Thermal Management of Golden DRAGON® LED

Application Note

Introduction

The Golden DRAGON® Package is the newest member of the OSRAM SMT package family. The Golden DRAGON® LED consists of a leadframe with integrated heat spreader and a thermoplastic body. The chip is mounted in a reflector formed by the thermoplastic. In order to dissipate the heat the package has an additional thermal connection. This connection is soldered to a thermal enhanced PCB, on the backside of the housing. Therefore the Golden DRAGON® package is suitable for high power dissipations in the range of 1 W. In order to achieve reliability and optimal performance a proper thermal management design is absolutely necessary. Like all electronic components, the Golden DRAGON® LED's have thermal limitations. The allowed operation temperature for the specific lifetime is limited by the glass-point of the LED resin. This means that the temperature of the die inside, doesn't have to exceed this value when exposed to the expected operation temperature. This brief will give the design engineer an introduction in the thermal basic of Golden DRAGON® LED's. Furthermore some concepts are shown in order to improve the thermal design.

Explanation of Basic Relationships

The power dissipation P_D on the junction of a chip is distributed in the package and in the substrate by means of heat conduction, and from the free surfaces to the environment by means of radiation and convection. "Junction" refers to the p-n junction within the semiconductor die. This is the region of the chip where the photons are generated.

To facilitate discussion of the static properties of the Golden DRAGON® LED, the internal structure and its method of mounting on the substrate is illustrated in figure 1.

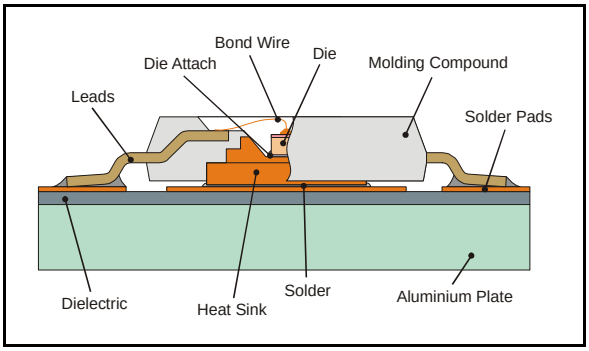


Figure 1: Internal Structure of Golden DRAGON LED Package

The Golden DRAGON® LED consists of a chip mounted on a chip carrier (heat spreader) by solder or bonding adhesive. The heat spreader consists of a high-conductivity material such as copper.

The associated static equivalent circuit diagram is shown in figure 2. The following analogies with electrical quantities have been used:

- The power dissipation P_D occurring close to the chip surface is symbolised by a current source.
- The "resistance network" is essentially a serial connection to the ambient temperature. As a first approximation, the parallel-connected thermal resistance of the plastic housing can be neglected.
- The ambient temperature T_a is represented by a voltage source.

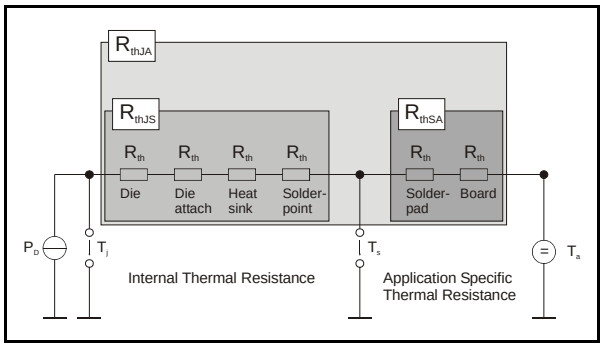


Figure 2: Static Equivalent Circuit

In accordance with the analogy, the thermal current P_D = Q/t can now be calculated from the "thermic Ohm´s law".

$$U = I \cdot R \text{ as } T_j - T_a = P_D \cdot R_{thJA}$$

Equation 1

For the purpose in application, the junction temperature T_j is of practical interest.

$$T_j = R_{thJA} \cdot P_D + T_a$$

Equation 2

The total thermal resistance R_{thJA} of these package can be further broken down into two contribution levels of the heat transfer path from a component's junction to it's ultimate environment.

