulations for different materials of the heat sink.



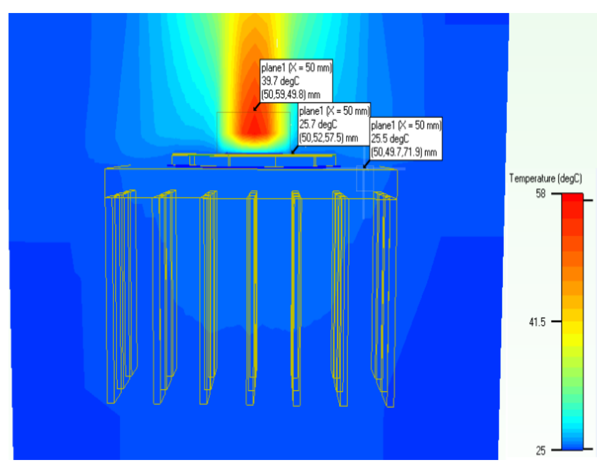
(a) Pure aluminum with Thermal Conductivity of 201 W/m·K



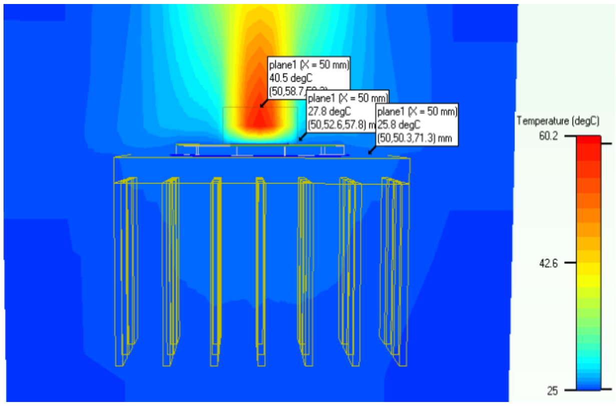
(b) Aluminum - 5052 with Thermal Conductivity of 137 W/m·K



(c) Aluminum - 6061 with Thermal Conductivity of 180 W/m·K

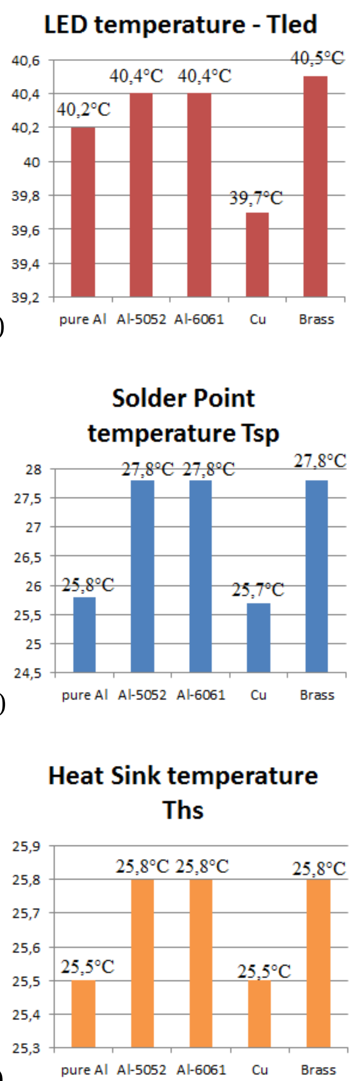


(d) Pure copper with Thermal Conductivity of 385 W/m·K



(e) Brass with Thermal Conductivity of 110 W/m·K

Figure 5. Simulation results of heat sink temperature



(a) (b) (c)

Figure 6. Compared results from the digital temperature simulations

The resulting temperature in the simulations for the LED system reveals that the basic standard pure aluminum heat sink dissipates heat very well. The temperatures obtained for aluminum alloys - aluminum 5052 and 6061 aluminum demonstrate that heat is dissipated with the same efficiency, although the 6061 aluminum has a high thermal conductivity of 180W/m·K, and in the case of aluminum 5052 is 137W/m·K. When the heat sink is made of copper low temperatures are observed in all parts of the LED system. This result is expected since copper has the highest value of thermal conductivity of 385W/m·K. Simulations show that the brass heat sink dissipates heat from the LED structure the least. In this case the highest temperature of LEDs on all studied cases is observed.

