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IMPROVED JUNCTION TEMPERATURE MEASUREMENT FOR HIGH POWER LED

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ABSTRACT

Peak wavelength and forward voltage methods are widely used to measure junction temperature of LED. However, these methods have an error in the measurement for high power LED caused by high current. In the calibration step, joule heating is not negligible if high current is applied even under low duty cycle. Improved junction temperature measurement by these methods is performed to solve that error. The LED package tested consists of six red LED chips attached on the metal board. The dimension of metal board is 30 mm x 32 mm with 3 mm thickness. When it is being operated, the operating current is 13.5 A with 25% duty cycle and 250 Hz of frequency. The result of peak wavelength method and forward voltage method are then compared. Forward voltage method shows higher standard deviation than peak wavelength method. The results of non-improved and improved measurement are also compared. Non–improved measurement shows the lower temperature. The influence of LED junction temperature to the luminous flux of light emitted is also investigated. Luminous flux tends to decrease while the junction temperature increases.

Keywords: light emitting diodes, junction temperature measurement, high power, peak wavelength, forward voltage.

INTRODUCTION

The mechanism of Light Emitting Diode to produce light is different with other light sources. LED consists of p-type and n-type semiconductor with a junction between them. When forward bias is applied to the LED, electrons and holes recombine at the junction accompanied by releasing heat and light energy [1].

Due to its advantages, LED technology has been applied in many applications to replace conventional light sources [2]. The weakness of LED is its performance is largely affected by junction temperature [3-4]. In high power LED, thermal management becomes a great interest for LED companies and researchers since high heat dissipation is produced [5-9].

Temperature measurement is usually performed by placing the sensor at the object. In LED junction temperature measurement, this method has limitation because the junction is located inside the chip where the sensor is almost impossible to place. Moreover, the size of sensor is larger than junction itself, so it causes error measurement. Due to this reason, the other methods have been introduced [10-15].

Peak wavelength and forward voltage of the LED are changed by the junction temperature. Therefore, one method to measure the junction temperature is to employ the LED itself as a temperature sensor. Currently, Peak wavelength and forward voltage methods are widely used to predict the junction temperature. Chajed *et al*. measured the junction temperature of low power LED by using forward voltage and peak wavelength method [12]. These methods have two steps, calibration step and actual step. In the calibration step, very low duty cycle was used to assume that joule-heating by electricity is negligible. For high power LED, due to the heat dissipation is much higher, that assumption causes error in the measurement. The correction for these methods should be taken into account to obtain more accurate measurement.

Improvements in junction temperature measurement of LED have been conducted to get more accurate measurement [16-17]. However, the use of low duty cycle without correction method is still used. This paper discusses the way to reduce error measurement caused by low duty cycle in calibration step for High Power LED junction temperature measurement. The measurement result of these two methods is compared. The influence of junction temperature to the luminous flux of light emitted is also investigated.

EXPERIMENTAL SETUP AND PROCEDURE

In this study, the high power red LED package for projector whose operating condition based on manufacturer recommendation is at 13.5 A of pulse current with 250 Hz frequency and 25% duty cycle was used. When it is being operated, the metal board must be maintained at the maximum temperature of 40 ºC. The LED package had six chips attached on the center of the metal board. The metal board dimension was 32mm x 30mm with 3mm thickness. The LED chips on the package were protected by thin transparent material. Figure 1 shows the schematic of the LED package.

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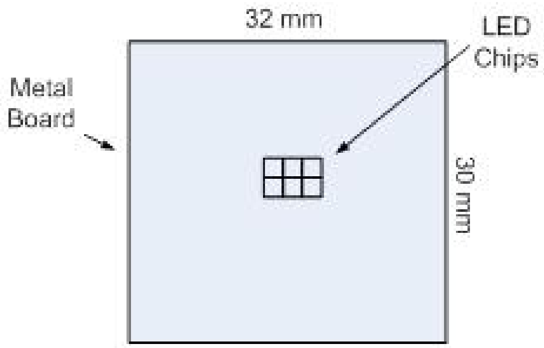

Figure-1. Example of figure in the text.

