Characterizing the Thermal Resistance of Alternating Current Light Emitting Diodes

by

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ABSTRACT

Light-emitting diode (LED) operating on alternating current (AC) is gaining popularity in lighting applications. The junction temperature of an LED has a significant influence on its performance, including light output, spectrum, and reliability. Since junction temperature cannot be measured directly, most methods presently used with direct current (DC) LEDs are indirect, and provide estimations of junction temperature. Manufacturers specify the thermal resistance of a package with respect to an external reference point. This way, users could estimate the junction temperature in a particular application by measuring the temperature at this reference point.

Although there are many proven methods for estimating the junction temperature of DC LEDs, only a few methods have been proposed for AC LEDs [1,2,3,4]. Of these, two different methods were selected for further investigation and analysis to determine their accuracy in estimating the AC LED junction temperature. Liu et al. [3], used a low reference current pulse when the AC LED is not conducting to extract the voltage across the junction to estimate the junction temperature. Zong et al. [2], estimated the junction temperature by recovering the first half cycle root-mean-square (rms) current using an active heat sink. The measured thermal resistance values of an AC LED package using these two methods didn’t agree [3]. Liu et al. [3], hypothesized that this discrepancy was due to the heating in the first half cycle of current that Zong et al. [2], did not account for in their method. However, no proof was given to validate this assumption.

In this thesis, several hypotheses were developed and verified using laboratory experiments. The results showed that by measuring and correcting for the temperature rise in the junction during the first half cycle of current, the thermal resistance values estimated using the two approaches agree.

In addition, a third method is described in which the peak wavelength value of the spectrum was used to estimate the junction temperature of a GaP (Gallium Phosphide) based AC LED package. The junction temperature values estimated using the peak wavelength shift method and voltage drop method for a GaP AC LED package is within

the measurement uncertainty of the two methods. The details of the methods, and the associated results, along with their accuracies are presented and discussed in the thesis.

Upon validating the accuracy of the voltage drop method, the thermal resistance of a GaN (Gallium Nitride) based white AC LED was characterized at different ambient temperature and input voltage conditions. The thermal resistance values of GaN AC LED samples measured using the voltage drop method showed an increase in thermal resistance when the ambient temperature increased. This behavior is consistent with the observed variation of thermal resistance to ambient temperature, for DC LEDs, in past studies. The thermal resistance showed a decreasing trend with increasing input voltage. This is consistent with past studies that show variation of thermal resistance in DC LEDs with high package series electrical resistance.

1. Background

Light emitting diode (LED) is a rapidly growing light source technology that has the potential to reduce lighting energy consumption [5]. An LED is a semiconductor P-N junction (P- high concentration of holes or positive charges; N- high concentration of electrons or negative charges). An LED generates light (photons) when the positive and negative charges combine radiatively. The fabrication of semiconductor packages with high optical emission efficiencies and better light extraction efficiencies has enabled LEDs to be used in general lighting applications. Heat generated at the junction is mainly a consequence of non-radiative recombination, extraction inefficiency and ohmic resistance.

In recent years, alternating current (AC) LEDs have entered the marketplace. The AC LED packages are fabricated by growing several junctions on an insulated substrate. The junctions are connected either in parallel or series, so that they could be directly connected to an AC power source [6]. AC LED packages do not require an AC to DC converter, and can be connected to an AC grid directly. The absence of a driver could reduce the overall system cost, increase reliability, and reduce the overall size of an LED luminaire. For these reasons, AC-LED technology has captured the interest of the LED lighting community.

The junction temperature of an LED has a significant influence on its efficiency, reliability and light output characteristics [7] . The reliability of semiconductor devices is often predicted using the junction temperature [8]. To design efficient and reliable LED lighting systems, it is critical to know the junction temperature of an LED in a given operating environment. It is practically impossible to obtain a direct measurement of the junction temperature. There are several methods that could be used to estimate the junction temperature of an LED [9,10,11,12,13,14,1,2,3]. The focus of these methods is to identify a measurable external parameter that has a close relationship with the junction temperature (ex: forward voltage, peak wavelength of the emission, etc.).

The users of LED packages rely on the thermal resistance value specified by manufacturers, between the junction and a measurable reference point, to estimate junction temperature. Thermal resistance measurement of a DC LED has been extensively studied [9,10,11,12,13]. However, there are only a few studies that discuss the junction temperature and thermal resistance measurement of AC LEDs [1,2,3,4].

In a study conducted at the Lighting Research Center (LRC), researchers developed a method for measuring the junction temperature of an AC LED and its thermal resistance [3]. In that study, LRC researchers measured the thermal resistance using another method, rms current recovery method, reported in literature for comparison [2]. The thermal resistance values measured using the two methods did not agree [3]. In that study, the authors hypothesized that the discrepancy was due to the additional heating in the first half cycle of current that Zong et al. [2], did not account for in their method. However, no proof was given to validate this assumption. The objective of this thesis is to investigate the reasons behind this discrepancy. Additionally, the thesis studied the thermal resistance values of an AC LED at different ambient temperatures and at different input voltages.

2. Literature Review

The literature review focused on the basics of LEDs, AC LED packages, junction temperature (T_j) prediction methods for DC and AC LEDs, and characterization of the thermal resistance of DC LEDs to identify parameters that affect the thermal resistance values.

2.1 Basics of LED

An LED is a P-N junction, made out of semiconductor materials, that emits photons when subjected to an external electric field. LEDs are fabricated using GaP (for emissions in red, amber and yellow regions) and GaN (for emissions in near UV, violet, blue and green regions) based compounds. Improvements in internal quantum efficiency, and light extraction efficiency, have enabled the development of high power LED packages [15,16].

The emission wavelength of an LED depends on the band gap of the semiconductor material [17]. The energy of the photon emitted as a result of the radiative recombination, depends on the band gap energy, if the thermal energy is negligible. The band gap in a semiconductor material is the “minimum energy necessary for an electron to transfer from the valence band (E_v) into the conduction band (E_c)” [18]. Figure 1 shows a band diagram of a semiconductor and the direct electron-hole recombination that generates a photon. Direct band gap materials such as GaN, ZnSe & GaAs are preferred over indirect band gap materials such as SiC, Ge, GaP, for high power light emitting devices [19]. This is because efficient radiative recombination occurs in direct band gap materials [20].