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Thermal Analysis and Optimization of 6.4 W Si-Based Multichip LED Packaged Module

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ABSTRACT

Multichip packaging was achieved the best solution to significantly reduce thermal resistance at the same time, to increase luminance intensity in LEDs packaging application. For the packaging, thermal spreading resistance is an important parameter to get influence the total thermal performance of LEDs. In this study, silicon-based multichip light emitting diodes (LEDs) packaged module has been examined for thermal characteristics in several parameters. Compared to the general conventional single LED packaged chip module, multichip LED packaged module has many advantages of low cost, low density, small size, and low thermal resistance. This analyzed module is comprised of multichip LED array, which consists of 32 LED packaged chips with supplement power of 0.2 W at every single chip. To realize the extent of thermal distribution, the computer-aided design model of 6.4 W Si-based multichip LED module was designed and was performed by the simulation basis of actual fabrication flow. The impact of thermal distribution is analyzed in alternative ways both optimizing numbers of fins and the thickness of that heatsink. In addition, a thermal resistance model was designed and derived from analytical theory. The optimum simulation results satisfies the expectations of the design goal and the measurement of IR camera results. tart after striking space key 2 times.

Key Words : Light Emitting Diode, Silicon, Heatsink, Substrate, Thermal Resistance

Ⅰ. Introduction

A light emitting diode (LED) is a semiconductor device composed of group Ⅱ-Ⅵ or Ⅲ-Ⅴ elements. Depending on their energy gaps, light of color is controlled. LEDs have many advantages of low power consumption, highly directional light emission, fast response time, long lifetime and environmental protection and used in variety of applications such as LCD back light source, automotive and general lighting due to precise wavelength and color output, long lifetime, anti-vibration[1-2]. Generally, 17% of the primary energy consumption in homes is consumed by lighting applications. Therefore, the white LED and its applications could replace the traditional light bulb in the near future[3]. When designing an LED lighting system, there is need proper structure to control LED junction temperature. It can improve the capability of heat conduction from the chip to the heat sink by optimizing the internal packaging structure of LED device[4]. For example, the lifetime of LEDs decreases from 42,000 h to 18,000 h, when the junction temperature increases from 40 °C to 50 °C. Thus, not only materials which are used in the packaging of LEDs plays critical role, but also optimum, thermal management plays against the thermal resistance. At the system level convection to

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the surrounding environment is the primary method for thermal dissipation and can occur through either natural or forced convection[5]. There are three major parameters that impact the junction temperature of the LEDs which are the input power, and thermal resistance between the die and thermal pad, and the ambient temperature. There are many packaging method to eliminate thermal elevation, and reducing size of that of packaging. Most commercially available packaging is chip-on-board (COB) surface provides efficient heat dissipation with compact size. However the thermal design process utilizing COB architectures on power electronic substrates relies heavily on the use of finite element analysis which require time consuming calculation when exploring the parametric design space. This is necessary due to the lack of analytical models which can account for the complex nature of the heat flow through a multilayer power electronic substrate and through the heat sink to the ambient temperature. In this study Si-based LED multi-chip module implementing COB packaging method were designed from actual fabrication flow process with appropriate parameter values and analyzed by finite element analysis (FEA) using Solidworks 2013 software.

Ⅱ. Heat Generation and Transfer in LEDs

LEDs generate light and heat by using different mechanisms as compared to the incandescent bulb. With the injection of electrical energy, the electron energy will be partly converted into light and partly into heat. Obviously the research into LED technology is focused on optimizing the light emitting efficiency. Currently, the LEDs in the market have an efficiency of about 10%－20%. Consequently 80%－90% of the energy is converted into heat. Hence, the challenge of thermal management is to conduct heat from the LED package to the environment with a sufficient heat transfer rate[6].

In general, generated heat from LED chips can be eliminated by conduction, convection and radiation heat transfer mechanisms. The heat is generated by the LED chip inside the package. Although some of the heat can be dissipated radiation and natural convection along package surface of the multichip array. Normally, 70-80% of heat is transferred by conduction into heatsink. The transferred heat is dissipated through the heatsink to the surroundings (ambient) by natural convection or radiation. The heatsink could also replaced by other thermal solution which include forced convection or forced air cooling, heat pipe, thermoelectric, synthetic jet flow cooling, liquid system, etc. Compared to forced or active thermal management, natural or passive solution have the advantages of a simple structure, easy fabrication, application flexibility and low cost. Thus, only passive cooling solution will be discussed in this study.

