Abstract—Infrared (IR) and thermocouple (TC) measurements of the light emission surface of white, blue, red and green LEDs are demonstrated using Transient Thermal Tester (T3Ster). It is shown that the IR measurement could obtain a more accurate result which is lower than the junction temperature (Tj) of LED. However, the TC measurement led to a higher temperature than Tj due to the heating effect resulted from the radiation of LED. IR measurement of the light emitting surface temperature of LEDs with dispensing remote phosphor driven by the pulsed current is analyzed to show the transient temperature response on light emission surface with correlation between the peak light emitting surface temperature and the pulse current and width.

Keywords—LED, phosphor, encapsulant, junction temperature, thermocouple, Infrared, thermocouple, pulsed

I. INTRODUCTION

Thermal management is critical for light-emitting diodes (LEDs) due to their efficacy and reliability is directly depending on their junction temperature during operation. Measurement of the encapsulant/lens temperature during operation had shown significantly higher than junction temperature when thermocouples are used [1], [2], [3]. Reference [1] concluded that using the unshielded thermocouples would result in a higher temperature measurement of lens surface than using IR due to the absorption of light radiation emitted by the LEDs. And a properly calibrated IR should be able to measure the encapsulant/lens surface temperature more accurately without the absorption of light radiation emitted by the LED package. Bohan Yan, et al. considered that it was insufficient to use junction temperature alone to characterize thermal performance of white LED emitters [4]. Xinglu Quan, et al. studied the optical-thermal coupled model for phosphor-converted LEDs [6] and Yongming Zhu, et al. developed the thermal model of phosphor self-heating in phosphor-converted light-emitting diodes [7]. In [8], the exploration the dynamic optical and thermal response of LEDs was presented. And VCSEL driven by pulsed and DC currents is investigated to propose a recursive algorithm modelling the transient responses [9].

Based on researches above, we analyze the light emitting surface temperature of LED from a different point of view. In our study, the IR and TC measurements for light emission surface of LEDs including white, blue, red and green are demonstrated comparing to their junction temperature measurement using T3Ster. In addition, both the IR and TC temperature measurement for the LEDs driven by the square pulsed current is analyzed to show the transient temperature response between junction and light emission surface and further to conclude the heating effect resulted from the radiation of LED in TC measurement. Finally, the remote phosphor become a more significant secondary heat source with a higher temperature than the junction temperature due to both the Stoke effect and heating effect resulted from the radiation of LED is demonstrated.

II. SYSTEM SETUP

The measurement system of light emitting surface temperature and junction temperature of LEDs includes IR, TC, T3ster and pulse power supply as shown in Fig. 1.

The spectral analysis system for the measurement of the optical parameters and spectrum of LEDs includes spectrometer and integrating sphere as shown in Fig. 2.

Fig. 1. Illustration of measurement system for junction temperature and surface temperature.

Fig. 2. Spectral Analysis System

III. MEASUREMENT AND ANALYSIS

After carefully calibration, the IR measurement can obtain an accurate light emitting surface temperature of LEDs with the emissivity of 0.98. This was demonstrated by adjusting the emissivity to match the surface temperature of silicone measured by IR with its temperature controlled by the thermostat of T3ster.
A. Red, green, Blue and Blue with Phosphor-dispersed White LEDs Driven by DC Current

In our study, IR and TC measurement for light emitting surface temperature of LEDs including white, blue, red and green as shown in Fig. 3 is demonstrated comparing to their junction temperature measurement using T3Ster. Here, White (10%), White (20%), White (35%), White (50%) are white light LEDs with dispensing phosphor concentration of 10%, 20%, 35%, 50% mixed in silicone encapsulant, respectively.

- IR measurement

It is shown in Fig. 4 that the light emitting surface temperature rise (ΔT_{ra}) with respect to air of the R, G and B LEDs, driven by DC current from 100 to 400mA, was lower than LED junction temperature rise (ΔT_{ja}). And the ΔT_{ja} increasing with the ΔT_{ja} suggests the encapsulant of light emitting surface is heated up by the LED chip through thermal conduction. For the blue LED and the white LEDs, their light emitting surface temperature is more closed to their junction temperatures comparing to those for the green and red LEDs. This is because the blue LED with much larger blue chip has more thermal conductive area than the green and the red ones.

For the white LEDs with dispensing phosphor, the ΔT_{ra} is lower than the ΔT_{ja} as shown in Fig. 5. And their ΔT_{ja} increases with ΔT_{ja}, but decreases with the different concentrations of phosphor. The explanation of this variation can be considered as the energy balance resulted from the stoke effect where phosphor becomes the heating source and the thermal conduction enhancement by phosphor mixed with the silicone.