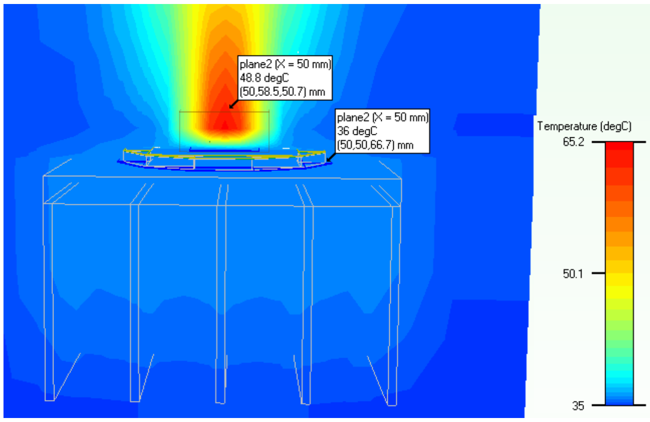
B. Thermal design of the LED system with heat sink with different structure and number of fins

The thermal efficiency of the heat sink depends on its design and size. Other factors that influence its effectiveness are the number of fins and the distance between them. Fins should have a shape and a number that does not impede air circulation. If air circulation is poor heat is retained by heat sink [4].

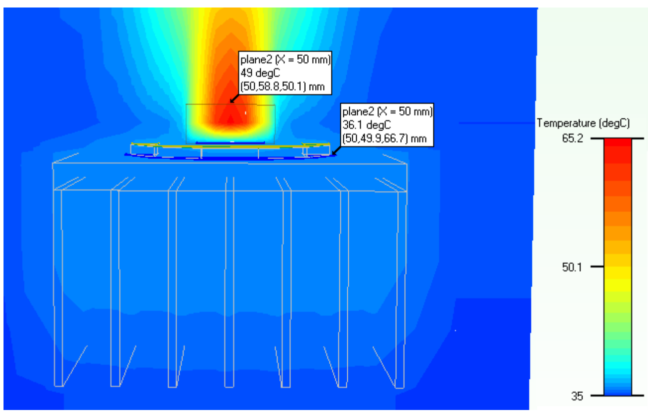
For the purposes of this study simulations were made and a digital model of the LED mounted on MCPCB was created, as well as different types of structures of heat sinks according to the type and number of fins was studied. There are studied the two main types of heat sinks: with flat fins and with fins - pins. In the simulations a heat sink of pure aluminum is used. Its dimensions are 37mm x 37mm x 3mm. Each fin is 29 mm high. The results from the simulations of a heat sink with a different numbers of fins are shown in Fig. 7, of heat sink with fins - pins arranged in a line is shown in Fig. 8 (a), and a heat sink with fins - pins in a staggered arrangement - in Fig. 8 (b).

All simulations are made at an ambient temperature of 35^0C. The results of the simulations of a heat sink with flat fins show that the temperature of the LED system is the lowest at the marked points (LED - $38,8^0$C and MCPCB board - 36^0C) in the case of five fins. By increasing the number of fins a rise in the temperature of the LED structure was observed, as the higher temperature is in the case of 12 plate fins (LED temperature - $39,2^0$C and MCPCB circuit board temperature - $36,2^0$C).