At the Golden DRAGON® component level the internal thermal resistance exists between the junction and exposed side of the internal heat spreader. This resistor value is given by the package construction e.g. geometry, used material and chip size. In the case of Golden DRAGON® LED this resistor value refers to the thermal resistance junction to solder point R_{thJS} in the datasheet. The solder point temperature is defined as the temperature of the solder joint under the heat spreader.

The external level resistance is the application specific resistance to the heat that flows from the internal heat spreader to the surrounding environment. This thermal resistance value can be divided into the thermal resistance solder point to board R_{thSB} considering the heat transfer through the printed circuit board and the thermal resistance board to ambient R_{thBA} considering the heat transfer to the surrounding fluid. The thermal resistance R_{thSB} is strongly influenced by various factors e.g. solder pad design, component placement, printed board material and board construction. The R_{thBA} characterize the heat transfer to ambient, e.g. external heat sinks.

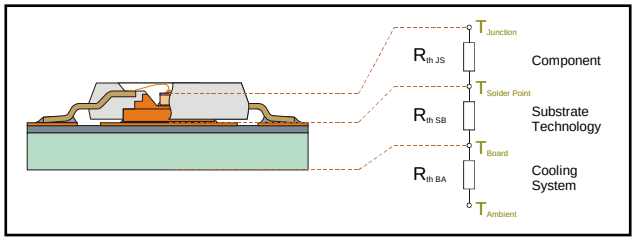


Figure 3: Resistances Series Configuration

These thermal resistances are in a series configuration (figure 3).

$$R_{thJA} = R_{thJS} + R_{thSB} + R_{thBA}$$

Equation 3

The values for the R_{thJS} can be found in the specific datasheet of the Golden DRAGON® LED and are fixed by the package design. The values of R_{thJS} were determined with consideration of the emitted optical power, and represent thus the real thermal resistance of the Golden DRAGON®.

There is a wide range of application systems in which Golden DRAGON® LED Packages can be used.

Summarise the explanations; in general thermal management can be divided into internal thermal management and external thermal management. Internal thermal management handles the thermal resistance from junction to the package case and external thermal management handles from the package case to the ambient. In this

case the external thermal management plays a significant role. External thermal manage includes the selection of the cooling mode, heat sink design, selection of substrate material and attachment process.

After the cooling mode is determined, the cooling system can be designed. The thermal resistances R_{thSB} and R_{thBA} have to be optimised for the application.

In general the junction temperature of the Golden DRAGON® LED temperature must be maintained below the maximum allowable limits mentioned in the specific datasheet of the Golden DRAGON® LED.

Thermal Resistance (Solder Point to Board): Substrate Technologies

To ensure the best efficiency and good thermal management the thermal resistance solder point to ambient has to be optimised. The used PCB technology plays a significant role. Nowadays in addition to the standard substrate, such as FR4 PCB material, thermal enhanced substrate technologies can be found. This chapter will focus on MCPCB (metal core printed circuit board), flexible PCB laminated on aluminium and enhanced FR4 PCB glued on aluminium.

For the use with the Golden DRAGON® LED it is necessary to choose the right technology that is able to fulfil the thermal requirements.

In order to show the thermal performance of these substrate technologies the method of numerical analysis is used. All the results based on a CFD[1]-Analysis with the following conditions. The goal of the analysis is a comparison under the same environmental conditions. Therefore a relative temperature scale is used in the illustrations.

- A geometry model of the entire configuration is created from the design drawings for the Golden DRAGON® LED package and the geometry data of the test board and its metallization. The geometric and material data as well as the standard boundary conditions are listed in the following table.

