A spectral measurement method for determining white OLED average junction temperatures

Yiting Zhu and Nadarajah Narendran*
Lighting Research Center, Rensselaer Polytechnic Institute, 21 Union St., Troy, NY 12180 USA

ABSTRACT

The objective of this study was to investigate an indirect method of measuring the average junction temperature of a white organic light-emitting diode (OLED) based on temperature sensitivity differences in the radiant power emitted by individual emitter materials (i.e., "blue," "green," and "red"). The measured spectral power distributions (SPDs) of the white OLED as a function of temperature showed amplitude decrease as a function of temperature in the different spectral bands, red, green, and blue. Analyzed data showed a good linear correlation between the integrated radiance for each spectral band and the OLED panel temperature, measured at a reference point on the back surface of the panel. The integrated radiance ratio of the spectral band green compared to red, (G/R), correlates linearly with panel temperature. Assuming that the panel reference point temperature is proportional to the average junction temperature of the OLED panel, the G/R ratio can be used for estimating the average junction temperature of an OLED panel.

Keywords: organic light-emitting diode, OLED, white OLED, fluorescent, phosphorescent, junction temperature measurement, thermal sensitivity, spectrum change

1. INTRODUCTION

Organic light-emitting-diode (OLED) technology has the potential to provide novel solutions in display and certain lighting applications with low power demand. For OLED technology to be widely adopted in lighting applications, standardized metrics and testing methods are needed. Currently, there is no standardized method for measuring the temperature of an OLED device. Manufacturers of OLED panels define different temperature measurement points as the reference location. The temperature of an OLED device is usually measured by attaching a thermocouple at the OLED panel emitting surface[1] or by using an infrared thermometer or an imaging infrared camera.[2,3] Junction temperature is an important parameter to determine semiconductor device performance. Since the OLED is a large area source, p–n junctions are spatially distributed. Therefore, the average junction temperature of the OLED panel can be used to estimate photometric and lifetime performance. Several methods have been used to estimate OLED junction temperatures, including voltage drop method[4], Raman-spectroscopy method by targeting specific molecules in the organic layers[5], and an optical method by deriving junction temperature profiles from luminance profiles on the OLED device emitting surface.[6]

The two most popular white OLED device structures are: (1) a hybrid device with fluorescent blue and phosphorescent green and red emitter materials[7]; (2) an all-phosphorescent device with blue, green, and red phosphorescent emitter materials.[1] Few studies have discussed how heat affects the spectrum of white OLED devices. Some studies have shown that temperature affects the light output and spectrum of individual emitter materials (e.g. "red" and "green").[8,9]

The objective of this study was to investigate a method for estimating the average junction temperature of white OLEDs based on changes in spectrum caused by temperature sensitivity differences in the radiant power emitted by individual emitter materials (i.e., "blue," "green," and "red").

2. EXPERIMENTS

The spectral radiance distributions of six white OLED panels from five manufacturers were characterized as a function of panel temperature when ambient temperatures varied from 25°C to 65°C at each panel's rated current. These panels were made up of all phosphorescent or a combination of phosphorescent and fluorescent red, green and blue materials. Each white OLED panel was mounted vertically inside a temperature-controlled enclosure similar to the experiment

Corresponding author: narenn2@rpi.edu; +1 (518) 687-7100; http://www.lrc.rpi.edu/programs/solidstate

