A Review on Thermal Management for High Power Led Street Lights

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***Abstract*- Light-emitting diode (LEDs) have a promising prospect because of its outstanding advantages: 1) long lifetime, 2) environmentally friendly, 3) flexibility of color mixing, 4) high illumination efficiency, etc. Based on the electrical characteristics of LEDs, a constant current driver is needed to support the LED working performance. The scope of this review paper is to consolidate various thermal factors which affect the performance of high power LEDs and also to summarize various cooling methods which improve both the efficiency and lifetime of LED lamps.**

Thermal factors such as thermal resistance, thermal spreading resistance, and thermal interface material, and thermal capacitance, active and passive cooling systems suitable for high power LED packages are discussed. The effect of junction temperature on the colour of emitted light and life of LED is also explored. Junction temperature of the LED depends on the current supplied and type of cooling system used. Higher junction temperature with poor cooling leads to shift in the light colour and drastically reduces the LED life. From the review it was found that heat sink and heat pipes are best solution for heat dissipation.

Index Terms- High-Power LEDs, Heat Pipe, Numerical Simulation, Thermal Management, Fins.

I. INTRODUCTION

Energy crisis, global warming, energy saving and emission reduction have become some of the most concerned topics in the world. As a new generation green solid-state light source, LED has been widely regarded due to its distinctive advantages such as high luminous efficiency, energy saving, long lifetime, and being environment-friendly. It is being developed for solid-state lighting (SSL) for general illumination in commercial and household applications while offering up to 75% savings in electric power consumption over conventional lighting systems. At present, some countries have already carried out LED semiconductor lighting R&D, production, and application such as the “solid-state lighting program” of USA, the “rainbow scheme” of Europe, the “21st century lighting plan” of Japan, and the “GaN semiconductor lighting plan” of South Korea. At the same time, China has launched the “semiconductor lighting major project”. Hundreds of semiconductor lighting research institutes, universities, and enterprises have begun to conduct R&D, production and application.

Today, light emitting diodes (LEDs) market is one of the most rapidly growing markets. LEDs are replacing conventional light sources such as incandescent lamps and fluorescents, because of their superiority in many properties like efficiency, reliability, short response time, durability, color variability, compactness and lightness. LEDs are used predominantly in LCD backgrounds, monitors, transportation equipment and general illumination. The applications that fall within the general illumination category include outdoor illumination in places like streets, bridges, stadiums as well as residential area and industrial illumination [1].

In LEDs, only 20% of the input electrical energy is converted into light, the rest is converted into heat [2]. During this heat generation, p - n junction has the highest temperature within the device. Thus, the temperature at this point is called the junction temperature. In LEDs, junction temperature is of vital importance because the life of the LED and light flux depend on it. Performance of a LED is affected significantly by its thermal and optical behavior. In order to design a high – performance LED application, as the case for other electronic devices, the heat generated has to be effectively removed from the system. The conventional method for heat dissipation in electronic devices is using a fan and a heat sink. Recently, alternative two–phase technologies such as heat pipe and thermosiphon systems are becoming popular. Heat pipe systems are used to dissipate heat from especially medium and high power LED illuminations. In the literature, there many studies that investigated the usage of heat pipes for cooling the LEDs.

1.1 Light Emitting Diode

Light emitting diode (LED) differs from standard lightweight sources; it provides an instantaneous transfer of voltage into lightweight. Though there are several lighting technologies, Light-Emitting Diode has been expected as Associate in nursing 'ultimate lamp' for the longer term. [1]

Theoretically, Light-Emitting Diode has several distinctive blessings admire high potency, smart dependable, long life, variable color and low power consumption. Recently, Light-Emitting Diode has begun to play a crucial role in several fields, so Light-Emitting Diode product are currently getting used in several fields together with traffic lights, vehicle headlights and tail lamps, LCD displays and street lamps and then on [2]. Light-Emitting Diode is anticipated to be utilized in general lighting that consumes regarding V-day of the overall energy round the world. It's believed those high-energy light - emitting diodes are going to be the dominant lighting technology by 2025 [3].