Component	Golden DRAGON® LED
Outer PCB Dimensions L x W	25 x 25 mm²
Board Material	FR4 on Aluminium MCPCB FPC on Aluminium
Material for Solder Pads	35 µm Cu
Power Dissipation	1 W
Reference temperature	25 °C

- In the analysis model the recommended solder pad layout is considered.
- The board is in thermal contact with a cold plate with reference temperature of 25 °C. No contact resistances are considered.
- In the thermal analysis only heat transfer through conduction is considered.
- Unless expressly stated, the steady state calculations are always performed with a fixed power dissipation of 1 W. Other heat sources, e.g. resistors, voltage regulators etc., are not considered in the analysis.

[1] **C**omputational **F**luid **D**ynamics

- The simulation results are valid under the mentioned boundary conditions.
- The Golden DRAGON® LED is soldered to the printed circuit board.

The thermal model can be seen in the following figures.

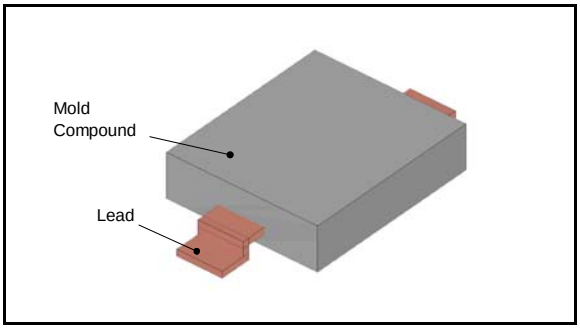


Figure 4: Thermal Model of Golden DRAGON® LED

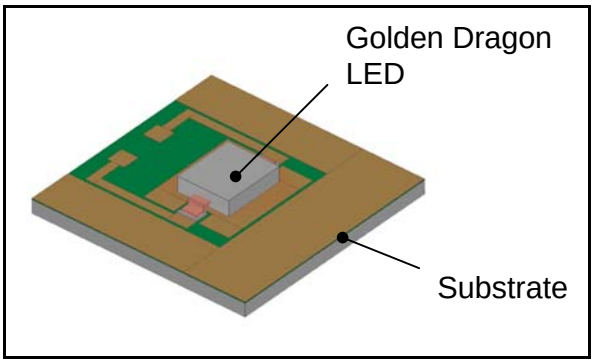


Figure 5: Thermal Model of Assembly

Metal Core Printed Circuit Board

MCPCB are those boards which incorporate a base metal material as heat spreader as an integral part of the circuit board. Single Layer MCPCB provides a very thermally conductive base material for heat spreading. Furthermore MCPCB can take advantage of a high thermal conductivity of the dielectric polymer layer (figure 6).

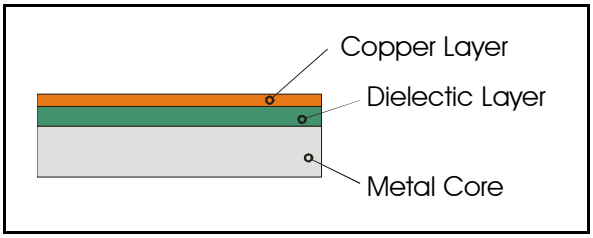


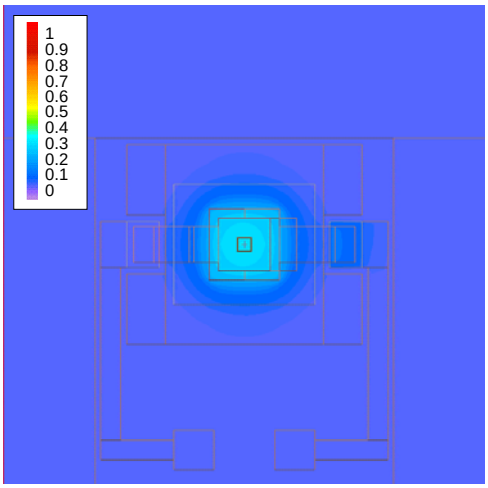
Figure 6: Structure of Single Layer MCPCB

According to figure 6 in the table below typical thickness of the base layers are listed.