- TC measurement

The temperature measured by the TC (T_{c}) is always higher than that by IR (T_{r}). It can be found that the temperature difference between T_{c} and T_{r}, ∆T_{c} = T_{c} - T_{r}, increases with the optical power (P_{o}) as shown in Fig. 6. This can be further inferred that the T_{c} can be higher than T_{j} due to the heating effect on TC resulted from the radiation of LEDs. ∆T_{c} increases with the optical power and is depending on spectrum of LEDs. For reference, the spectrums of LEDs were measured by spectral analysis system as shown in Fig. 2. Fig. 7 shows the spectrums of LED samples at the typical P_{o} of 0.5W.

Therefore the temperature measured by TC is not the actual encapsulant surface temperature of LED is confirmed.
The spectrums of LED samples with typical power 0.5W.

B. Blue LEDs with remote phosphor
   - DC Current Driving

With the more accurate IR measurement to further investigate the temperature rise on of remote phosphor, the 1~2mm remote phosphor silicone plates with phosphor concentration 10, 20, 35 and 50% are placed on the light emission surface of the blue LEDs as shown in Fig. 8.

The light emitting surface temperature comparison between the white LEDs with dispensing phosphor and the blue LEDs with remote phosphor is made as shown in Fig. 8. The remote phosphor configuration shows an obviously higher temperature difference on their light emitting surface than the dispensing phosphor one. The major reason is because the remote phosphor configuration can be considered as a heat source due to stoke effect and can only be cooled by the nature convection. On the other hand, the dispensing phosphor configuration is able to be cooled through the leadframe by thermal conduction although the chip is another heat source with a relative lower temperature.

As shown in Fig. 9A, the light emitting surface temperatures decreases with the remote phosphor thickness at the same remote phosphor concentration 50%. And Fig.9B shows the variation of light emitting surface temperatures with respect to the remote phosphor concentration where the remote phosphor film thickness is 1.36mm. It’s found there is an obvious maximum light emitting surface temperature near the 20% remote phosphor concentration when driving current above 1 amp.

Fig. 7. The spectrums of LED samples with typical power 0.5W.

Fig. 8. Comparison of the light emitting surface temperatures between the blue LED with remote phosphor and white LEDs with dispensing phosphor.

Fig. 9 A. Light emitting surface Temperature of different remote phosphor thickness at 50% concentration, and B. Light emitting surface temperature of different remote phosphor concentration with the thickness of 1.36mm.

- Pulsed Current Driving

By the square pulsed current of peak 1.5A with duty 50%, the transient light emitting surface temperature response is shown in Fig 10 for the blue LED from DC, and pulse width 0.5~15sec. And its $T_j$ is 75.6°C measured by T3ster is higher than the light emitting surface temperature 70°C at 1.5Adc.

Fig. 10. Transient light emitting surface temperature response of the blue LED with 1.5Adc and 0.5~15sec pulse width, duty 50%.

With the same test conditions, the light emitting surface temperature of dispensing and remote phosphor is shown as in Figs. 11 and 12, respectively. It can be found that the temperature response of remote phosphor is significantly slower but higher than the blue and dispensing phosphor LEDs. This result suggests, by using the higher frequencies with the shorter pulse width, the peak light emitting surface temperature can be significantly suppressed to the average temperature. If the comparison based on the same average optical power, where peak optical power x duty is a constant, then their average light emitting surface temperatures should be the same when the steady-state reached.
Because the optical power of blue LED is supposed to increase with the driving current, the correlation between peak light emitting surface temperature rise (ΔTra,peak) with respect to peak pulsed current (I) and the pulse width (τ) is proposed by equation (1) and (2) and shown in Figs. 13 and 14 for blue (0%) and 20% and 50% remote phosphor concentrations (x).

\[ ΔT_{ra, peak} = K I \tau^{1/8} \] (1)

where I is the peak pulsed current in A, \( \tau \) is the pulse width in sec., and

\[ K = -352.23x^2 + 202.37x + 19.05 \] (2)

where x is the remote phosphor concentration in %.

It can be found that there is a maxima of K at the phosphor concentration near 30% as shown in Fig. 14.

IV. CONCLUSIONS

It is clearly demonstrated that the light emitting surface temperature higher than junction temperature of red, green and blue LEDs measured by thermocouple is an illusion. However, for LEDs with the dispensing and remote phosphor, the light emitting surface temperature higher than junction temperature is possible. The better way is using the IR measurement due to no absorption of radiation from LEDs. The remote phosphor can be considered as a second heat source, which is possible to be with a higher temperature than junction. And for the pulsed current driving, the peak light emitting surface temperatures correlated with the \( I^* \tau^{1/8} \) for the blue and remote phosphor concentration 20% and 50% are proposed.

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REFERENCES