Basically, the procedures of peak wavelength and forward voltage method are similar. The difference is only at the measured parameter. These methods have two steps, calibration and actual step. Calibration step aims to obtain the temperature dependence of LED forward voltage or peak wavelength. In this step, LED was placed and heated inside the temperature controlled oven at the certain temperature. After thermal equilibrium between LED and oven had been reached, pulse current with very low duty cycle was applied to get assumption that no heat dissipation, thus the oven temperature and the junction temperature were assumed the same. Pulse current generator which is able to produce high current in pulsed shape was used in this calibration step. Forward voltage and peak wavelength were then measured by oscilloscope and spectrometer respectively.

In high power LED, since the high current is employed, heat dissipation still increases the junction temperature even under low duty cycle. To solve this problem, the correction method is needed. Therefore, 0.25%, 0.5%, 0.75%, and 1% duty cycle were used. To estimate the lowest duty cycle, those data were extrapolated to get the peak wavelength and forward voltage at 0% duty cycle which was assumed no heat dissipation in this condition. These procedures were repeated at different temperatures to obtain the relation between the junction temperature with peak wavelength or forward voltage by plotting to the graphs. The slope of the graphs were then determined. Equipment set up for the calibration measurement is shown in Figure-2.

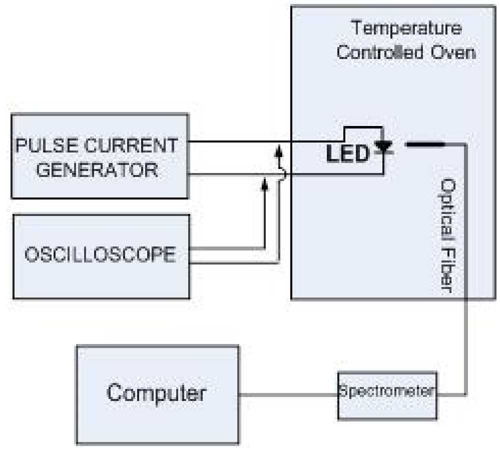

Figure-2. Calibration step measurement setup.

In the actual step, LED package was placed at room temperature (T_o). First, same pulse current with the calibration measurement is applied. Then, peak wavelength (λ_o) and forward voltage (V_o) were measured. Second, the LED was turned on at its operating condition. The metal board temperature was maintained at 40 ^oC by employing heat sink and fan. After stable condition had been established, the peak wavelength (λ_t) and forward voltage (V_t) were measured.

The peak wavelength and forward voltage of LED are assumed linear to the junction temperature up to 80-100 ^oC [13]. Therefore junction temperature was calculated by equation (1) for peak wavelength method and equation (2) for forward voltage method.

$$T_j = T_o + \frac{\lambda_t - \lambda_o}{K_\lambda} \quad (1)$$

$$T_j = T_o + \frac{V_t - V_o}{K_V} \quad (2)$$

Where T_j is junction temperature, K_λ and K_V are the slope of peak wavelength and forward voltage to the junction temperature respectively.

LED measurement system which consists of spectrometer and integrating sphere were used to measure luminous flux [18]. The LED light was directed to integrating sphere and travelled through optical fiber to the spectrometer. Luminous flux was then read at the computer. These parameters were measured simultaneously with the actual measurement, shown in Figure-3.

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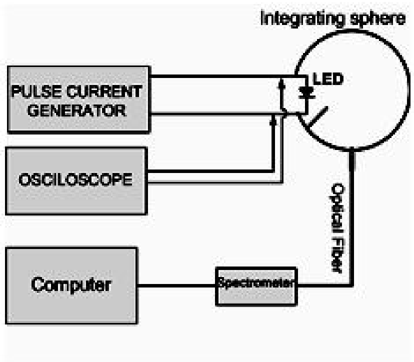
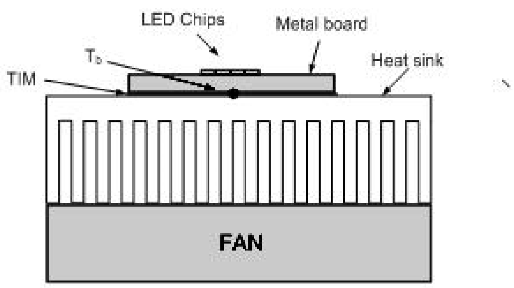


(a)