Copper Layer	35 – 200 µm
Dielectric Layer	75 – 100 µm
Metal Layer	1 – 3 mm

In the flowing analysis a thickness of 100 µm for the dielectric is used. The metal core consists of aluminium alloy, with a thickness of 1.5 mm. For the copper layer the standard thickness of 35 µm is used.

The lowest thermal resistance can be reached with a thermal enhanced dielectric layer. In the simulation a thermal conductivity of 1.3 W/m-K was assumed.

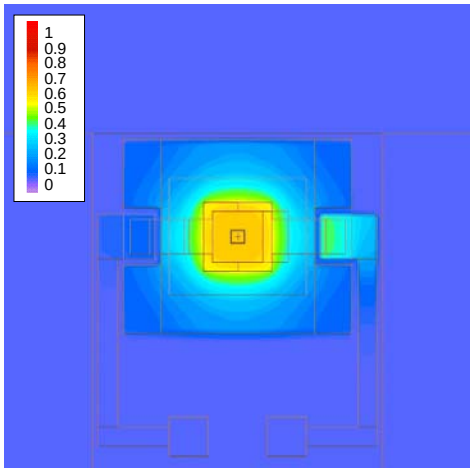


Cutting Plane: Solder Pads

Figure 7: MCPCB with thermal enhanced dielectric (λ = 1.3 W/m-K)

The use of FR4 as the dielectric layer shows an increase of the thermal resistance. This effect is illustrated in figure 7 and 8.

Generally speaking the usage of metal core printed circuit board shows the best performance according to the thermal management.



Cross Section: Solder Pads

Figure 8: MCPCB with standard dielectric (λ = 0.3 W/m-K)

Flexible PCB on Aluminium

Another possible solution is mounting the Golden DRAGON® LED on a flexible substrate such as PEN, PET or PI material placed on an aluminium heat sink using a pressure sensitive adhesive (PSA). Like the metal core of the MCPCB the aluminium acts as a heat spreader. The principle construction of a one layer FPC on aluminium can be seen in figure 9.

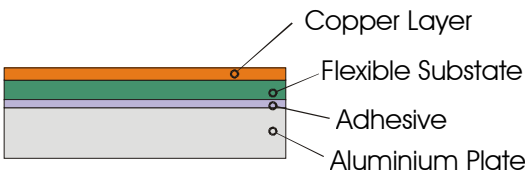
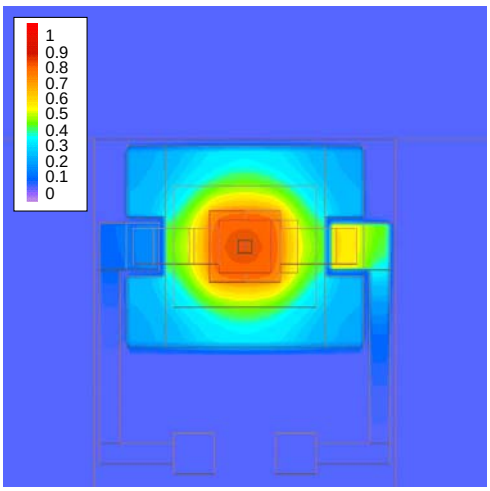


Figure 9: Structure of flexible PCB on Aluminium

For the thermal comparison the thickness of each layer and the material is listed in the following table

Copper Layer	35 µm
Dielectric Layer	50 µm (PEN)
Adhesive Layer	50 µm (Standard PSA)
Aluminium Plate	1.5 mm

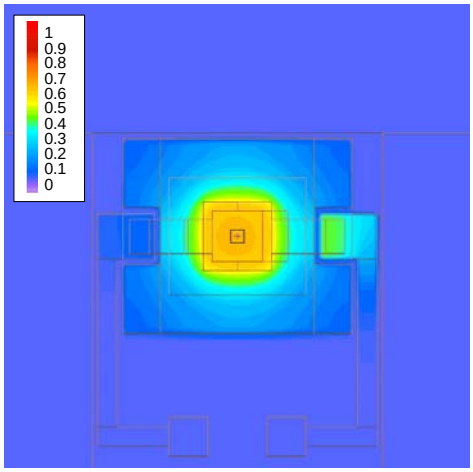
Compared to the MCPCB with FR4 dielectric the thermal performance decreases in the range of 30 % (figure 10).