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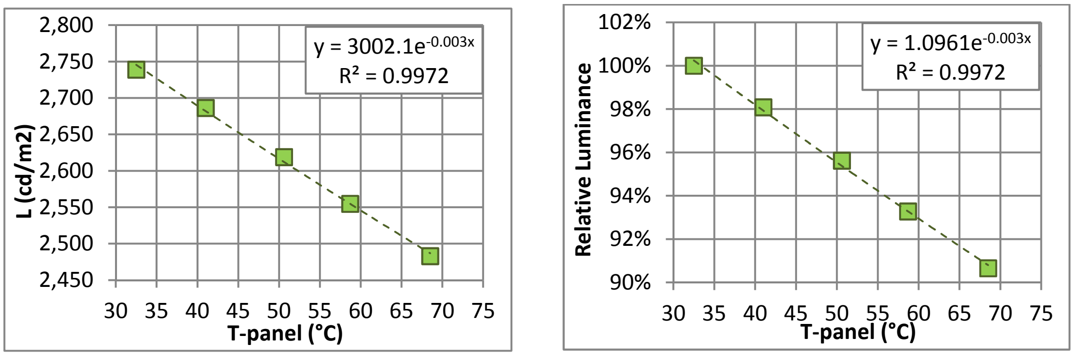
apparatus described in the authors' previous study.[10] A spectroradiometer was placed 1.96 m away from the OLED panel at the same height as the center of each OLED panel and aimed perpendicularly to the center of each OLED panel through the clear acrylic front cover of the temperature-controlled enclosure. An aperture size of 0.25 degree was used for the spectroradiometer for all spectral radiance measurements. The ambient temperature was monitored using a thermocouple located at the same height as the center of the OLED panel and at the back of the panel inside the temperature-controlled enclosure. Any direct optical radiation from the OLED panel was shielded from the thermocouple bead to avoid erroneous temperature readings. The panel temperature was monitored using a thermocouple attached to the center of the OLED back panel surface.

During each measurement, first the ambient temperature was set to a target value and spectral measurements were taken after each OLED panel reached thermal and optical stability. Spectral radiance distributions were recorded from the spectroradiometer and the corresponding ambient temperatures and panel temperatures were recorded simultaneously.

3. RESULTS

3.1 Results for OLED panel A

Detailed results are shown only for OLED panel A while similar analyses were conducted for other tested panels, and the summarized results are discussed in section 3.2. Figure 1(a) and Figure 1(b) show the luminance measured at the center of OLED panel A as a function of panel temperature in absolute units (cd/m^2) and relative units, respectively. When the ambient temperature reached the highest target level of 65°C, the panel temperature, which was measured at the center of the OLED back panel surface, reached 68.5°C and the relative luminance dropped to 90.7% of the initial luminance at an ambient temperature of 25°C (with corresponding panel temperature of 32.5°C). An exponential fit was applied following the Shockley model[11], and the correlation R^2 values are above 0.99.



(a) (b)

Figure 1. (a) Luminance at the center of OLED panel A as a function of panel temperature in absolute units (cd/m^2); (b) Relative luminance at the center of OLED panel A as a function of panel temperature.

Figure 2 shows the chromaticity coordinates measured at the center of OLED panel A at varying panel temperatures plotted in the CIE 1931 (x,y) chromaticity diagram. There was a 8.9 step MacAdam ellipse color shift towards red when the OLED panel temperature increased from 32.5°C to 68.5°C. Figure 3(a) and Figure 3(b) show the spectral radiance distributions at the center of OLED panel A at varying panel temperatures in absolute units and relative units, respectively. The relative spectral radiance distributions in Figure 3(b) revealed a higher amount of decrease in the "blue" and "green" spectral bands than in the "red" spectral band, and therefore there was a "red" color shift when the temperature increased.

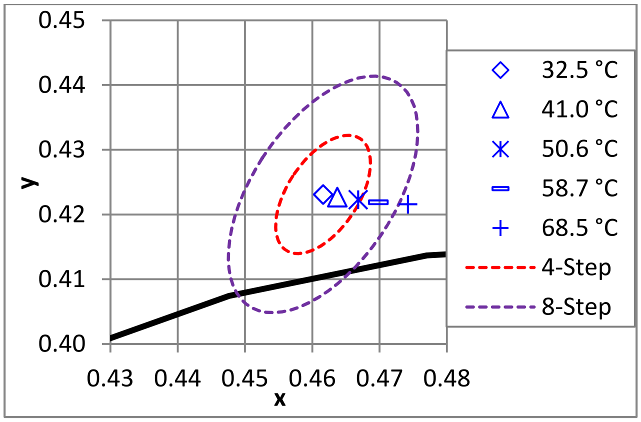
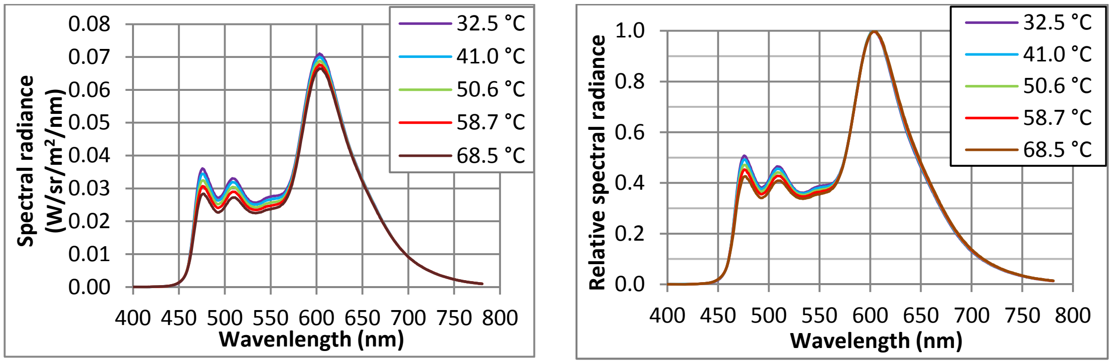