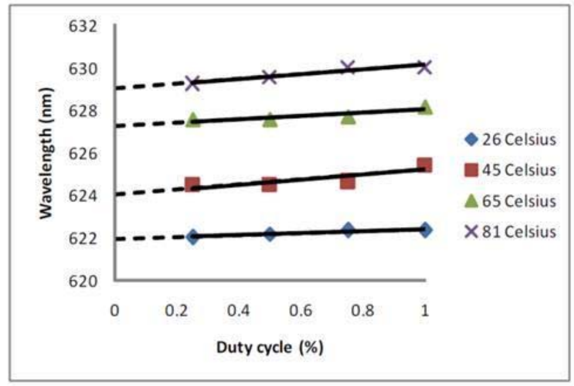


(b)

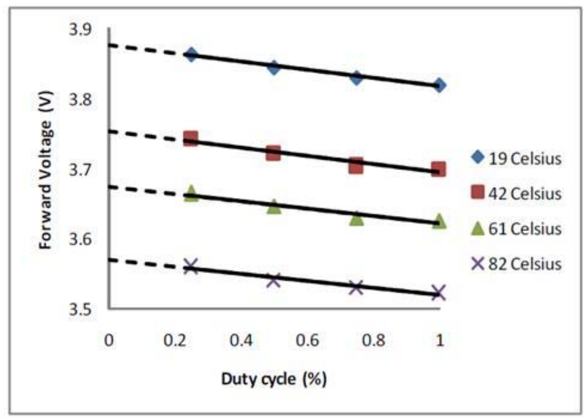
Figure-3. Actual measurement, radiant flux, and luminous flux measurement: (a) apparatus set up, (b) Heat sink and fan arrangement.

RESULT AND DISCUSSIONS

In the calibration step, the effect of duty cycle to the peak wavelength and forward voltage are shown in Figure-4. The peak wavelength and forward voltage are slightly different at every duty cycle since higher heat dissipation is produced at higher duty cycle and causes junction temperature slightly increase. To estimate at 0% duty cycle, peak wavelength and forward voltage are extrapolated at each temperature. The relation between junction temperature with peak wavelength or forward voltage at 0% duty cycle is established. The result shows that peak wavelength increases linearly with the increase of junction temperature, while forward voltage decreases with the increase of junction temperature. For comparison, the graphs of 1% and estimated 0% duty cycle are shown in figure 5. The slopes of peak wavelength and forward voltage, K_λ and K_V, are obtained 0.139 nm/°C and -4.8 mV/°C respectively for 0% duty cycle.



(a)



(b)

Figure-4. Effect of duty cycle in calibration measurement: (a) Duty cycle versus peak wavelength, (b) Duty cycle versus forward voltage.

Standard deviation is one of the important parameter to predict the measurement uncertainty [19]. The measurement was conducted ten times for each method to investigate uncertainty of measurement. The comparison between these methods is shown in Table-1.

Table-1. Result comparison of junction temperature measurement methods.

Method	T_j (0%)	T_j (1%)	Std. Deviation
Peak wavelength	68.3 °C	59.7 °C	2.3 °C
Forward Voltage	62.7 °C	55.6 °C	7.6 °C

The junction temperature was obtained 62.7 °C with standard deviation of 7.6 °C by forward voltage method. On the other hand, peak wavelength method results the junction temperature 68.3 °C with standard deviation of 2.3 °C. It means that the uncertainty of