Cross Section: Solder Pads

Figure 10: FPC on aluminium with standard adhesive

Using a thermal conductive adhesive can further optimise this concept. This step improves the thermal performance. The analysis points out a similar performance than MCPCB with FR4 (figure 11). Further improvements can be done by the use of thermal vias (see next section) or two layer FPCs.



Cross Section: Solder Pads

Figure 11: FPC on Aluminium with thermal conductive adhesive

FR4 PCB / FR4 on Aluminium

A standard substrate material such as FR4 doesn't provide a proper thermal management through the low thermal conductivity of FR4.

An analysis of a FR4 PCB (thickness t = 1 mm) glued on aluminium plate using standard pressure sensitive adhesive shows an high R_{thSB} in the range of 50 K/W.

The performance can be significantly improved by actions like array of thermal vias and the usage of Multi Copper - Layer PCBs. Thermal vias are often used to reduce the thermal resistance of materials with low thermal conductivity like polyimides on substrates or FR4 PCB. Figure 12 shows an example of a typical via design on PCB. A thermal via has an outside diameter D, height h and is plated with copper of the thickness t (figure 13).

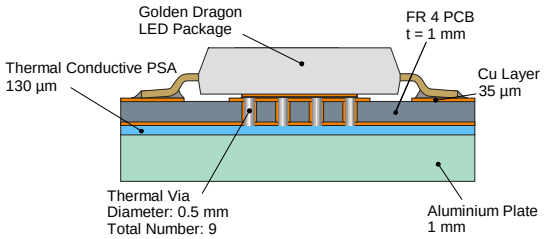


Figure 12:Structure of FR4 PCB on Aluminium with thermal vias

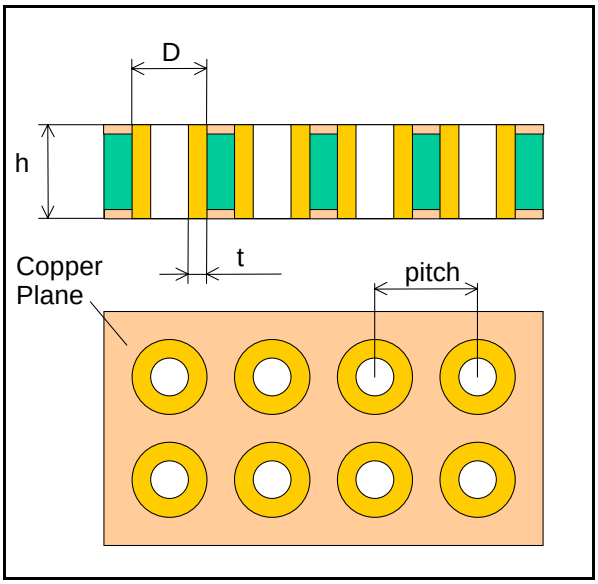


Figure 13: Thermal Via

The thermal resistance of the n vias can be approximately estimated using one dimensional heat conduction analysis:

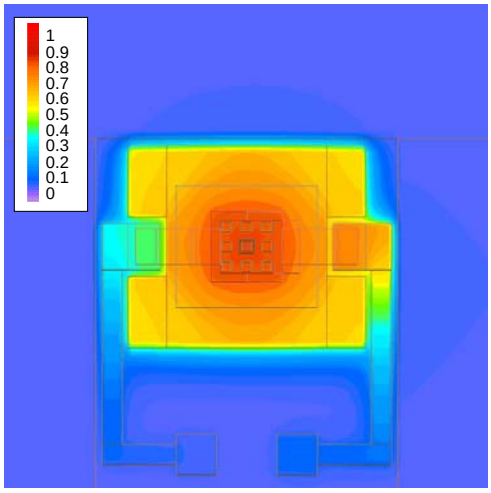
$$Rv = \frac{h}{n \cdot k \cdot \pi \cdot (D \cdot t - t^2)}$$

