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Junction Temperature and Thermal Resistance Measurement in High-Power Light Emitting Diodes Using A Real-Time Diode Forward Voltage Sampling Technique

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1. Introduction

The introduction of high power and high brightness LEDs has led to an aggressive application on general lighting in the near future. LEDs suitable for such an application should have luminance efficiency at least eaching 60~80 lm/W and with superior thermal design for heat dissipation [1]. Recently, lots of efforts have been made to increase the LED light output power (P_{LO}) through increasing chip size or forward current (I_f) [2]. And more attentions have also paid on the thermal issues of power LEDs in the mean time. Essentially, further increasing LED efficiency and decreasing the overall thermal resistance of packaged LEDs would be the key solution.

To evaluate thermal performances of LEDs, efficient and accurate methods for the measurement of thermal resistance of LEDs are urgently required. To the knowledge of the authors, various schemes have been proposed for the analysis of therma1 properties of LEDs [1-6]. Among them, complicated junction-temperature (T_j) measurements were commonly employed. Recently, Y. Xi *et. al.* reported their investigations on T_j of LEDs through diode forward voltage, V_f, measurements. Though a nearly linear relationship between T_j and V_f was found, however, the assumption that T_j and V_f kept unchanged for a 1-ms-pulse current is questionable because T_j and V_f change abruptly at the initial state after pulse current was applied.

In this study, a real-time data acquisition (DAQ) technique was employed for measuring of V_f and T_j waveforms in a more accurate way. By controlling both the LED case and ambient temperature simultaneously in an isothermal chamber, the process to convert the measured V_f waveforms to V_f-T_j curves was proposed and linear V_f-T_j curves of LEDs were obtained. Based on these results and the measured dissipated power of LEDs (P_d), results of thermal resistance measured by the present method were presented and discussed.

2. Thermal resistance model of packaged LED

Figure 1 shows the thermal resistance model of a packaged LED. The overall thermal resistance between the LED junction and ambient (i.e., the case the LED package) was denoted by θ_{LED}. The total power dissipated by the LED (P_d) can be expressed as

$$P_d = V_f I_f - P_{LO} \qquad (1)$$

By precisely setting the LED case and ambient temperature, T_c, θ_{LED} can be obtained from Eqn. (2) once T_j is known, i.e.,

$$\theta_{LED} = \Delta T / P_d = (T_j - T_c)/(V_f I_f - P_{LO}) \qquad (2)$$

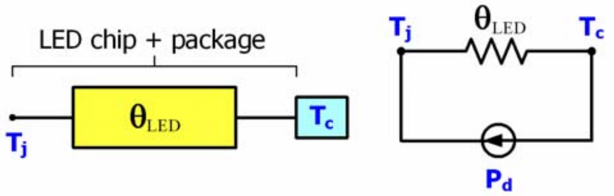


Fig. 1 Thermal model and equivalent thermal circuit of a packaged LED.

To establish an accurate T_j–V_f relationship for the LED under test, disturbance of I_f on T_j should be carefully avoided. In our work, a constant I_f was employed and the corresponding V_f was sampled by a real-time DAQ system with LabVIEW software in which a sampling rate of 10 kS/s was employed.

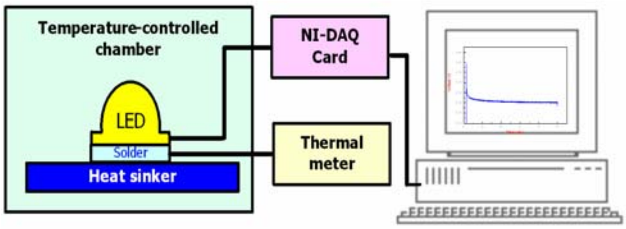


Fig. 2 Schematic diagram of the set-up for the measurement of V_j-T_j curves.of LEDs.

Figure 2 shows the set-up for measuring V_f-T_j characteristics of LED. The LED under test was attached to a temperature-controlled heat sink and placed in a temperature-controlled isothermal chamber. A true or clean (*i.e.*, not distorted by any power dissipation in LED junction caused by applying I_f) V_f was sampled (denoting as V_f^0) from the moment as I_f was turn on. After V_f stabilizes at its final value (V_f*) for a long enough time (about 10~15 s, depending on the value of I_f), V_f* was recorded and P_{LO} was measured by an integrating sphere (not shown). Note that V_f in Eqn. (2) should now be changed to as V_f* to get rid of the influence of heat dissipation caused by I_f.

3. Experimental results and discussion

In experiments, Cree XLamp 7090 LEDs [6] were used for V_f measurements. A dc I_f ranging form 250 to 450 mA with a T_c in the range of 0~80°C were employed for V_f measurements. Before each V_f measurement, the temperature-controlled chamber was preset at a give temperature for a long enough time to ensure the T_j exactly equals to T_c. Figure 3 shows a typical V_f waveform with I_f and T_c set at 250 mA and 20°C, respectively. It is seen that V_f decreases very rapidly (with a decreasing rate of around 2V/sec) as I_f was applied and then stabilized at a relatively lower value after about 9~10 s. P_{LO} was then measured after the stabilization of V_f. Note that the corresponding T_j waveform, derived from the V_f-T_j curves as will be presented later, was also shown in the figure. A considerable rise in T_j of ~1.25 and ~ 5.2°C was found at 1 ms and 9 s, respectively, after I_f was applied.