High-power LEDs operation will manufacture for high Luminas; however they additionally generate important heat at an equivalent time. It's been rumored that the optical output of the Light-Emitting Diode is sharply degraded with the rise in junction temperature [4] as a result of the warmth considerably influences the dependable and sturdiness of the Light-Emitting Diode [5].

Light-Emitting Diodes (LEDs) are tangency devices created from semiconductor materials, cherish gallium compound (GaAs), gallium compound phosphate (GaAsP), or gallium phosphate (GaP). Semiconducting material and germanium are unsuitable to be used in LEDs as a result of these junctions turn out heat with no considerable infrared (IR) or visible radiation. The junction in LEDs is forward biased.

When electrons cross the junction from the n-type to the p-type material, the electron-hole recombination method produces photons in an exceedingly method referred to as electroluminescence. An exposed semiconductor surface will then emit light-weight.

Wavelength size is said to the energy gap of the fabric. Materials with larger energy gaps turn out shorter wavelengths [6]. 2 primary approaches will be accustomed acquire white light from LEDs. The primary methodology is to mix light from red, green, and blue LEDs. White light fashioned during this manner will be "tuned" to seem heat or cool by adjusting the amounts of every colorize the combo. The second methodology uses a blue Light-Emitting Diode with a phosphor coating. The coating emits a yellow light once the blue light from the Light-Emitting Diode shines thereon. The combo of the yellow light with the blue light forms a white light. Unskillfully in phosphor conversion is one reason that a white Light-Emitting Diode is a smaller amount economical than a colored Light-Emitting Diode. Some light energy is lost within the conversion to yellow [7]. Light-Emitting Diode epitaxial layers emit heat centered on little areas.

When a Light-Emitting Diode lamp with varied diodes is switched on, the temperature of the lamp will increase quickly because the Light-Emitting Diodes or LED modules among emit heat. If the warmth isn't well dissipated, it's going to cause flicker and degrade the illumination quality of the Light-Emitting Diode lamp. It's going to conjointly shorten the service lifetime of the lamp. Thermal management and management are thus major problems in solid-state lighting merchandise.

Heat sink is an electronic component or a device of an electronic circuit which disperses heat from other components (mainly from the power transistors) of a circuit into the surrounding medium and cools them for improving their performance, reliability and also avoids the premature failure of the components. For the cooling purpose, it incorporates a fan or cooling device.[10]

Extended surfaces or fins are commonly found on electronic components ranging from power supplies to transformers. The dissipation and subsequent rejection of potentially destructive self-produced heat is an important aspect of electronic equipment design. The dissipation of heat is necessary for its proper function. The heat is generated by the resistance encountered by electric current. Unless proper cooling arrangement is designed, the operating temperature exceeds permissible limit. As a consequence, chances of failure get increased.

Figure 1: LED Street Light

1.3 Heat Sink

With high-power LEDs, it is crucial that you remove heat through efficient thermal management. Without good heat sinking, the junction (internal) temperature of the LED rises, causing the LED characteristics to change for the bad.

As the junction temperature of an LED increases, both the forward voltage and the lumen output decreases (see Figure 1.2). Not only is this decreasing the brightness and efficiency of your LED but this junction temperature affects the overall lifetime of the LED as well. LEDs don’t usually fail catastrophically (although some may, especially if you over heat them); instead, the lumen output of the LED will decrease over time. Higher junction temperatures lead to faster LED deterioration. This is why it is crucial to keep your LED junction temperature low. Also take note that if you are over driving your LED (putting more current to it than what it is rated) this will drive temperatures up so high that permanent damage can occur.

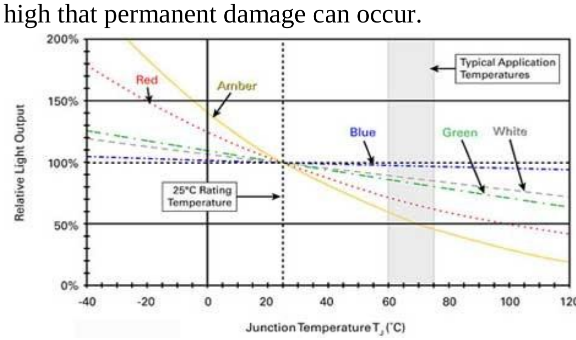

Figure 2: Junction Temp. V/s Relative Light output

The ambient temperature and the drive current both affect the junction temperature of LEDs. Other influences are the nature of the light, whether it is steady state or pulsed, and then the one we are really interested in, LED wattage per unit area of heat sink (surface that dissipates heat).