Equation 5

Where *Rv* is the total thermal resistance of the number n of vias and k is the thermal conductivity of the via plating material. The density and size of the thermal vias depends on many factors, e.g. hole diameter, pitch or copper plating thickness. The thermal resistance of the array of vias can also be optimised.

In order to give a feeling for improvements the example illustrated in figure 12 was analysed in the simulation.

Figure 14 shows the temperature distribution. The thermal performance is now in the range of MCPCB with FR4 dielectric.



Cross Section: Solder Pads

Figure 14: FR4 PCB on Aluminium with thermal conductive adhesive and thermal vias

The results indicates that the use of standard FR4 on aluminium with further improvements is possible but it strongly depends on the construction of the PCB e.g. thermal vias, thermal conductive adhesive.

For an overview the thermal resistance solder point to board R_{thSB} is briefed in the following table. The values are only valid for the mentioned PCB constructions and boundary conditions.

Substrate Technology	Thermal Resistance R_{thSB}
MPCB with enhanced dielectric	3.4 K/W
MPCB with FR4 dielectric	7.3 K/W
FPC on aluminium with standard PSA	9.5 K/W
FPC on aluminium with thermal enhanced PSA	7.6 K/W
FR4 – PCB glued on aluminium with thermal vias	9.7 K/W

Thermal Resistance (Board to Ambient)
Heat Sink Considerations

Due to the increased power dissipation of the Golden DRAGON® LED an effective thermal enhancement is required. Heat transfer from a solid body to a fluid can be enhanced by extending the surface of the solid body. Inspection of convective heat transfer rate equation shows that, for a given heat dissipation, the temperature difference is controlled by the product[2] $h \cdot A$. Increasing the product is usually not easily achieved by increasing the heat transfer coefficient h. The increase of the heat transfer surface area is most often a more effective method to accomplish the desired performance improvement. One of the common methods to increase the surface area is the use of heat sinks.

Thermal Simulation has been carried out in order to show the thermal impact of heat sink configurations. Several dimensions of flat, rectangular heat sink areas are considered. The material used for flat heat sinks is usually aluminium.

All the results are based on a CFD-Analysis with the following conditions.

- A geometry model of the entire configuration is created from the design drawings for the Golden DRAGON® LED package and the geometry data of the test board and its metallization. The geometric and material data as well as the standard boundary conditions are listed in the following table.

Component	Golden DRAGON® LED
Outer PCB Dimensions L x W	Variable
Board Material	MCPCB with thermal enhanced dielectric
Material for Solder Pads	35 µm Cu
Power Dissipation	1 W
Air Velocity	still air (free convection)
Ambient Temperature	25 °C

- In the analysis model the recommended solder pad layout of the Golden

[2] *A*: area exposed to fluid
h: heat transfer coefficient

DRAGON® LED is used. The solder pad layout is specified in the datasheet.

- The board is in test environment with two orientations according to gravity.
- In the thermal analysis heat transfer through conduction, convection and radiation is considered.
- Unless expressly stated, the steady state calculations are always performed with a fixed power dissipation of 1 W. Other heat sources, e.g. resistors, voltage regulators etc., are not considered in the analysis.
- The simulation results are valid under the mentioned boundary conditions.

The thermal model can be seen in the following figures.