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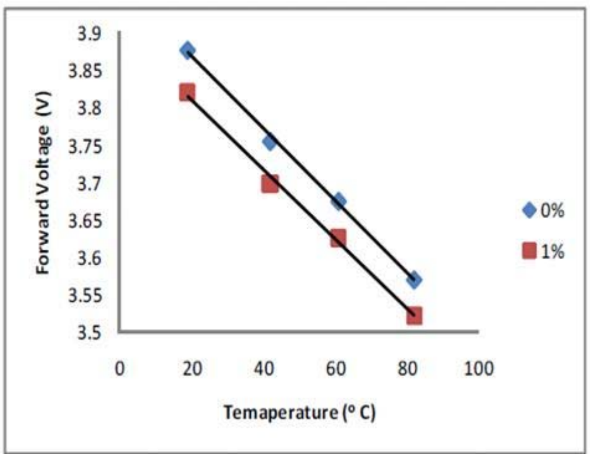
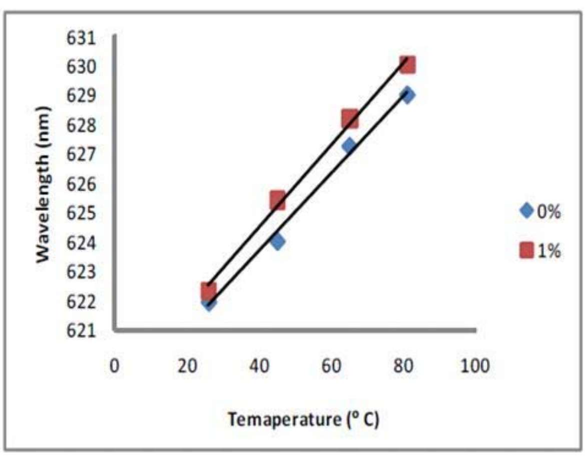
measurement by forward voltage is higher than peak wavelength method. Contact electrical resistance at the LED connector is affected even by small changes of its position. Meanwhile, the actual step uses pulsed high current at constant level which absolutely creates forward voltage when it flows to the electrical resistance. This fact causes the high sensitivity of forward voltage and makes uncertainty relatively high. On the other hand, peak wavelength method measures the wavelength of light produced by LED. Light properties of LED, including peak wavelength, tend to be constant if the current is not changed. Therefore, the uncertainty of peak wavelength method is relatively low.



(a)



(b)

Figure-5. (a) Temperature dependence of forward voltage, (b) Temperature dependence peak wavelength.

The junction temperature measurement by 0% duty cycle is higher than 1 % duty cycle because heat dissipation at 1% duty cycle causes additional error to the measurement. The results show that the temperature difference between 0% duty cycle and 1% duty cycle are 8.6 ^{o}C and 7.1 ^{o}C for peak wavelength and forward voltage method respectively.

Since the uncertainty of peak wavelength method is lower, this method is used to investigate the influence of junction temperature to the luminous flux of LED, shown in Figure-7. The trend shows that higher junction temperature causes the decreasing luminous flux significantly. The gap energy between valence and conduction band in semiconductor materials depends on the temperature [20]. The lower gap energy band occurs at the higher temperature. Luminous flux, which is a measure of light power, depends on this gap energy. Therefore, the lower band gap energy results the lower luminous flux. This also causes forward voltage decrease and peak wavelength increase when the temperature increases.

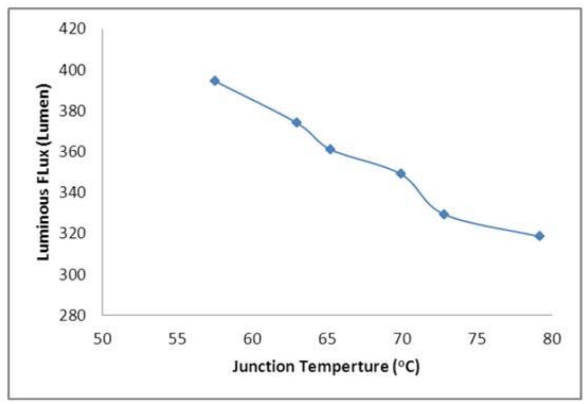


Figure-6. Influence of junction temperature to the luminous flux.

CONCLUSIONS

In this paper, an improved junction temperature measurement by peak wavelength and forward voltage method for high power LED are presented. In the calibration step, the method to estimate the lowest duty cycle (0%) is performed to get more accurate measurement. Non-improved measurement (1% duty cycle) shows 8.6 ^{o}C and 7.1 ^{o}C lower than improved measurement result for forward voltage and peak wavelength method respectively. In the comparison between the two methods, the result shows that the standard deviation of peak wavelength method (2.3 ^{o}C) is lower than forward voltage method (7.6 ^{o}C). The luminous flux is also observed decrease while the junction temperature increases.

REFERENCES

[1] Fangming YE. High Power LEDs: a review, Topic Paper for ECE226 Optoelectronic Devices.

[2] Jeff Y. Tsao, Solid-state Lighting. 2004. IEEE Circuits & Devices Magazine May/June.

[3] S. Chajed, Y. Xi, Y.-L. Li and Th. Gessmann, E. F. Schubert. 2005. Influence of junction temperature on chromaticity and color-rendering properties of trichromatic whitelight sources based on light-emitting diodes. Journal of applied physics. (97): 054506.