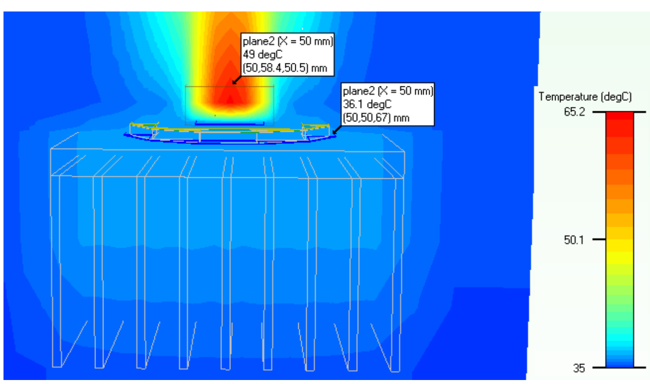
The shown thermal simulations indicate (on Fig. 8 (a)) that the heat sink with 16 pins has the lowest temperature at the marked points (LED - $38,8^0$C and MCPCB board - 36^0C) and has optimal thermal design in the case of heat sink with fins - pins arranged in a line. It is noteworthy that in the case with 9 pin, the temperature is lower than in the case of 20 and 24 pins.



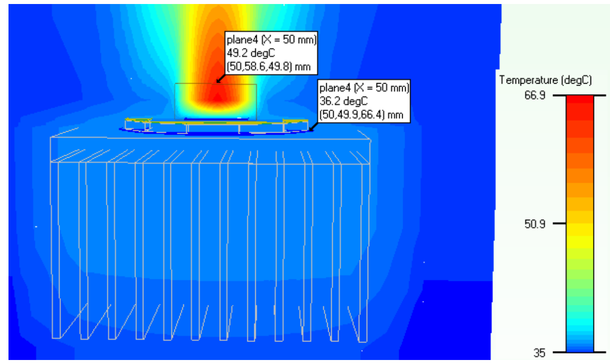
5 flat fin



7 flat fin

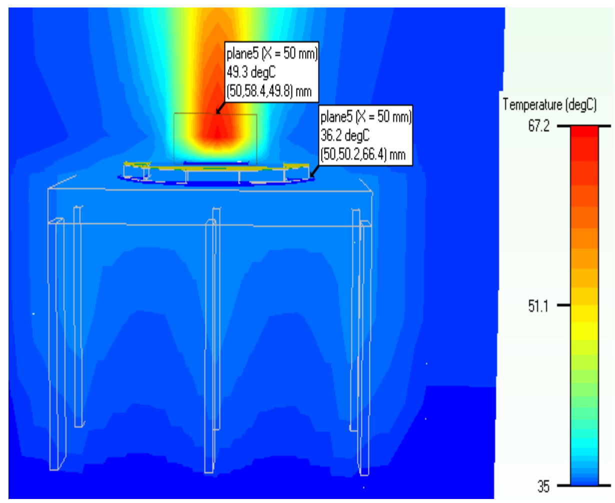


9 flat fin

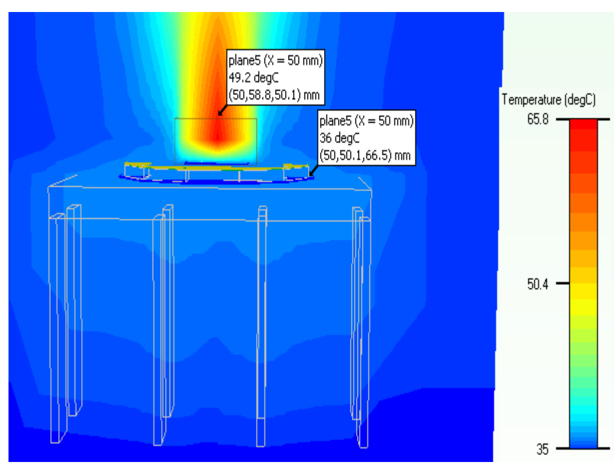


12 flat fin

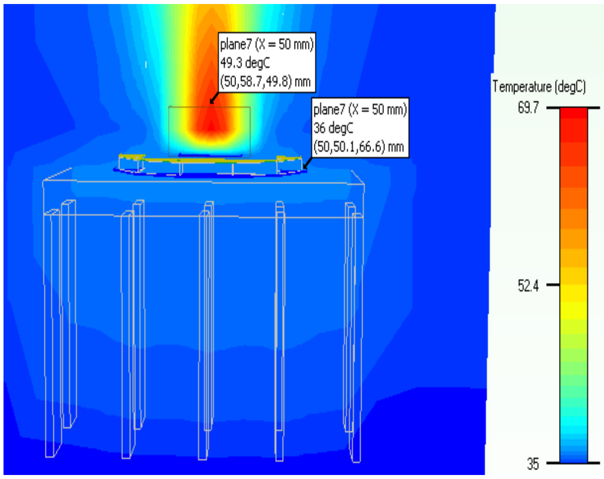
Figure 7. Results of thermal simulations heat sink with a different number of plate fins