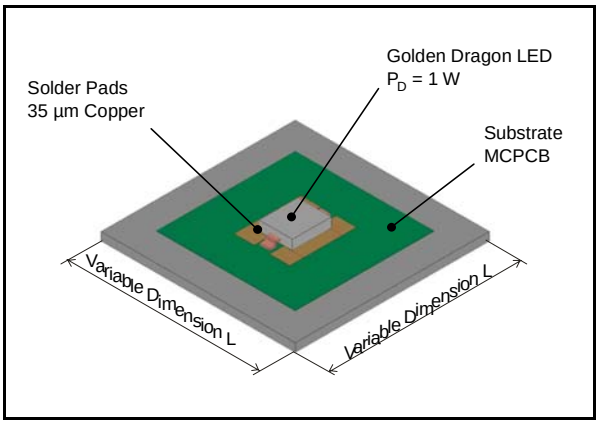


Figure 15: Thermal Model Configuration

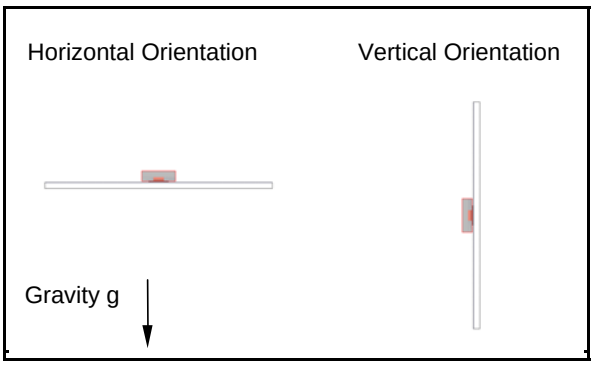


Figure 16: Orientation of MCPCB with test environment

Figure 17 shows the relation between thermal resistance (board to ambient) and the substrate area (footprint) with flat horizontal and vertical heat sink.

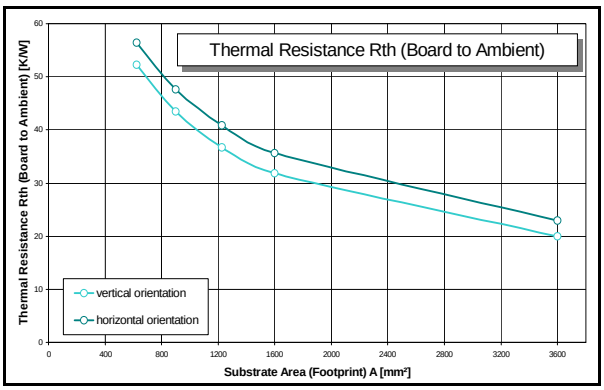


Figure 17: Thermal Resistance (Board to Ambient) vs. Substrate Area (Footprint)

Another way to extend the surface area to the coolant is the usage of heat sinks. Heat sinks vary in shape, size and material depending on application. Heat sinks may also be components or integrated in the system, like housing.

The example below illustrates the effect of a finned heat sink in still air environment.

According to the thermal analysis the fanned heat sink decreases the thermal resistance R_{thBA} in the range of 40 %.

The selection or construction of the heat sink strongly depends on the boundary conditions, e.g. velocity, orientation to gravity.

In the above section the contact between heat sink and substrate was considered as ideal. In reality a thermal interface resistance formed between heat sink and the mounting area has taken into account. Under some circumstances, this contact resistance can be substantial, impeding heat flow and reducing the overall effectiveness of the heat sink.