[4] Jen-Cheng Wang, Chia-Hui Fang, Ya-FenWu, Wei-Jen Chen, Da-Chuan Kuo, Ping-LinFan, Joe-ir Jiang, Tzer-En Nee. 2012. The Effect of Junction Temperature on the optoelectrical properties of InGaN/GaN multiple quantum well-emitting diodes. Journal of Luminescence. (132): 429-433.

[5] C.T. Yang, W.C. Liu, C.Y. Liu. 2012. Measurement of thermal resistance of first-level Cu substrate used in high-power multi-chips LED package. Microelectronics Reliability. (52): 855-860.

[6] Lan Kim, Woong Joon Hwang, and Moo Whan Shin. 2006. Thermal Resistance Analysis of High Power LEDs with Multi-chip Package. Electronic Components and Technology Conference 56th p. 6.

[7] Ting Cheng, Xiaobing Luo, Suyi Huang, Sheng Liu. 2010. Thermal analysis and optimization of multiple LED packaging based on a general analytical solution. International Journal of Thermal Sciences. (49): 196-201.

[8] Lianqiao Yang, Sunho Jang, Woongjoon Hwang, Moowhan Shin. 2007. Thermal analysis of high power GaN-based LEDs with ceramic package. Thermochimica Acta. (455): 95-99.

[9] Tri Ayodha, Hun Sik Han, Joongnyon Kim, Seo Young Kim. 2012. Effect of Chip Die Bonding on Thermal Resistance of High Power LEDs. 13th IEEE ITHERM Conference. pp: 957-961.

[10] Yimin Gu and Nadarajah Narendran. 2004. A non-contact Method for determining junction temperature of phosphor converted white LEDs. Third International Conference on Solid State Lighting, Proceedings of SPIE. (5187), pp. 107-114.

[11] Y. Xi and E. F. Schubert, Junction–temperature measurement in GaN ultraviolet light-emitting diodes using diode forward voltage method. 2004. Applied Physics Letter. (85): 2163-2165.

[12] S. Chhajed, Y. Xi, Th. Gessmann, J.-Q. Xi, J. M. Shah, J. K. Kim, and E. F. Schubert. 2005. Junction temperature in light-emitting diode assessed by different methods. Proc. of SPIE, pp: 16-24.

[13] Chi-Yuan Lee, Ay Su, Yin-Chieh Liu, Wei-Yuan Fan and Wei-Jung Hsieh. 2009. In Situ Measurement of the Junction Temperature of Light Emitting Diodes Using a Flexible Micro Temperature Sensor. MDPI Journal Sensors. (9): 5068-5075

[14] Jason Chonko, Using Forward Voltage to Measure Semiconductor Junction Temperature. 2006. Keithley Instrument Inc. paper. (2): 1-3.

[15] J. Senawiratne, A. Chatterjee, T. Detchprohm, W. Zhao, Y. Li, M. Zhu, Y. Xia, X. Li, J. Plawsky , C. Wetzel. 2010. Junction temperature, spectral shift, and efficiency in GaInN-based blue and green light emitting diodes. Thin Solid Films. (518): 1732-1736.

[16] HE Su-Ming, LUO Xiang-Dong, Zhang Bo, FU Lei, Cheng Li-Wen, Wang Jin-Bin, LU Wei. 2012 An Improvement on the Junction Temperature Measurement of Light-Emitting Diodes by using the Peak Shift Method Compared with the Forward Voltage Method, CHIN. PHYS. LETT. (20): 127802.

[17] Huaiyu Ye, Xianping Chen, Henk van Zeijl, Alexander W. J. Gielen, and Guoqi Zhang. 2013. Thermal Transient Effect and Improved Junction Temperature Measurement Method in High-Voltage Light-Emitting Diodes. IEEE Electron Device Letters vol. (34): 1172-1174

[18] Handbook of LED Metrology, Instrument Systems GmbH, Version 1.1, Germany pp. 20-24

[19] Stephanie Bell. 2001. Measurement Good Practice Guide. Issue 2 Chapter. 6 pp. 11-12,

[20] Robert F. Pierret. 1996. Semiconductor Device Fundamentals Chapter. 2 pp. 31-32