EXPERIMENTAL STUDY ON THE EFFECT OF JUNCTION TEMPERATURE ON POWER LED'S

[1]Amrutha Thomas, [2]Aju S Nair
[1]P.G Student, [2]Assistant Professor
Amal Jyothi College of Engineering, Kanjirappally, Kottayam, Kerala
Email:[1]thomasamrutha89@gmail.com, 2ajusnair@amaljyothi.ac.in

Abstract— Lights account for a great portion of total energy consumption, and unfortunately a huge amount of energy is wasted by improper lighting. Nowadays, high-power light-emitting diodes (LED's) have become an important competitor for traditional light sources for various applications, such as home and office lighting, automotive lights and traffic lights as they consume less energy than incandescent and fluorescent lamps. In spite of their higher efficiency, high-power LED's dissipate a considerable amount of heat. The associated increase of their junction temperature gives rise to various problems. Based on an experimental study the effect of junction temperature on the performance of power LED's such as lifetime, light output etc. were discussed in this paper.

Index Terms — heat transfer path, junction temperature, light-emitting diodes, power LED's, surface mount device

I. INTRODUCTION

Lighting systems are a major source of electricity consumption in the world. About 20% of the electricity consumed in the world is spent on residential and public lighting [1]. Therefore, there is a demand for high efficiency lamps. Nowadays, LED's are already being used in applications traditionally dominated by incandescent and fluorescent lamps being used in home and office lighting's, traffic signals, vehicle interior lighting, illumination of architectural environments and luminous panels. LED lamps are also more energy efficient compared to traditional lamps. LED's consume only 50% of the energy consumption compared to the fluorescent lighting device [2]. LED's have an average source lumen efficacy of >100 lm/W when compared for 60 lm/W for Compact Fluorescent Lamps (CFL) and 16 lm/W for incandescent lamps. LED's also have longer lifetime than other types of lighting up to 100,000 hours compared to 10,000 hours for CFL's and only 1000 hours for incandescent lamps[3].

In case of power LED's used as light sources, thermal issues are very important. Although light conversion efficiency of these devices is rather high, 65-70% of the supplied electric power heats up the LED that result in junction temperature rise of 25-50˚C , depending on the thermal resistance of the device and its enclosure[4]. Thus, besides reaching high efficiency and meeting photometric targets, the proper thermal management of the power LED devices is gaining importance. Since the power of LED's used in lighting ranges from 1 to 10 Watts, severe overheating problems may occur and in case of semiconductor devices, this overheating may destroy, or reduce their lifetime. In addition to that, the good thermal management is also a key factor in avoiding thermally induced variation of photometric/colorimetric properties of power LED's such as variation of relative light output of the lighting spectrum. In general the emission intensity of LED's decreases with the increase of the temperature and depends on the type of LED used.

II. POWER LED’S

Power LED's are typically 1-3 W devices that are usually run at 350mA [5]. Their dice are substantially larger than those of small LED's, although their footprint need not be. These devices are typically used in places requiring lighting, rather than as indicators. The working principle is same for both small and power LED's. When a voltage is applied across the LED, electrons from the semiconductors conduction band recombine with holes from the valence band releasing sufficient energy to produce photons which emit a monochromatic (single colour) of light. This effect is called electroluminescence, and the colour of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor. These photons should be allowed to escape from the device without being reabsorbed.

Depending on its type, the construction of an LED differs to a great extent. Through hole LED's and Surface mount device (SMD) LED's have very similar constructions. But the construction details of a high power LED is considerably different from the other two types. A through LED is based on two holes and an epoxy housing, which also acts as the lens. A typical high power LED has a built-in heat sink, or slug, on which the chip is placed and connected with two wires with the cathode and anode leads. In case of white LED's, the chip is uniformly coated with a layer of phosphor [5]. The chip is then covered by a silicone gel and a lens is placed on top of it. There are two general methods to generate white light with LED's. The first is by the use of phosphors together with a short-wavelength LED, resulting in a broadband radiation spectrum, referred to as a phosphor-converted white LED, or PC white LED. The second method is to utilize mixed light from two (dichromatic), three (trichromatic), or more LED's emitting different narrow bands of radiation. To achieve reasonable color-rendering properties, at least three colors (R,G,B) must be combined. Maintaining color balance is critical, considering that the radiated emission spectra from each individual device respond differently to changes in temperature and current, and experience different rates of degradation over time.