The most important part of LED cooling is the thermal path from the LED junction to the outside of the light fixture. Heat needs to be conducted away from the LED in an efficient manner, and then removed from the area by some sort of cooling or dissipation.

Figure 3: LED Heat Sink

Heat sinks are an important part of LED lighting because they provide the path for heat to travel from the LED light source to outside elements. Heat sinks are able to dissipate power in three ways: conduction (heat transfer from a solid to a solid), convection (heat transfer from a solid to a moving fluid, air in most cases), or radiation (heat transfer from two bodies at different temperatures through thermal radiation).

1.4 Applications

Heat sinks are widely used in various industrial applications to cool electronic, power electronic, telecommunications, and automotive components. Those components might be high-power semiconductor devices, audio amplifiers, microcontrollers and microprocessors. More precisely, the passive cooling heat sinks are widely used in CPU cooling, audio amplifiers and power LED cooling.

II. LITERATURE REVIEW

In the past few years, LED lamps have been assuming a large role in the illumination market, mainly due to their potential in creating not only light but interesting light environments, associated with low power consumption even when compared with other energy-saving lamp types. Still, from the energetic viewpoint, LED lamps have not yet the desirable efficiency, as a considerable amount of energy is released as heat. This tends to increase the temperature of the LED lamps, leading to a decrease of their lifetime. In order to meet the expected long lifetime, LED lamps must operate below a certain temperature threshold, as given by the manufacturer. To ensure this, the heat sink associated to the LED lamps must provide the needed cooling, requiring the minimum mass of the involved material to obtain the heat sink.

Numerous parameters may influence the heat dissipation effect of fin heat sinks. Some studies can be found in the literature concerning the cooling of LED lamps which are given below.

2.1 Previous Work

Sahiti et al. [2006] compared the performance of airfoil-shaped streamline fins developed by the National Advisory Committee for Aeronautics and drop-shaped fins with that of elliptic, circular, and square pin fins under various conditions.

Sahin et al. [2008] applied the Taguchi method to design perforated rectangular and circular fin heat sinks, which achieved optimal heat dissipation performance. They reported that the heat dissipation efficiency was influenced the most by wind velocity, followed by the fin height and fin spacing.

Kim et al. [2009] compared plate-fin and pin-fin heat sinks and determined that the heat dissipation performance of plate-fin heat sinks was superior to that of pin-fin heat sinks when wind velocity was high and the fins were short. Conversely, with low wind velocity and long fins, the pin-fin heat sinks exhibited superior heat dissipation performance compared with that of the plate fin heat sinks.

Chang and Lees [2010] show a novel compound heat transfer enhancement (HTE) measure. It combines deepened scales and pin-fin array to strengthen cooling. Moreover, because of the trend of product weight reduction, numerous studies have investigated designs for the weight reduction of fin heat sinks such as hollow or perforated fin heat sinks.

Elshafei [2010] compared solid and hollow circular pin fins and investigated the influence of the thickness of hollow pin fins on the temperature difference among the fins. The result revealed that the hollow pin fins exhibited a comparatively small temperature difference and light weight, compared with that of the solid pin fins. Additionally, as the thickness of the hollow pin fins increased, the temperature difference decreased. In recent years, the design optimization of quality characteristics has become required in the field of engineering.

Tony Tan et al. [2013] present hollow geometry introduced inside the rectangular fins and used three kinds of hollow geometries (circular, rectangular, and trapezoidal). The results show that the “hollowed” fins have better heat dissipation efficiency compared to the solid fins.

Shung-Wen Kang et al. [2014] proposed to replace traditional street lamps with an LED street lamp containing a multilayered substrate structure for heat dissipation. Used simulation software to analyze the heat distribution for the proposed model. The simulation showed that our model would be effective at dissipating heat in the LED lamp. We tested temperature changes at 120 and 180 W of inputted power. The LED heat sink slug’s average temperature remained in safe ranges. Less than 5 oC difference existed between actual and simulated results. The average thermal resistance values were 0.24 oC/W at 120 W and 0.22 oC/W at 180W. The data showed that a multilayered substrate structure is not only able to improve LED efficiency but also to solve the heat dissipation issue in LED lamps.

