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Design of an LED Thermal System for Automotive Systems

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Abstract — The paper examines the high power Light Emitted diode (LED) and the hear distribution of the heat sink. Beside we also study the relationship between temperature and the current on the LEDs luminous efficiency. The temperature rise to over the limit level that the luminous efficiency will decrease rapidly. The current increase will cause the nonequilibrium electron diffuse out of the potential wall and will increase the temperature, so as to decrease luminous efficiency and the LEDs life [1]. Enhancing the heat manage of LEDs that can improve the luminous efficiency. Thermal design examines by using the thermal analysis.   Finally we propose the electrical circuit to drive the LEDs in constant current power to maintain the temperature more constant of LEDs.

Keywords — LED, thermal design, luminous efficiency, constant current power, vehicle lighting

I. INTRODUCTION

Illumination is very important for our daily life [1-3]. For all the light source developed, the semi-conductor lighting is e=seen to be a prominent device. Nowadays, Light Emitted diode (LED) is current widely used in the lighting industries.   In the case of the traffic lights in many countries, they use 70W – 165W incandescent bulbs traditionally and will be totally replaced by the semiconductor-based solid-state lighting (SSL), such as LEDs in the next five to ten years. The lighting with LEDs has several advantages which are ease of control, simple circuit design and high efficacy [4-5].   It also has a long life time. The reported lighting of more than continuous 20 years is not surprised. Although today, the materials cost is still on the high side, because of its favourable feature, many researcher, industries and civilian are considering the applications.

The long life and low power consumption make LEDs the ideal candidates for lightings system. The improvement in efficacy and lumen output from LEDs is following an exponential growth with 50 lumen/watt in 2005 to a foreseeable 100 lumen/Watt in the near future. It is now possible to improve the efficacy to 125 lumen/Watt by using specific light condensers and power converter. Thus current high power LEDs can provide 700 lumens per 5W. Using LED instead of traditional light bulbs can reduce around 40 – 70% energy. As a result, using LED as the lighting application becomes a new trend. Thermal distribution is major problem of high power LED life and lumen maintenance that dependent on many factors including, the method of electrical control, driver current and effective thermal management.

This paper is to discuss the thermal design of the LED. The design if the heat sink, thermal conductivity and its applications to lamp unit design are examined.

II. OPERATING PRINCIPLE OF LIGHT EMITTED DIONDE(LED)

A light-emitting-diode (LED) is a electronic device that is based on a p-n junction semi-conductor. It behaves as a diode but the people uses it as a light emitting device most of the applications.   Its efficiency is not very high and is around 20% and less but its internal efficiency can be achieved to be very high. Nevertheless the efficacy is still much higher than the conventional lighting sources such as incandescent lamp and is compatible to the fluorescent lamp.

According to Van Roosbrock-Shockley's law [1] and [6], solid-state material's emissivity is:

$$L(\nu) \approx 8\pi\nu^2 n^2 \alpha(\nu)\exp(-h\nu/k_BT)/c^2 \qquad (1)$$

n is refractive index, $\alpha(\nu)$ is absorption coefficient. For the junction-type semiconductor of electroluminescence LED, the emissivity of the photon with frequency ν is:

$$L(\nu) = n_u n_1 W_{em} = n_i^2 W_e \qquad (2)$$

n_u is the density of electrons with upper energy level. n_1 is the density of holes with lower energy level. n_i is the density of carrier under intrinsic excitation. Combining equation (1) and (2), we can get the transition probability in unit volume:

$$W_{em} = 8\pi\nu^2 n^2 \alpha(\nu)\exp(-h\nu/k_BT)/(c^2 n_i^2) \qquad (3)$$

The square of density of carrier under intrinsic excitation is:

$$n_1^2 = 2.32 \times 10^{30}(m_p^* m_n^*/m_0)^{3/2}T^3\exp(-E_g/k_BT) \qquad (4)$$

Combining equation (3) and (4), we can get the transition probability in unit volume further:

$$W_{em} = \frac{3.45 \times 10^{-30}\pi\nu^2 n^2\alpha(\nu)(m_p^* m_n^*/m_0)^{-3/2}\exp(E_g - h\nu/k_BT)}{T^3 c^2}$$

$$\approx \frac{\exp[(E_g - h\nu/k_BT)]}{T^3} \qquad (5)$$

From equation (5) it can be found that the radiant transition probability of the photon with frequency v is a decreasing function of temperature. That means high temperature decrease the radiant recombination rate. Then the lighting efficiency will also be decreased.

The radiation power is directly influenced by the junction temperature. And the radiation power increases linearly with the current increases. Keeping junction temperature constant that mean keeping cooling condition constant. When junction temperature of LEDs with higher thermal resistance increases more rapidly, hence the luminous efficiency decreases more obviously.