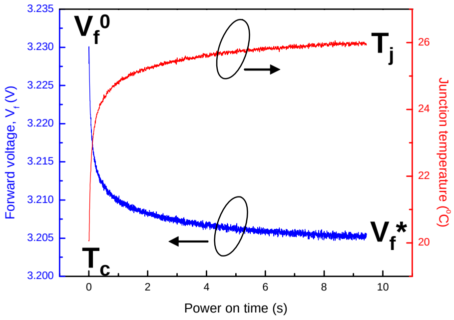
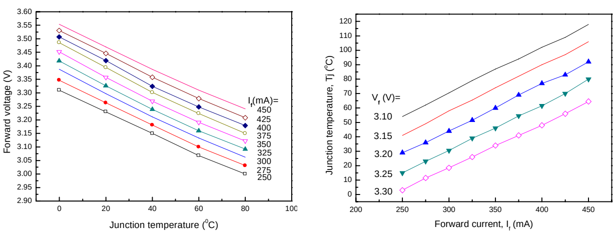


Fig. 3 Typical waveform of V_f and Tj obtained from the real-time DAQ system under I_f=250 mA and T_c=20°C.

3. Results and Discussion

Based on the fact that V_f^0 and T_c were not distorted by the power dissipation of LED, data of V_f^0 and the corresponding T_c were employed to create V_f-T_j curves for the LED under test. Figure 4(a) shows one of the typical V_f-T_j curves obtained from Cree XLamp 7090 LEDs. A nearly perfect linear relation between V_f and T_j was obtained for each I_fs, which is in good agreement with theoretical model [3]. The temperature coefficient of V_f for different I_f is seen being with almost the same magnitude of about -4.03 mV/°C which is very close to the theoretical value. Our experimental results indicate that accurate values of V_f and T_j could be obtained from the real-time V_f sampling technique. These linear V_f-T_j curves thus enable one to find the actual junction temperature based on the measured V_f and, in addition, to convert V_f waveform to T_j waveform as shown in Fig. 3. Figure 4(b) shows the T_j-I_f curves derived form Fig. 4(a). One observes that T_j is a linear function of I_f. (with a slope of about 0.3 °C/mA) Similar results have also been found in GaN UV-LEDs [3, 4] and LDs [7].



(a) (b)

Fig. 4 (a) Experimental V_f-T_j curves for different I_fs. (b) The Experimental T_j-I_f curves derived from Fig. 4(a).

By converting each measured V_f* into T_j and measuring the corresponding P_d, then θ_{LED} $(= (T_j - T_c)/(V_f^* I_f - P_{LO}))$ was calculated. The dependence of the calculated θ_{LED} on I_f was shown in Fig. 5. It is seen that the calculated θ_{LED} is of around 11.4 °C/W for $I_f \leq 375$ mA, which is a little bit larger than the one listed in the data sheet of the diode. However, with further increasing I_f to 450 mA, θ_{LED} increases to 12.0 °C/W. The same situation was also fond for the calculated θ_{LED} without considering P_{LO}, which yields a relatively lower value in the calculated θ_{LED}. The increase in θ_{LED} for larger I_f might be arising from a poor control of T_c. In our experiment, T_c was found being increased by about 2~3°C after reaching V_f*, indicating that the thermal connection at the LED case/heat sink and/or heat sink/heater is poor or the thermal reservoir providing by the heat sink/heater system is not large enough in capacity. Work is underway to overcome the drawbacks.

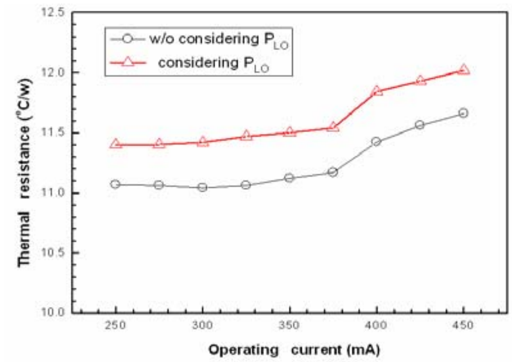


Fig. 5 The thermal resistance θ_{LED} derived form the experimental T_j–V_f curves.

4. Conclusion

In summary, a real-time sampling technique for accurately measuring V_f waveform has been proposed and a nearly perfect linear T_j–V_f curves of LED has been obtained. Based on experimental T_j–V_f curves, a linear dependence between T_j and I_f has also been achieved, which is in good agreement with the theoretical results. In addition, after taking into account the true power dissipation of LED, thermal resistance of LED with a good accuracy has also been derived. It is expected that the present method would provide an accurate and convenient way for the evaluation of LED thermal performance.

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