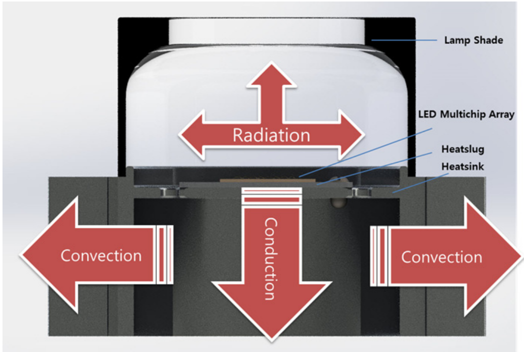
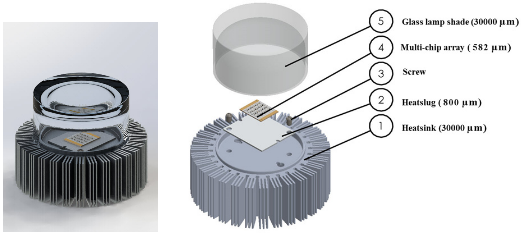


Fig. 1. Heat transfer 3 mode of LED

Ⅲ. Finite Element Modelling

In this paper, the structure of Si-based LED multichip array is designed and analyzed shown in Fig. 2. The main structure composed of five parts which are heatsink, heatslug, screw, multichip array, and glass lamp shade. Screw and glass are disabled to save calculation time to for the simulation. Critical parameters and dimensions of the vertical structure of the proposed multichip array are shown in Fig.3. Because conductive layers are thinner than Si substrate, we only consider thermal effect on the Si substrate to reduce calculation time. The designed chip has an actual size of 610 by 610 µm, and a thickness is 150 µm, and it is provided courtesy of Epistar Corporation (model: ES-CADBV24B). The



(a) (b)

Fig. 2. (a) Full 3D view of CAD model of Si-based LED module, (b) Exploded view of the proposed Si-based LED module

heatslug provides a thermal path between the multi-chip array and heatsink. The effective area of the multi-chip array is 14540 µm by 17970 µm, and the area divided into 16 paddles (4 by 4); in each individual paddles contain two chips. The single paddle size is 2800 µm by 2800 µm. The distance between two chips in a single paddle is 535 µm. The distance between two chips to the adjacent paddle is 1162 µm. The proposed Si-based multi-chip array is mounted directly on the heatslug. The heatslug consists of two screw-holes and uses the support of screw to keep the heatslug closer to the heatsink, which improves the thermal conduction between the heatsink and heatslug. The total size of the heatslug is 27600 µm by 32600 µm. The screw-hole diameter is 3400 µm, and the thickness of the heatslug is 800 µm. Lastly, a glass lamp shade is designed to protect the structure from dust and improve the quality of the light output. Heatsinks are typically manufactured using a variety of metal-forming approaches, including extrusion, stamping, casting, milling, and bending. The extrusion heatsink with rounded fin is generally

Component	Material	Thickness (µm)	Thermal Conductivity (W/m·K)
Chip	Gallium Nitride (GaN)	150	1242.6
Reflective layers	Silver (Ag)	3	428.7
	Gold (Au)	1	317.6
	Nickel (Ni)	1	91.21
Substrate	Gold (Au)	0.5	317.6
	Nickel (Ni)	2	91.2
	Copper (Cu)	7.5	386.3
Heat Conductive Layer	Silicon Dioxide (SiO2)	1.1	10
	Aluminum Oxide (Al2O3)	1.2	214.8
	Pure Silicon (Si)	580	151.1
Heatslug	Alloy 1060	1000	200
Heatsink	Alloy 6061	30000	170

Fig. 3. Material properties of actual LEDs[7]

implemented in natural convection for LED applications. The outer diameter of the heatsink is 53000 µm, and the innermost diameter is 50000 µm. The length of the fin is 15000 µm, and the height is 30000 µm. The thickness of the centre base metal is 2000 µm.

Ⅳ. Result and Discussion

The primary goal of the design was to calculate individual die power of 0.2 W, and examine whether our heatsink with a fin number of 90 and thickness of 30 mm can effectively dissipate generated heat into the ambient. In general, most LED suppliers suggest that luminaries be designed so that LED junction temperatures are maintained well below 100 °C in typical applications. To optimize the heatsink with this design, the simulated result is determined to be 51.5 °C. Typically, designers use automatic mesh generation. For the results to be accurate, the number of cell size should be high; ultimately, users will require a computer with a large memory. There are 3 different types of cells, solid, fluid and partial, and 2 different types of initial conditions, basic initial and local initial, that are performed to calculate results. We used a method for reducing the number of cell size in the basic initial condition and increasing the number of cell size in the local initial condition. When only accurate result was needed, we used the local initial condition, which included the heatsink, heatslug, and LED multi-chip array, while reducing the overall fluid cell size in the basic initial condition resulting in more accurate results and a ten-fold reduction in time consumption. The number of mesh cells is approximately 800,000, including the solid cell, partial cell, and fluid cell. The optimal thickness of the heatsink and the number of fins were considered, fin numbers of 30, 60, 90, and 120 fins were examined. Corresponding simulation results are shown in Figs. 4 (a), (b), (c), and (d), where the temperature distribution of the junction, Si-substrate, heatslug, and heatsink are displayed. Heatsinks provide increased surface area to dissipate heat effectively from the LED to the external environment. Key heatsink performance

