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Optimization of Arrangement of LED on the PCB for High Power LED Module

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Abstract*: *LED operating under high-temperature condition badly affects reliability. To reduce junction temperature of LED is crucial. In this paper, luminous intensity and photo conversion efficient with respect to electrical power are discussed. Moreover, three arrangements for LED module are suggested, and design parameters are discussed in terms of the number of LEDs and distance between each LED. In order to evaluate thermal performance of designed the module, computer simulation was conducted. Distance between each LED is selected by 7.6, 9.6, and 13.3mm for 80, 128, and 240 LEDs, respectively and unit heat flux is calculated to be 0.47W/mm², 0.29W/mm², 0.16W/mm² for 80, 128, and 240 LEDs, respectively. In this case, Maximum temperature on the PCB was 67.8℃, 62.5℃, and 57.1℃ for 80, 128, and 240 LEDs, respectively. The Maximum temperature and unit heat flux was reduced by 15.7% and 66%, respectively, when the number of LEDs are increased by three times. We found that the temperature between LEDs can be reduced if unit heat flux can be reduced.

Keywords* : *Thermal resistance, Thermal degradation, High power LEDs, Heat transfer, Heat flux.

I. INTRODUCTION

LED is comparatively more energy efficient, environment friendly, longer life, lighter mass and smaller volume than the conventional luminaries of fluorescent lamp and incandescent lamp. Though the photo conversion efficiency of the LED of 15-25% is about twice of 10% of fluorescent lamp, the practical efficiency is much higher considering the spectrum matching to useful illumination. Therefore, LED has become a strong alternative replacing the artificial luminaries in various fields of industry [1].

Recently, LED has continuously widened its application as the power of single LED grows higher than watt level, however, the junction temperature has also increased with the power of single LED growing. Thermal problem is still existing problem again due to the degradation of luminous intensity and lifetime as well as wavelength shift [1].

To avoid many disadvantages caused by excessive heat generation and insufficient heat extraction from p-n junction, the temperature of LED should be maintained under a certain temperature that guarantee the normal operation as designed and expected. Normally, brighter illumination requires more number of small power LED or small number of LED with higher power. If large number of LEDs are attached to PCB(Printed circuit board) to get a certain illumination, the each LED requires low electrical energy compared to small number of high-power LEDs. In this case, though the heat generation from each LED can be significantly reduced, it is not sure the temperature of each LED to be maintained low because the distance between LEDs is closer due to large number of LED. Furthermore, the heat dissipation of LEDs is inefficient because the dielectric layers of the LED and the PCB have low thermal conductivity of 0.3-3.0W/mK[2]-[4]. MCPCB, metallic layer of high thermal conductivity attached to the PCB, is now widely used to increase thermal conductivity of the PCB [5]. Another method to reduce the junction temperature is to find the optimum arrangement of proper number of LEDs on the PCB. In this paper, we calculated parameters of heat flux and thermal resistance to find the most effective LED lighting system in three arrangements of LEDs on the PCB. In each arrangement of the LEDs the unit heat flux and temperature distribution are also discussed.

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II. THERMAL RESISTANCE ANALYSIS

In the medium heat transfers from high temperature to low temperature region. Heat flux in the medium depends on thermal conductivity, area, length, and temperature difference as follows:

$$Q = k\frac{T_1 = T_2}{L} \quad (1)$$

Where Q is heat flux, T_1 is highest temperature, T_2 is lowest temperature, k is thermal conductivity, and L is length of medium. If heat is exchanged between surface of medium and fluid that meets the surface, heat flux can be given as [6]-[8]:

$$Q = hT_n = T_{outer} \quad (2)$$

Where, T_n is temperature at nth point on the surface, T_{outer} is fluid temperature, h is convection coefficient and n is integer.

Thermal resistance is used to evaluate thermal performance of electronic devices and the resistance is defined as follows [6]-[8]:

$$R = \frac{T_1 - T_2}{Q} \quad (3)$$

Where R is the thermal resistance. Fig. 1 shows the many LEDs attached on the PCB and its equivalent thermal circuit. If the number of LED on the PCB is increased, each LED requires less electrical energy when Q_{tot} is assumed to be constant. In order to reduce junction temperature, the arrangement and the number of LEDs on the PCB are crucial.