The most common inactivation of LED is the decrease of luminescence and efficiency. However, the instantaneous inactivation is also possible. The dislocation in the growth of the crystal can cause defect in crystal lattice. The defect can be further worse by heat, high temperature and light emitting.

High electron current under high temperature will make metal atom diffuse from electrode to active region. For some materials, especially indium oxide, tin oxide and silver oxide, the case of electron transfer is easy to take place. In some cases, especially for diode with GaN/InGaN, metal in blocking layer is used to block the transfer of electron. Mechanical stress, high current and corrosive environment can make tiny conjunction occur and then cause short circuit.

III. THERMAL MODELING

The main objective in any design is to restrict the junction temperature of a device within its permissible range under worst operating conditions. The junction temperature can be kept within the permissible range by mounting the device on a heat sink which conducts the heat away from the junction of the device thereby keeping the junction temperature to a safe limit. The transfer of heat between two surfaces can take place in a variety of ways. Three mechanisms of heat transfer can thus be identified and they are: (1) Conduction (2) Convection and (3) Radiation.

The thermal resistance is given by (6)

$$R_\theta = \frac{\Delta T}{P} = \frac{d}{\lambda A} \qquad (6)$$

where, λ is the thermal conductivity in W/m/sec, A is the cross-sectional area perpendicular to the flow of heat energy as shown in Fig 1.
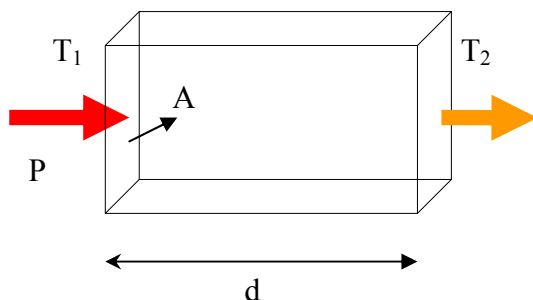

Fig 1 The heat transfer through any material is proportional to the temperature difference between the two ends

The convective thermal resistance is given by (7):

$$R_{\theta-convec} = \frac{1}{1.34 A_{convective}} \left(\frac{h}{\Delta T} \right)^{0.25} {}^0C/W \qquad (7)$$

where A is the surface area exposed to the surrounding air and h is the vertical height of the surface

Thermal resistance due to radiation is given by (8):

$$R_{\theta-rad} = \frac{\Delta T}{5.7 * 10^{-8} E A_{radiative} (T_S^4 - T_a^4)} {}^0C/W \qquad (8)$$

where E = emissivity of the surface (E = 0.9 for a black body & 0.05 for a polished surface), T_s is the surface temperature and T_a is the ambient temperature. Fig 2 shows the illustration of fictitious cuboid surrounding the heat sink.
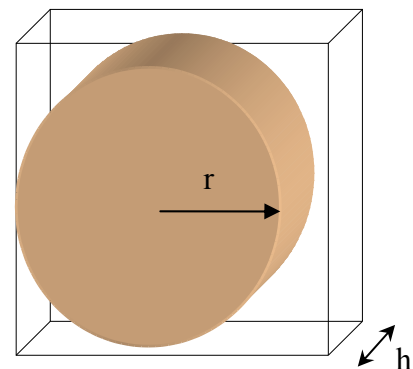

Fig 2 A fictitious cuboid surrounding the heat sink

IV.EXPERIMETAL RESULTS

The following diagram as shown in Fig 3 is the dimension (140 mm diameter) of the heat sink made of aluminum. It is primary used for the analysis of the thermal behaviour of the LEDs and heat sink.,
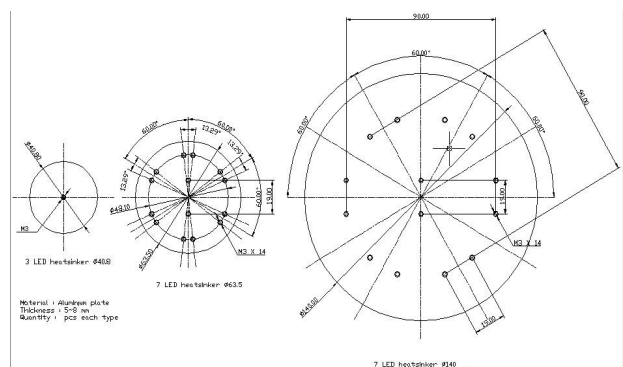

Fig 3 Heat sink dimension

The experiment is used the single 5W LED to obtain the 3600 samplings for each second shown as Fig 3. A high power LED is mounted on a circular disc of radius 14 cm and thickness 0.8 cm at the center. Seven sensors are connected at various points on the heat sink to measure the temperature of the heat sink. The sensor capture the steady and transient heat data with the power excitation time.