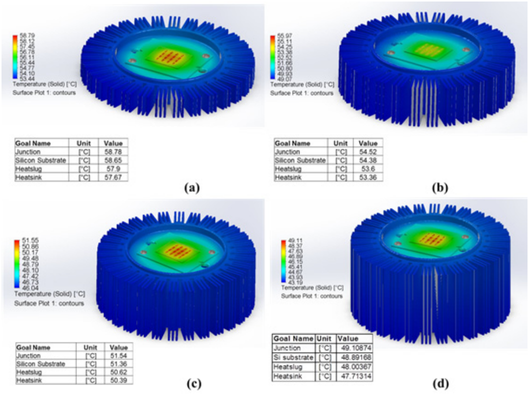


Fig. 4. Varying thickness of aluminium heatsink at supplied power 6.4 W (a) 10 mm; (b) 20 mm; (c) 30 mm; (d) 40 mm

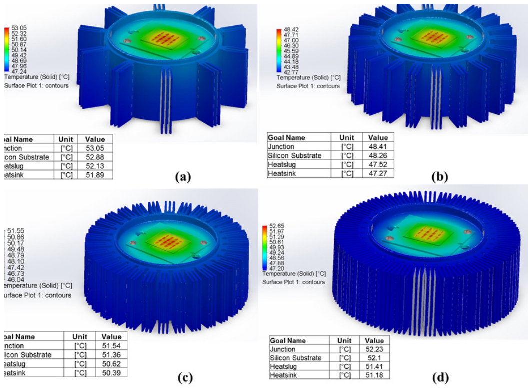
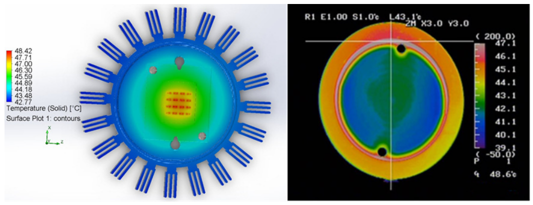


Fig. 5. Varying number of fins for aluminium heatsink at supplied power 6.4 W (a) 30; (b) 60; (c) 90; (d) 120

parameters include a large surface area to spread the heat generated by the LED and provide access to circulating air, a flat contact area to provide effective heat transfer from the substrate, effective aerodynamic design to ensure effective air circulation, effective thermal transfer within the heatsink, and a secure method of mounting the heatsink to the substrate, which is also required to provide heat transfer from the substrate. Based on simulation, it is determined that when the number of fins is 60, optimum result of 48.41 °C is attained, and compared with IR camera measurement results shown in Fig. 6. That is because of adequate space for air circulation from the surface to the external environment. An increase in fin number of the heatsink causes increase in cost and weight. In reality, the heatsink and multi-chip array surface will typically have minor surface imperfections, which impede effective thermal transfer because the surface of the two materials are partially separated by air pockets. To address these deficiencies, properly designed LED thermal management systems use various types of thermal interface materials. To reduce calculation time effectively, the TIM was ignored in this design. As the thickness of the material increases, the temperature gradient increases, which indicates that a high rate of heat transfer will occur. In addition, material conductivity has significant effect on the heat transfer rate. Fig. 5 shows heatsink with varying thicknesses: (a) 10 mm; (b) 20 mm; (c) 30 mm; and (d) 40 mm when the number of fins to be 90. When the thickness was 40 mm, the junction temperature was 49.1°C. The junction temperature can be controlled and lowered even if the thickness is increased. As the thickness increases, it directly affects to the cost and weight; therefore, luminaire designers need to consider adequate size and heat dissipation.



(a) (b)

Fig. 6. Temperature distribution supplied power 6.4 W (a) simulation results by Solidworks; (b) measurement results by IR camera

Ⅴ. Conclusion

In this paper, 6. W Si-based LED packaged module was introduced, simulated and analysed successfully, which has a high thermal conductivity and a low thermal resistance and the thermal stress compared to a metal core printed circuit board (MCPCB). The heatsink analysis is performed by changing the thickness of the heatsink from 10 mm to 40 mm and the number of fins from 30 to 120. The optimum junction temperature is 48.41 °C and the temperature of the packaged actual module is measured by the IR thermal camera to be 48.6 °C. The junction to ambient resistance was based on analytical thermal resistance network and was determined by the optimal condition.

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