In this case, total thermal resistance and heat generation can be written as follows:

$$Q_{tot} = Q_1 + Q_2 + Q_3 + \cdots + Q_n$$
$$\unrhd (T_1 - T_2)\frac{1}{R_1 + R_2 + R_3 + \cdots + R_4} = \frac{(T_1 - T_2)}{R_{tot}} \quad (4)$$

Where Q_{tot} is total heat, Q_n is individual heat which produced from the LED, R_{tot} is total thermal resistance, R_n is thermal resistance of individual LED, and n is integer.

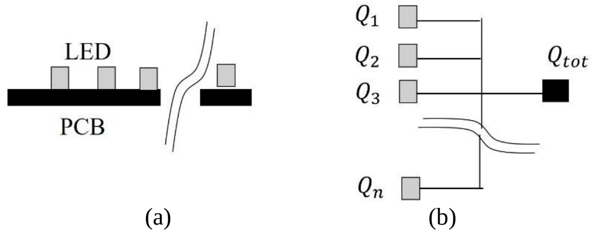


Fig 1. Schematic diagram. (a) LEDs attached on the PCB, (b) thermal equivalent circuit for LEDs

Heat flux of LED can significantly be lowered in case of the large number of LED on the PCB. Unit heat flux for each LED can be calculated as.

$$Q = \frac{Q_{tot} \times \eta}{n \times a} \quad (5)$$

Where η is thermal conversion efficiency, n is the number of LED, a is the surface area of single LED.

III. RESULT AND DISCUSSION

We investigated photo conversion efficiency and luminous intensity of LED module with respect to the electrical input power. The module of 12 LED was placed inside integrating sphere, and the electrical power applied to the module with adjusting the electrical input power from 1.3W to 5.7W to measure the luminous intensity and the photo conversion efficiency. Single LED consumes 100mW and 480mW when 1.3W and 5.7W applied to the module, respectively. Fig. 2 shows the luminous intensity and photo conversion efficiency versus the electrical input power applied to the LED. The luminous intensity was 328lm at 1.3W and it was increased to 1100lm at 5.7W. Photo conversion efficiency was 246.5lm/W at 1.3W and it was decreased to 192.6lm/W at 5.7W. Photo conversion efficiency was decreased by 21.8% when the electrical power is increased from 1.3W to 5.7W. According to this result, the temperature of each LED should be kept as low as possible.

Computer simulation was performed to evaluate the thermal performance of LEDs. The distance between each LED were 7.6, 9.6, and 13.3mm when the number of LEDs were 240, 128 and 80, respectively. Thermal conversion efficiency and total electrical input power are assumed as 75% and 100W. The surface area of single LED is about 2.0mm^2, and the calculated unit heat flux were 0.47W/mm^2, 0.29W/mm^2, 0.16W/mm^2 for 80, 128, and 240 LEDs, respectively. When the number of LED is increased by three times, the unit heat flux is decreased by 65.9%. Fig. 3 shows the simulated model for 240 LEDs.

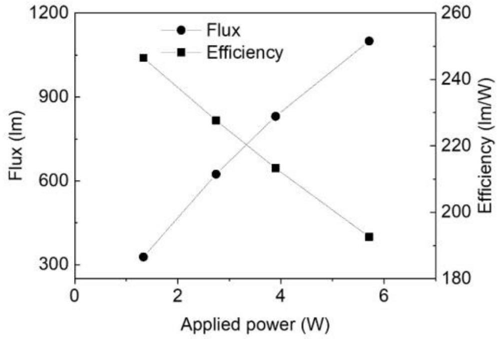


Fig. 2. Luminous intensity and photo conversion efficiency with respect to applied electrical power.

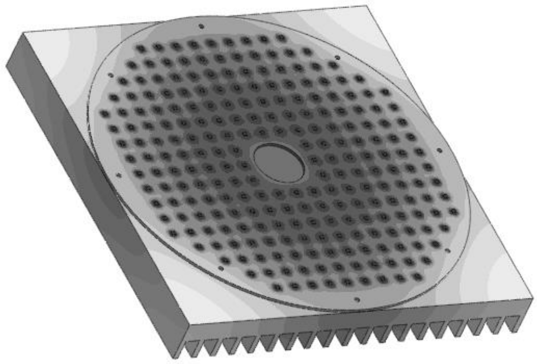
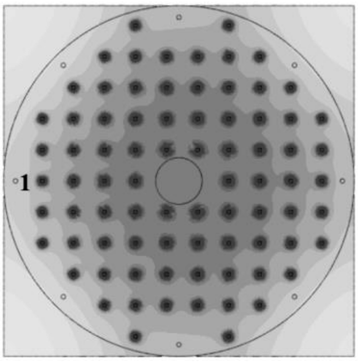
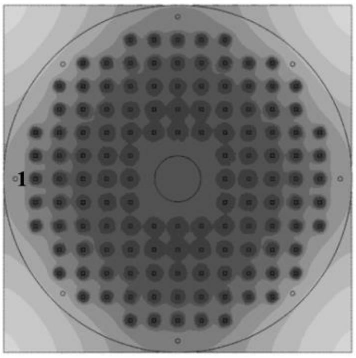