Fig. 4 The thermal experiment setting

Fig. 4 shows the thermal experimental setup which the LED is amounted to the proposed heatsink. The unit is then under the thermal tracing test.
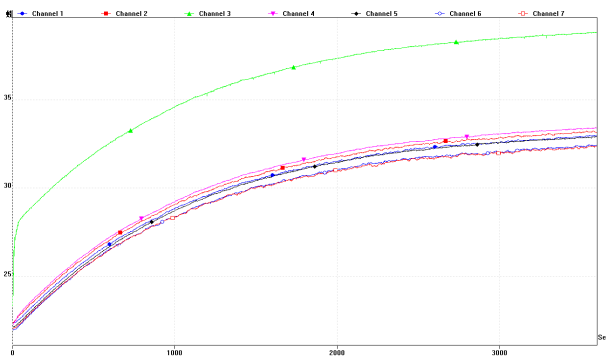

Fig. 5 Single 5W LED was used to do the thermal experiment (3600 samplings for each second)

V.PROPOSE ELECTRICAL FOR DRIVING LEDS

4.1. The circuit

For driving the LEDs, electrical circuit design of the better performance can be achieved by constant current power. The constant current power control can be providing the constant current to the LEDs which are very important to the LEDs life and the lumen maintenance. The advantage of constant current drive is that it can maintain the thermal of the LEDs. The LEDs cannot be operating at over heat to resulting reduced lumen maintenance and life.
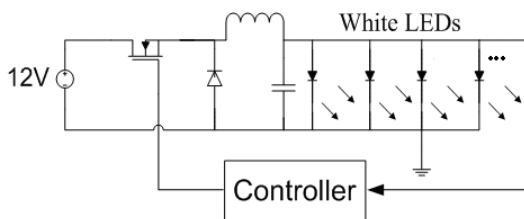

Fig. 6 LEDs drive of Buck converter

The forward current i_{LED} is proportional to the luminous flux of the LED. And the forward current is controlled by the duty ratio of the buck converter. The forward current has a direct relationship with the LED junction temperature. The over current flow of the LED will cause the junction temperature increase rapidly. Then the LED lifetime will be reduced and the luminous efficiency decrease. The buck is a dc to dc converter typically designed to stabilize the output current. So that the proposed topology can be applied. The converter also has an inductor in the output side. This stabilize the current to the LED. The method can provide a good current source to the LED and hence enhance the overall performance.

4.2. The current source driving

One of the important consideration of the LED driving is to use current source for the driving control. Because each of the LED is not high illumination enough, a number of LEDs are used are connected in parallel or series for the application. In the application design, the LED are connected in any series path should has a current mode control for each path. Fig 7 shows the configuration. Fig 8 and 9 show the fabricated LEDs for front-lighting unit. Seven LEDs is amount on a heart sink. The power for each LED is maximum 5W. The maximum power for each group of lamps is 35W. Two sets are in the lamp units. One for main beam and one of dipped head light.
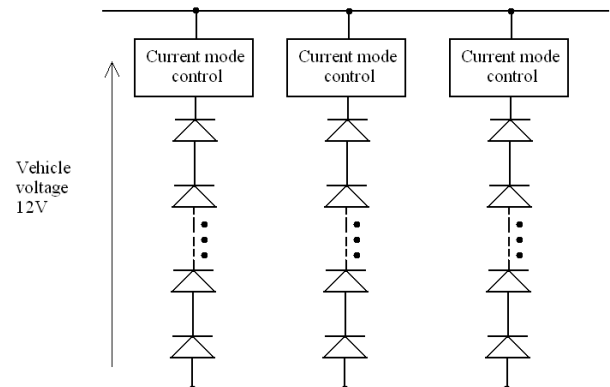

Fig. 7: The connection of LEDs in a current mode control manner

Fig. 8: LED front-lighting units for vehicle.

Fig. 9. LED front-light units for vehicle after excitation

Fig 10 and 11 show the installation of the matrix lighting of LED using a group of LEDs. Fig 10 is the LED tail light that provide signal, braking and reverse lighting. Fig 11 shows the installation of the tail lighting into a vehicle for the tail lighting.

Fig. 10. LED tail lighting for vehicle

Fig. 11. Installation of the LED to the tail lighting.

VI. CONCLUSION

LED is now a useful lighting for illumination. Its application has found in street lamp, vehicle front and tail lighting. Much research effort has been put in the field. One of the most important consideration is the thermal design. The LED is a hit spot that is different from other lighting such as fluorescent lamp which is large in surface areas and does not have hot spot problem. Other lighting such as HID and incandescent lamp, their emission are largely biased to radiation heat and therefore the thermal design is nit as important as LED.

This paper provides an analysis of the thermal design of the heat sink that is amounted with LEDD. The work started form single LED and examined its thermal behaviour and analysis its prediction of the thermal point. The analysis provide a analytical study of the thermal data for a heat sink unit under the fabrication of the LED.

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