Figure 2. Chromaticity coordinates measured at the center of OLED panel A at varying panel temperatures plotted in the CIE 1931 (x,y) chromaticity diagram.



(a) (b)

Figure 3. Spectral radiance distributions at the center of OLED panel A at varying panel temperatures in: (a) absolute units and (b) relative units.

The radiance of each spectral band, "blue," "green," and "red," was calculated by integrating the area under the spectral radiance distributions plotted in Figure 3 following Equation 1:

$$\boldsymbol{Radiance} = \int_{\boldsymbol{\lambda_1}}^{\boldsymbol{\lambda_2}} \boldsymbol{S(\lambda)d\lambda} \qquad \text{(Eq. 1)}$$

in which $S(\lambda)$ represents the spectral radiance distribution, and λ_1 and λ_2 represent the starting and ending wavelengths for the radiance calculation (e.g., "blue" spectral band). Table 1 lists the relative radiance at each tested ambient temperature for "blue," "green," and "red" spectral bands, normalized at an ambient temperature of 25°C. The "blue" spectral band ranges from 400 to 530 nm; "green" spectral band ranges from 530 to 560 nm; and "red" spectral band ranges from 560 to 780 nm. The criterion in selecting the wavelength range for each spectral band was based on emission spectrum cross-over points. For each spectral band, the relative radiance was calculated by taking the ratio of the radiance at each elevated ambient temperature over the radiance at an ambient temperature of 25°C. Figure 4 shows the relative radiance ratios for spectral bands "blue," "green," and "red" as functions of panel temperature for OLED panel A. The figure shows that the relative radiance ratios for each spectral band all follow a linear relationship as a function of panel temperature measured at the reference location, with R^2 values above 0.99. The "blue" spectral band decreased the most with increasing temperatures, followed by "green" and then "red". This is consistent with the chromaticity shift towards red with increasing temperature seen in Figure 2. Figure 5(a), (b), and (c) show the relative radiance ratios for "blue" over "red" (B/R), "green" over "red" (G/R), and "blue" over "green" (B/R) as functions of panel temperature for OLED panel A, respectively. Relative radiance ratios for B/R and G/R show better linear correlations than B/G ratios as functions of panel temperature, which is due to the relatively smaller difference in thermal sensitivity between “blue” and “green” spectral bands. Similar results were observed for the other five panels, named B, C, D, E and F.

Table 1. Relative “blue,” “green,” and “red” radiance at different panel temperatures for OLED panel A.

Panel T(°C)	32.5	41.0	50.6	58.7	68.5
Ambient T1(°C)	25	35	45	55	65
“Blue” Radiance (400-530nm)	100.0%	96.8%	92.5%	88.2%	82.9%
“Green” Radiance (530-560nm)	100.0%	97.2%	93.8%	90.6%	86.9%
“Red” Radiance (560-780nm)	100.0%	99.1%	97.8%	96.6%	95.5%