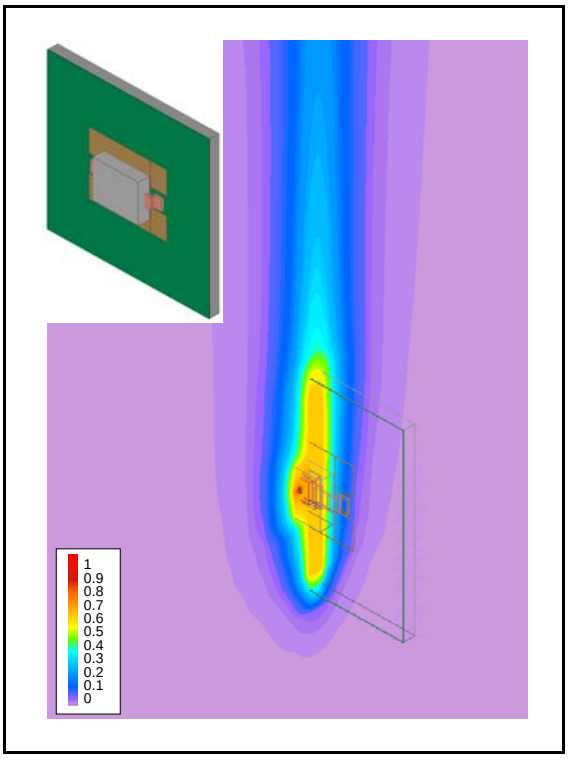


Figure 18: Vertical orientated flat heat sink (footprint: 25 mm x 25 mm) in still air

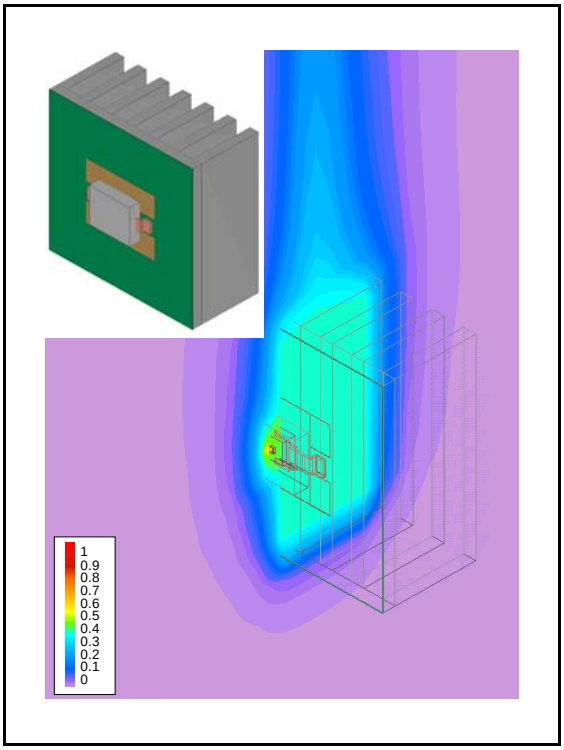


Figure 19: Vertical orientated fanned heat sink (footprint: 25 mm x 25 mm) in still air

Summary

The Golden DRAGON® LED dissipates approximately 1 W of thermal energy. The thermal design in application is very critical. The application note shows some concepts to reduce the total thermal resistance R_{thJA} by optimising the thermal resistances R_{thSB} and R_{thBA}.

A general recommendation cannot be given due to the variety of application specific boundary conditions. Nevertheless important design rules are:

1. The thermal resistance from the back of the exposed heat spreader of the Golden DRAGON® LED to the coolant must be kept to an optimum to ensure that the junction temperature is maintained below maximum allowable limits within the application specific boundary conditions. The operating environment has been carefully analysed.

2. The method to mount the Golden DRAGON® LED is IR or reflow soldering. This ensures a good thermal contact between the internal heat spreader and the printed circuit board. Other soldering processes are not suitable.

3. Other electrical components, e.g. resistors, transistors have to be placed far away from the Golden DRAGON® LED. They can act as additional heat sources and influences the thermal behaviour of the LED.

4. Depending on the environmental conditions in most cases an additional heat sinking is required.

In the concept phase numerical methods, e.g. thermal analysis software can support the design process. When physical prototypes of the application are available, it is very important to evaluate the design according to the thermal behaviour. Within the evaluation the expected ambient temperature range have to be examined.

Additional information about electronics cooling:

www.coolingzone.com

www.mhtl.uwaterloo.ca

www.electronics-cooling.com

Author: Rainer Huber

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