Luo et al. [2016] studied a micro jet array cooling system for thermal management of a high-powered LED lighting supply. Experimental and numerical investigations were conducted. AN infrared measuring device was wont to Measure the on-line temperature, and thermocouples evaluated the cooling performance of the planned system. The experimental and numerical results explained that the micro jet-based cooling system has smart cooling performance.

Lai et al. [2017] proposed an indoor LED lighting prototype that used pressed-flat grooved heat pipes as heat transfer channels to conduct heat emitted by LEDs to heat-sink fins. Single layered heat dissipation module in the above design cannot provide a reliable solution in high power LED streetlamps.

X. Luo, T. Cheng, W. Xiong, Z. Gan and S. Liu et al. [2017] experimented thermal analysis of an 80 W LED street lamp was presented. Sixteen thermocouples were used to measure the temperature points at the aluminum base and fins. The experiments demonstrated that the temperatures near the chip were nearly the same; no obvious temperature difference existed in this area. A numerical model was also proposed based on the experiment. The numerical results were compared with the experimental results to ensure the feasibility of the numerical model. The numerical results of the thermal resistance analysis showed that at an environment temperature of 458C, the maximum junction temperature of the LED chips on the present 80 W LED street lamp would be equal to the critical temperature 1208OC, which leads to poor reliability and lower life and optical efficiency of the LED street lamp.

Kim et al. [2018] investigated the thermal management system for associate degree semiconductor diode light in a very rear projection TV. Their results showed that decreasing thermal resistance between LEDs and substrate was the foremost effective thanks to dissipate heat, and also the applicable limit of thermal resistance existed for varied heat-dissipating conditions of LEDs. They additionally steered that the warmth transport system uses red, inexperienced and blue Light-Emitting Diode lights to confirm product quality.

Wilcoxon and Cornelius et al. [2018] delineated the thermal management approach for a light engine and given the results of their finite-element model. The practical blueness of the model was well-tried by the experimental knowledge and was wont to assess varied style aspects of the sunshine engine to grasp their effects on the general thermal resistance. The results of their finite-element model indicated that the junction temperature of the LEDs during this lightweight engine would be near to their most values in a very high-temperature atmosphere. However, through the utilization of exotic materials appreciate diamond/aluminum composites, Light-Emitting Diode temperatures may be considerably reduced below the values obtained during this testing.

Lall et al. [2019] performed some experiments for non-uniform powering of a multiple-chip module mounted on a vertical board in natural convection. the common chip temperature thanks to multiple sources at intervals the module was thought of because the reference temperature for evaluating the junction temperature rise of a specific chip. This approach offered a additional refined methodology for analysis of no uniformly battery-powered multi-chip modules compared to previous strategies.

Zahn et al. [2019] mentioned however a central composite style of experiments may be applied to produce an additional correct thermal characterization of a multi-chip module package. The tip product was a series of linear or polynomial equations that would be used by the client to calculate individual device junction temperatures over a good variation of convection cooling environments and multiple device power dissipations.

III. CONCLUSIONS

Thermal factors such as thermal resistance and thermal capacitance at different location of the LED package are the main cause of LED degradation. The temperature change in the LED is mainly due to forward voltage, forward current from the source and ambient temperature. The change in driving parameters and junction temperature directly affects the luminous output and also degrades the life time of LED and shifts the original colour (it is designed for). Various solutions like changing the heat sink size, substrate size and other internal dimensions may improve the heat dissipation. Various active and passive cooling mechanisms which are discussed should be employed not only by considering the LED package, the location where the mechanism is going to operate also needs to be considered. Apart from thermal capacitance and thermal spreading resistance, the colour temperature also needed to be considered on every LED package before using it for particular application.Thus, temperature estimation is often a vital issue for LED development. To keep the temperature under a certain limit is the most important aspect for optimum performance of LED lights.

For this new designs of fins must be used to optimize the performance.

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