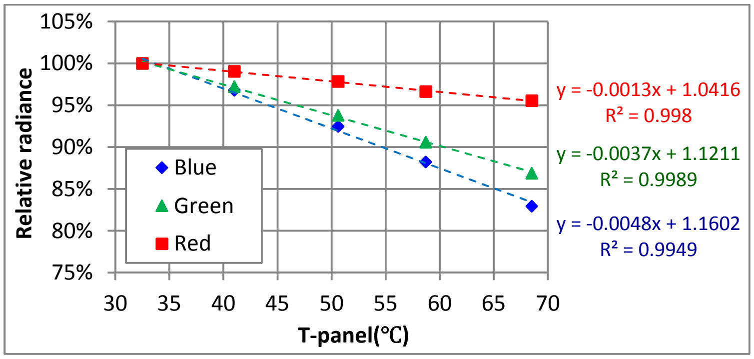
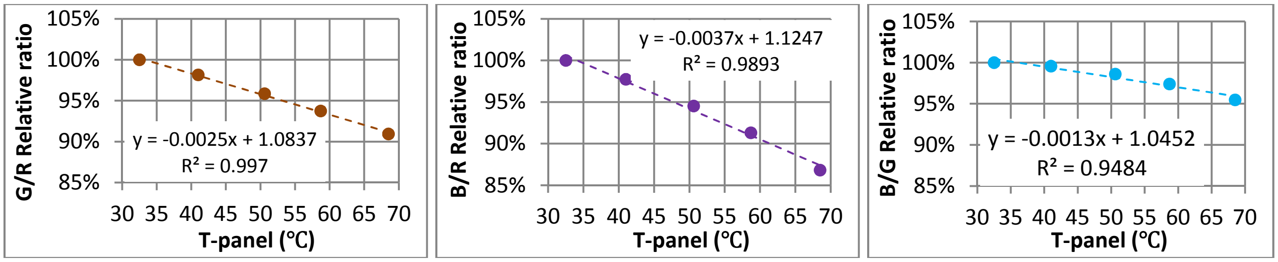


Figure 4. Relative radiance for spectral bands “blue,” “green,” and “red” as a function of panel temperature for OLED panel A.

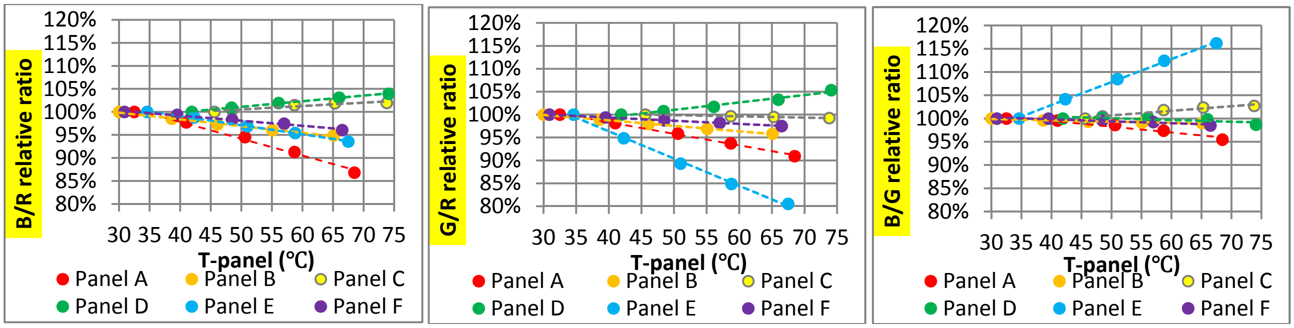


(a) (b) (c)

Figure 5. (a) Relative radiance ratios for B/R as a function of panel temperature for OLED panel A; (b) Relative radiance ratios for G/R as a function of panel temperature for OLED panel A; (c) Relative radiance ratios for B/G as a function of panel temperature for OLED panel A.

3.2 Short-term performance

Figures 6(a), (b), and (c) show relative radiance ratios for B/R, G/R and B/G as functions of panel temperature for all tested OLED panels, respectively. Overall, relative radiance ratios for G/R show better linear correlations than B/G and B/R ratios, based on the linear correlation R^2 values. Four out of the six OLED panels showed decreasing G/R values with increasing panel temperature. Panel C showed very little change and panel D showed increasing G/R values as the panel temperature increased.