Fig. 3. Simulation model

The diameter of MCPCB is 300mm and it is attached to the aluminum heatsink. The width, length and thickness of the heat sink are 300mm, 300mm and 18mm, respectively. The thermal conductivity of metal core PCB is 8.5W/mK [9,10]. LED is assumed as GaN. Thermal conductivity of LED is 130W/mK and thermal conductivity of heatsink is 204W/mK [9,10]. Convection coefficient, h is normally from 5×10^{-6}W/mm2 to 30×10^{-6}W/mm^2. In this simulation, the coefficient is assumed to be 30×10^{-6}W/mm^2 [10]. Fig. 4 shows the simulated thermal image. Darker region represent higher temperature. The temperature of the center position, indicated 1 in fig.4 located along the horizontal line, was used from comparison. The highest temperatures at 1 position were 67.8°C, 62.5°C, and 57.1°C for modules of 80, 128, and 240 LEDs, respectively. The lowest temperatures were 49.7°C, 50.6°C, 50.3°C for modules of 80, 128, and 240 LEDs, respectively. Those temperature distributions are shown in fig. 5. The module of 80 LEDs shows the lowest temperature distribution. The thermal conductivity of PCB is quite low compared to aluminum heat sink. The heat surely transferred to the heat sink rather than the surface direction of MCPCB. Longer distance between each LED showed the less heat transfer along the PCB surface. Therefore, the module of 80 LEDs shows the lowest temperature at the position between LEDs on the MCPCB in three arrangements. However, when we compared the modules of 128 LEDs and 240 LEDs, the temperature at the position between LEDs in module of 240 LEDs shows 0.3°C lower than that of the 128 LEDs module because the unit heat flux of 240 LEDs module is significantly lower than that of 128 LEDs module.



(a)



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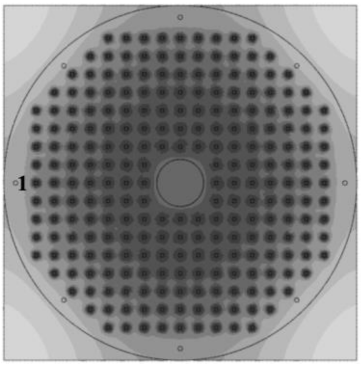
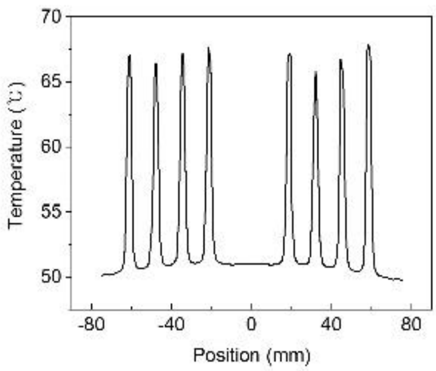


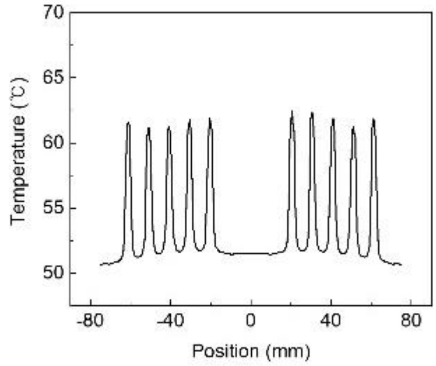
(c)

Fig. 4. Simulated thermal image. (a) 80LEDs, (b) 128LEDs, (c) 240LEDs

Fig. 5 shows that the temperature of LED p-n junction depends on the unit heat flux. The temperatures of the spike top represent the p-n junction temperature, and the temperatures of bottom background are for the between LEDs.



