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Abstract
Performance of white light LEDs has improved significantly over the past few years. White LEDs are typically created by incorporating a layer of phosphor over the GaN-based blue emitter. Heat at the *p-n* junction seems to be the major factor that influences light output degradation in these devices. In an earlier paper, the principal authors of this manuscript demonstrated that the junction temperature of white LEDs could be measured from the (W/B) ratio, where W represents the total radiant energy of the white LED spectrum, and B represents the radiant energy within the blue emission peak. In that earlier study, the concept was verified using commercially available 5-mm type white LEDs. The goal of the study presented here was to evaluate whether the (W/B) ratio could be used to estimate junction temperature of new high-flux white LEDs. The results show that (W/B) ratio is proportional to the junction temperature of the high-flux white LED; however, the proportionality constants are different for the different white LED types.

Introduction
Since the first demonstration of white light-emitting diodes (LED) in the mid-1990s, the performance of these devices in terms of light output, efficacy, and lumen maintenance, has improved significantly [1]. Presently, white LEDs are created by incorporating a layer of phosphor over the GaN-based blue emitter. Similar to most light sources, the light output of white LEDs, too, degrades slowly over time [2]. Yellowing of the encapsulant and the die attach epoxy, oxidation of the metal reflector cup and lead wires, and diffusion of impurities and growing crystalline defects are some factors that have been cited as possible reasons for long-term light output degradation in white LEDs. Heat at the *p-n* junction influences almost all of these factors and contributes to the degradation of white LEDs. Therefore, reducing the junction temperature should improve the performance of LEDs.

The question is how one should measure the junction temperature of LEDs. Most methods presently used for measuring junction temperature require access to the lead wires of the LEDs, which may not be easy when the LEDs are packaged into a system. In 2003, the principal authors of this manuscript demonstrated a method by which the junction temperature of white LEDs were measured non-intrusively [3]. The method was validated using 5-mm type white LEDs with a single phosphor. The method depended on the fact that with increasing junction temperature, the emission intensities of the blue and yellow radiations of white light emitted by the LED decreased at different rates [4]. The ratio of the total radiant energy of the white LED spectrum (W) to the radiant energy within the blue emission peak (B) was shown to change proportionally with the junction temperature [3]. The next question is whether the same method can be used for other types of white LEDs that use more than one phosphor. Therefore, the goal of the study presented in this paper was to investigate whether the method proposed by Gu et al. is applicable to other types of white LEDs.

Methodology

The experimental setup and the method used in this study were very similar to Gu et al's setup and method [3]. The junction temperatures, T_j, of the LEDs were estimated from the following equation [5, 6]

$$T_j = T_p + P_j \cdot R\theta_{j-p} \quad \text{(Equation 1)}$$

where T_p, P_j, and $R\theta_{j-p}$ are the LED pin temperature, junction power dissipation, and thermal resistance coefficient from the junction to the pin, respectively. This method is referred to as the pin temperature method. Junction power dissipation is the product of the forward current and the forward voltage. Although the pin temperature method for estimating junction temperature was convenient, the thermal resistance coefficients of the white LEDs used in this study were not readily available. Therefore, the thermal resistant coefficient was measured by measuring the junction temperature using the forward voltage method described in Hong et al's study [7]. Once $R\theta_{j-p}$ was determined, then T_j was easily measured by measuring the pin temperatures. A J-type thermocouple was used to monitor the pin temperatures of the LEDs.

Two high-flux white LEDs, each with more than one phosphor, were used in this experiment. At three different ambient temperatures, the current through the LEDs was changed systematically. The corresponding junction temperatures were measured and, at the same time, the spectrum was captured using a spectrometer. From the spectrum, the (W/B) ratio was calculated as described in Gu et al's paper [3].

Results

Figure 1 illustrates the spectral power distributions of the different LEDs. Figure 2 illustrates the (W/B) ratio versus junction temperature for the three types of LEDs. The data for the 5-mm type LED was taken from the earlier study. Figure 2 illustrates that the (W/B) ratio is proportional to junction temperature for each type of white LED. The slope of each white LED was obtained from a linear regression line drawn through the data points. Figure 3 illustrates the linear relationship between the W/B ratio and the junction temperature for the three types of white LEDs. As seen in Figure 3, the slopes are different for the different types of white LEDs.