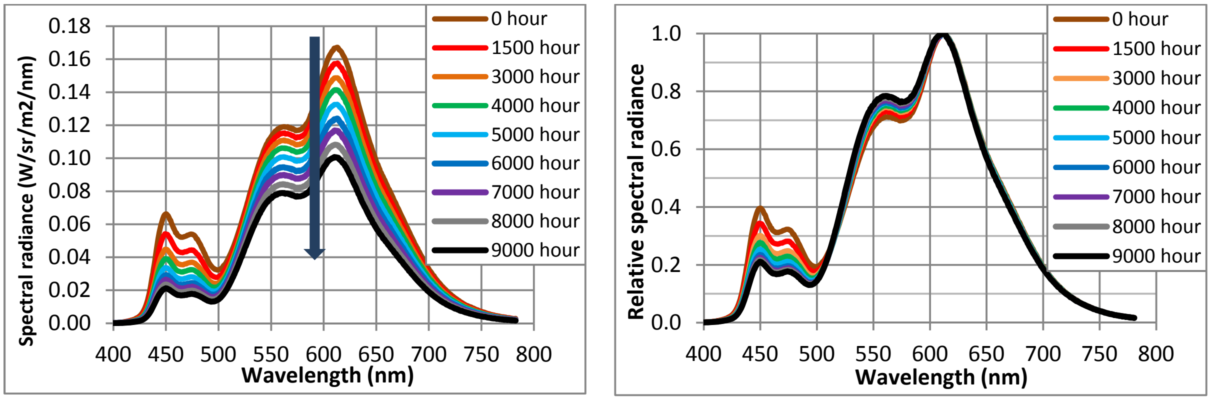


(a) (b) (c)

Figure 6. (a) Relative B/R ratio as a function of panel temperature; (b) Relative G/R ratio as a function of panel temperature; (c) Relative B/G ratio as a function of panel temperature.

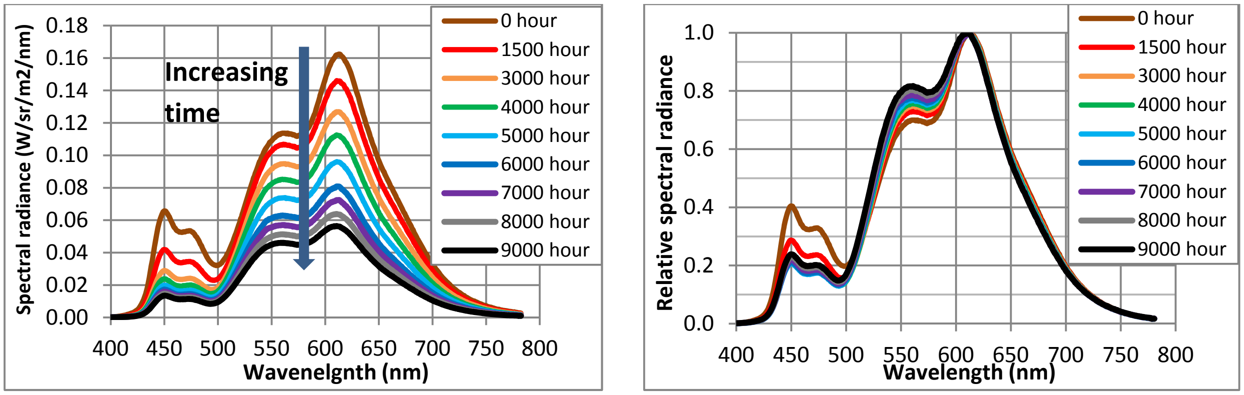
3.3 Long-term performance

Two additional samples of OLED panel C were tested for long-term performance at ambient temperatures of 40°C and 55°C (with corresponding initial panel temperatures of 55°C and 68°C, respectively) in a similar experiment apparatus. Figures 7 and 8 show the absolute and relative spectral radiance of the two OLED panel C samples tested from 0 hour to 9000 hours. During the long-term aging test, the “blue” degraded the most followed by “red” and then “green” spectral bands at both ambient temperatures. Figure 9 shows the absolute and relative G/R ratios (normalized at the beginning of the long-term test) for the two OLED panel C samples tested. The G/R ratios changed significantly over the aging time. The time rate of change for G/R was greater for ambient at 55°C compared to 40°C and both followed a linear trend.