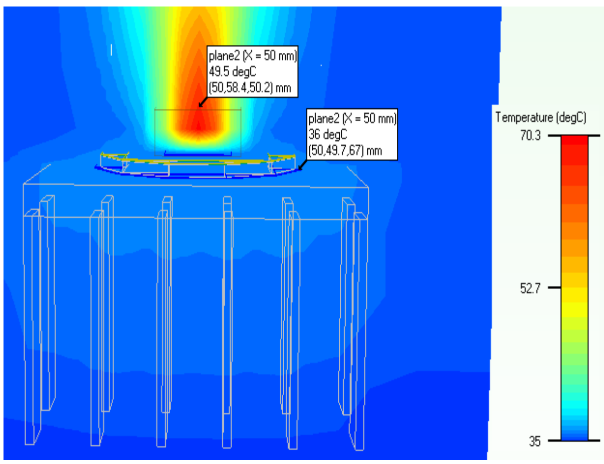
9 fin - pins



16 fin - pins

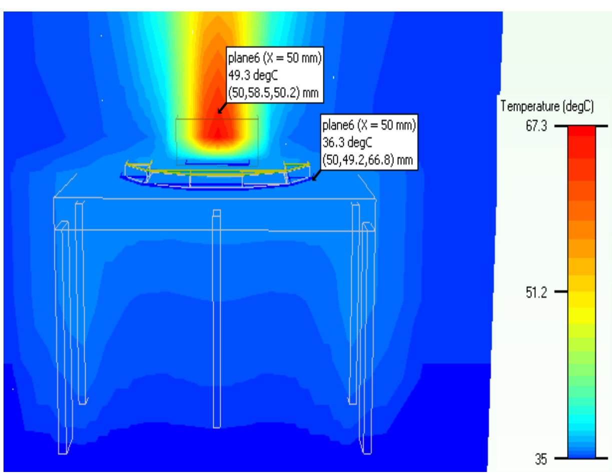


20 fin - pins

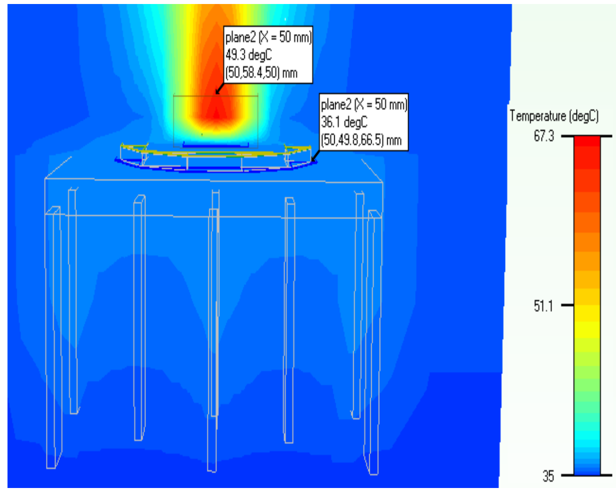


24 fin - pins

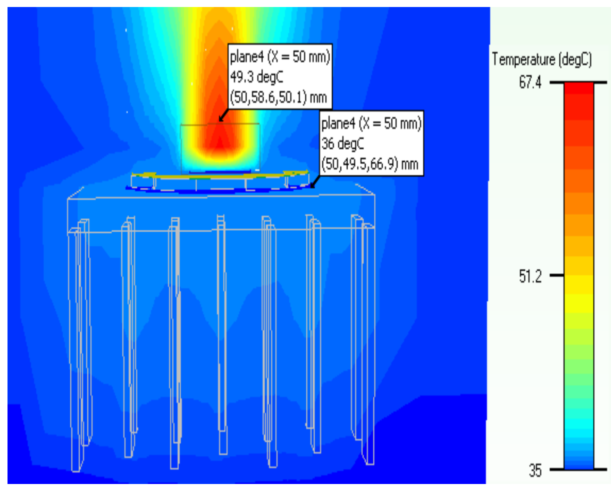
Figure 8(a). Results from simulations of heat sink with fins - pins arranged in a line



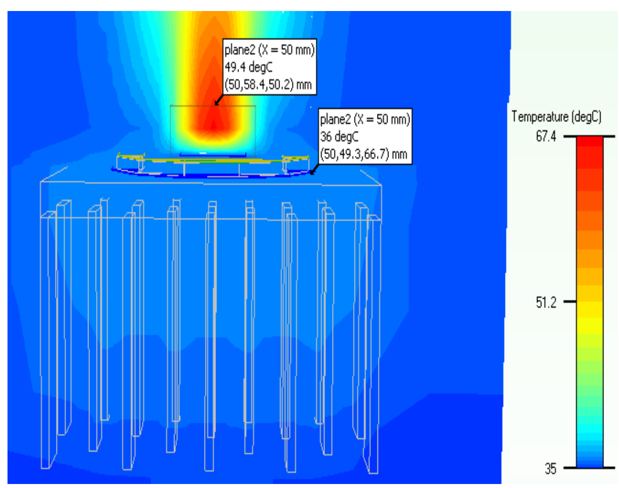
6 fin - pins



13 fin - pins



25 fin - pins



32 fin - pins

Figure 8(b). Results from simulations of heat sink with fins - pins staggered

Heat simulations are made for a heat sink with staggered pins (Fig. 8 (b)). They show that the heat sink with 25 pins has the lowest temperature at the marked points (LED - 49,3^{0}C and MCPCB board - 36^{0}C). In the heat sink with 6 pin and the 13 pin, it is occurs very similar thermal behavior, despite the large difference in the number of fins. The heat sink with 32 staggered pins dissipates heat very well, but the temperature of the LED increases to 49.4^{0}C.

Conclusions

The computational experiments with heat sink of different materials show that all tested samples of copper heat sink have low temperatures and therefore dissipate heat best. This is due to the great thermal conductivity of copper. Therefore that makes copper heat sinks very suitable for high-power LED applications. Pure aluminum heat sink shows temperatures very close to those of the copper heat sink. It has a high thermal conductivity and is easily handled and has a cost lower than that of copper, which makes it an optimal choice for material for the heat sink. Aluminum alloys aluminum 5052 and aluminum 6061 show higher temperatures and have similar thermal behaviour. They have the advantages of aluminum as easy handling and low cost and therefore are suitable for LED applications with low power. Further optimization of the design of the heat sink as size, number and type of fins can improve significantly the heat exchange.
Brass heat sink has the highest temperatures in the simulations, which makes this material an unsuitable choice for heat sink for power LED applications.

The results from thermal simulations of heat sinks of different design and number of fins show that the optimal number of flat fins of the heat sink is 7. By increasing the number of fins the temperature of the LED system increases, although increasing the number of fins increase the surface area of the heat sink. Thus the air flow around the fins can be reduced and the heat sink cannot dissipate heat.
Simulations of a heat sink with fins - pins arranged in a line show similar thermal behavior. The optimum heat sink design is a variant with 16 pins, while by increasing the number of pins the temperature begins to rise. Thermal simulations of heat sink with fins - pins staggered show that increasing the number of pins from 6 to 32 leads to no increase in the temperature of the LED system. This is due to the greater void space between the pins, which improves airflow and helps to improve the heat dissipation from the heat sink.

Acknowledgments

This work was supported by the NIS-TUS under Grant Projects 142PD0057-03.

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