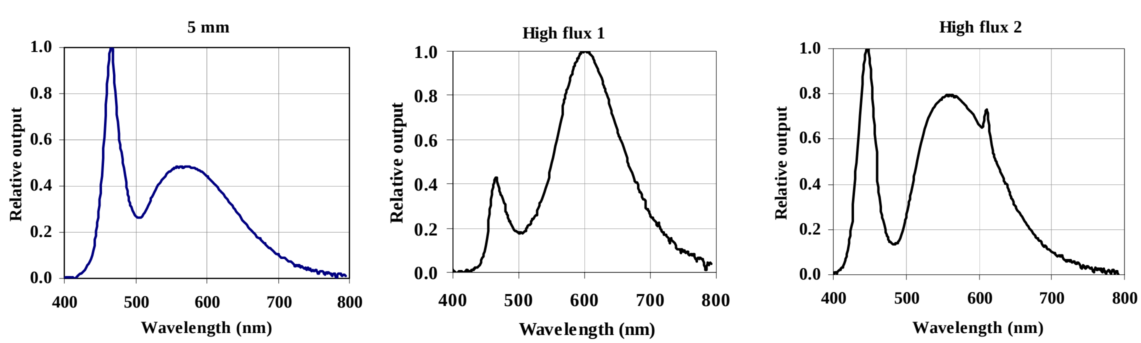

Figure 1: Spectral power distributions for the different white LEDs.

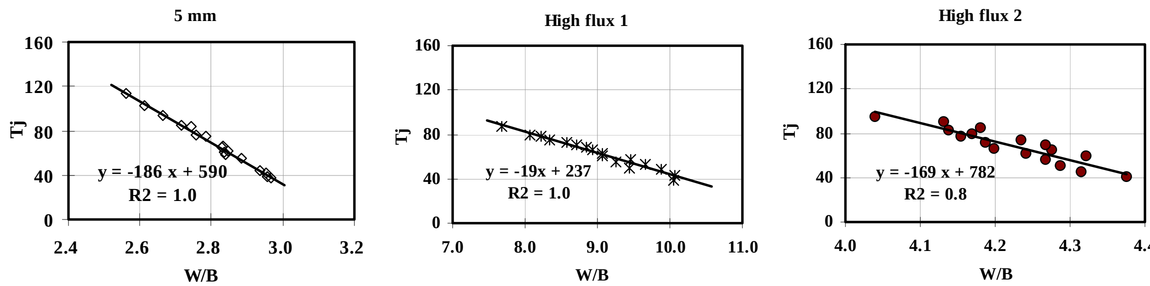

Figure 2: Effect of junction temperature on W/B ratio for the different white LED samples.

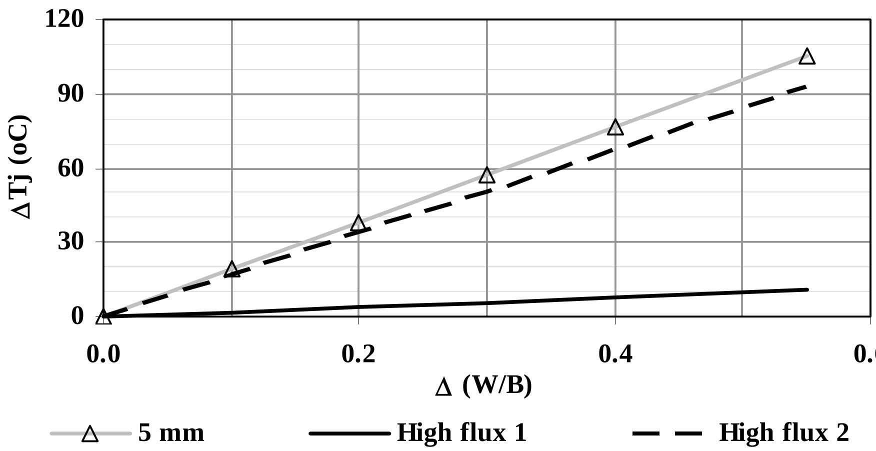

Figure 3: Relationship between change in junction temperature and change in (W/B) ratio for the three types of white LEDs.

Summary

This study verified that that the W/B method can be used to estimate junction temperature of different types of white LEDs; however, the proportionality constants are different for the different white LED types.

Acknowledgements

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References

1. Nakamura, S., T. Mukai, and M. Senoh. 1994. Candela-class high brightness InGaN/AlGaN double-heterostructure blue-light-emitting-diodes. *Appl.Phys. Lett.* 64 (13): 1687-1689.
2. Narendran, N., et al. 2001. What is useful life for white light LEDs? *J. Illum. Eng. Soc.* 30 (1): 57-67.

3. Gu, Y., and N. Narendran. 2003. A non-contact method for determining junction temperature of phosphor-converted white LEDs. *Third International Conference on Solid-State Lighting, Proceedings of SPIE* 5187: 107-114.
4. Tamura, T., et al. 2000. Illumination characteristics of lighting array using 10 candela-class white LED under AC 100V operation. *J. Luminescence* 87-89: 1180-1182.
5. Lumileds. LuxeonTM, AB05, Thermal Design Considerations for LuxeonTM Power Light Sources.
6. OSRAM Opto Semiconductors. Thermal Considerations for LEDs in Display Application. Application Notes V00-01.
7. Hong, E., and N. Narendran. 2003. A method for projecting useful life of LED lighting systems. *Third International Conference on Solid-State Lighting, Proceedings of SPIE* 5187: 93-99.