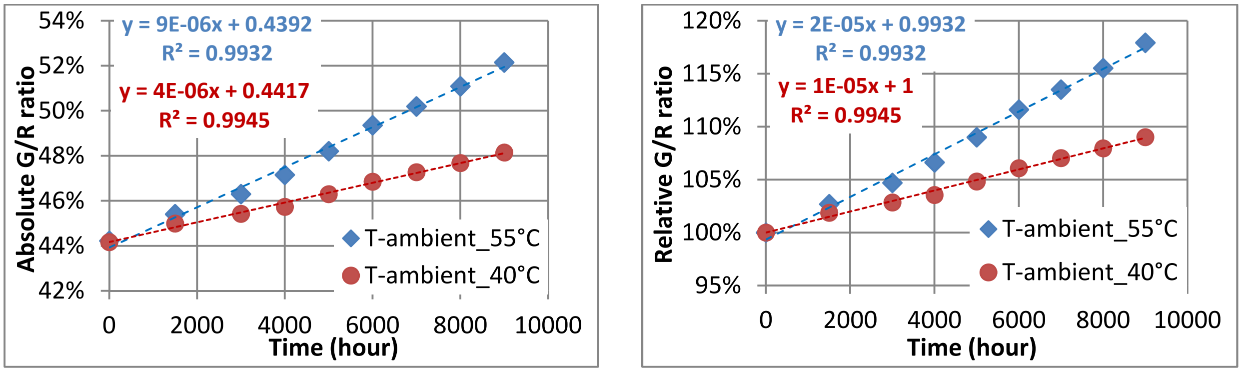
(a) (b)

Figure 7. (a) Absolute spectral radiance and (b) relative spectral radiance of one sample OLED panel C tested at 40°C ambient temperature from initial through 9000 hours.



(a) (b)

Figure 8. (a) Absolute spectral radiance and (b) relative spectral radiance of one sample OLED panel C tested at 55°C ambient temperature from initial through 9000 hours.



(a) (b)

Figure 9. (a) Absolute and (b) relative "green" over "red" radiance ratios for the two OLED panel C samples tested at 40°C and 55°C ambient temperature, respectively, from initial through 9000 hours.

At the beginning and after 9000 hours, the OLED panel C that was continuously operating at an ambient temperature of 55°C was subjected to a short-term temperature test at different ambient temperatures from 25°C to 65°C (with corresponding panel temperatures varying from approximately 45°C to 75°C). The results are shown in Figure 10. The G/R ratio as a function of panel temperature at 0 and 9000 hours are different, even though at both times the changes were linear.

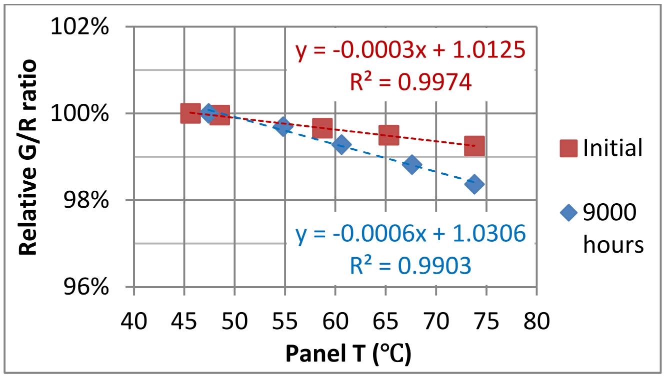


Figure 10. Relative radiance ratios for G/R as a function of panel temperature for OLED panel C at 0 hour ("initial") and after continuously operating for 9000 hours at an ambient temperature of 55°C.

4. SUMMARY AND DISCUSSION

Six commercial white OLED panels were characterized using a spectroradiometer to test their spectral radiance change for each spectral band of “blue,” “green,” and “red” as a function of OLED panel temperature when the ambient temperature changed from 25°C to 65°C. For most panels, the G/R ratios showed high linear correlations with panel temperatures. Therefore, the G/R ratio method has the potential to be used in estimating the OLED panel temperature as well as the average junction temperature. However, the long-term test showed that the G/R ratio changes with time, and the temperature sensitivity of G/R also changes. Therefore, this G/R ratio may only be used for determining the average junction temperature of OLED panels immediately after characterization or within the short term. A new calibration will be needed for OLED devices that have operated for a long period.

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