(a)



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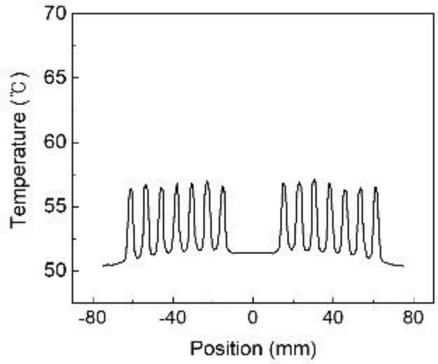
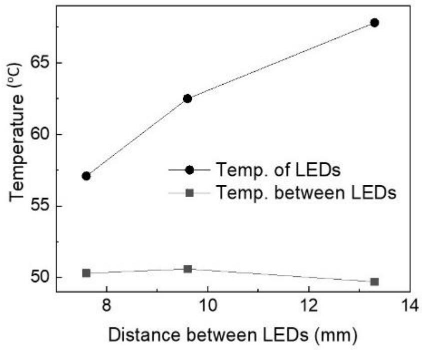
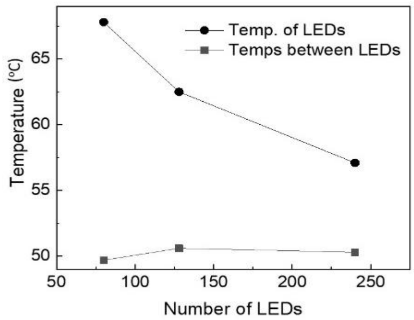


(c)

Fig. 5. Temperature distribution along horizontal line at the center, indicated as 1 in fig. 4 (a) 80LEDs, (b) 128LEDs, (c) 240LEDs



(a)



(b)

Fig 6. Temperatures at positions of LEDs and between LEDs as functions of (a) distance between LEDs and (b) the number of LEDs

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Fig. 6 shows the variations of temperatures at positions of LEDs p-n junction and between LEDs as functions the distance between LEDs and the number of LEDs. The temperature of LEDs shows the incremental and decremental changes as increasing the distance between LEDs and the number of LEDs, respectively. It can be easily understood because the electrical input power to individual LED and the distance between LEDs depend on the number of LEDs. However, the temperature at position between LEDs showed the different results. It increased when the number of LEDs changed from 80 to 128 as the distance between LEDs changed from 13.3mm to 9.6mm, respectively. After then decreased when the number of LEDs changed from 128 to 240 as the distance between LEDs changed from 9.6mm to 7.6mm, respectively. When the distance is getting close, the heat generated from the LEDs interferes each other. Therefore, the temperature between LEDs can rise. However, the reduction of unit heat flux contributes to reduce the temperature between LEDs although the heat of adjacent LED interferes each other.

IV. CONCLUSION

The LEDs operating under high temperature led to several disadvantages related to reliability. In order to overcome the disadvantages, Low temperature at the junction should be kept.

Moreover, the number of LEDs on MCPCB should be carefully selected for the optimum operation. The total electrical input power also depends on the property of single LED and MCPCB. And the size of luminaries and the distance between LEDs also should be considered to control the heat dissipation. In this paper, we simulated three arrangements to get the optimum arrangement. The luminous intensity and photo convection efficiency were investigated with respect to various electrical input power. The luminous intensity was increased from 328lm to 1100lm when the electrical input power to single LED is adjusted from 1.3W to 5.7W. Whereas, the photo conversion efficiency was decreased from 246.5lm/W to 192.6lm/W when the electrical input power to single LED is increased from 1.3W to 5.7W.

Each LED on PCB need consume less electrical input power with reliability. In order to efficiently design the LED module, three types of the LED module were simulated with different distances between each LED. The distance between each LED was 7.6mm, 9.6mm, and 13.3mm, respectively and the number of LEDs are 80, 128, and 240 for 7.6mm, 9.6mm, and 13.3mm, respectively. Maximum temperature was 67.8°C, 62.5°C, and 57.1°C for 80, 128, and 240 LEDs, respectively.

We could find the temperature between LEDs were 49.7°C, 50.6°C, 50.3°C for 80, 128, and 240 LEDs, respectively. Therefore, the optimum arrangement was assumed to be the module of 128 LEDs.

We showed the right way to find the optimum arrangement when the desired illumination should be designed in terms of the number of LEDs, the total electrical input power. It was to find the inflection point as functions of the distance between LEDs and the number of LEDs on PCB at a given electrical input power conditions. The photo conversion efficiency and the unit heat flux also should be considered.

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