A. LED Characteristics

Basically, LED behaves like a constant voltage load with low Equivalent Series Resistance (ESR). An LED is a device that emits light when electrically biased. LED's are similar to standard diodes and thus most of electrical characteristics of diodes also apply to LED. Similar to diodes, once the threshold voltage of LED is reached, any further increase in voltage will lead to rapid increase in the current through them as shown in Fig. 1(a). Due to this behavior the preferred method to drive LED is with constant current rather than constant voltage. The current through LED is a key parameter that determines the intensity, forward voltage and also the color or wavelength of light emitted from LED as seen in Fig. 1(b). Thus a controlled brightness requires driving LED with a constant current, which must be maintained regardless of fluctuation in input voltage.

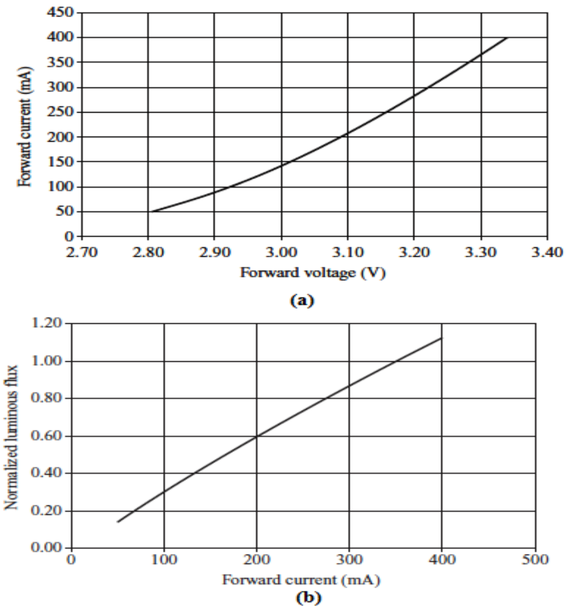

Fig. 1: (a) V-I chara of power LED; (b) Luminous flux versus Forward current chara at junction temperature 25˚C [5]

III. LED JUNCTION TEMPERATURE

Junction temperature arises as heat is generated at the junction within LED device due to the inefficiency of the semiconductor processes that produce light. In case of power LED's used as light sources, thermal issues are very important. The LED properties, including luminous flux, forward voltage, color characteristics, useful life and reliability are dependent upon junction temperature. Optimal performance and long term reliability of LED lighting requires proper thermal management.

Useful operating life is one of most important factor based on which a light source is selected. LED lighting is claimed to have very long life compared to traditional light sources. The temperature of the junction is the most critical factor as it affects the reliability and performance of the LED luminaire, in terms of functional and useful lifetime of the luminaire. The wall-plug efficiency of LED luminaires is usually less than 10%, which means nearly 90% of the input power is lost as heat [6]. The manufacturers measure the performance of an LED at a junction temperature of 25˚C (ideal laboratory conditions). But in practice, LED's operate at a much higher junction temperature (Tj) in between 60˚C and 80˚C. This means under normal operating conditions, the light output/flux of the LED will always be lower than its rated value. LED's vary in wavelength and lumen output which is also depend on temperature and time. It is true that the quantum efficiency and junction thermal resistance of LED are the two limiting factors in LED technology. The LED lamps can have luminous efficacy of 150 lm/W at junction temperature Tj of 25˚C. The luminous efficacy of various LED's typically decreases by approximately 0.2-1% per degree Celsius rise in temperature.

To ensure long life and dependability of LED lighting products, design engineers must deal with heat management issues at the system and component level [7]. Although light conversion efficiency of these devices is rather high, 65-70% of the supplied electric power heats up the LED that result in junction temperature rise of 25-50˚C, depending on the thermal resistance of the device and its enclosure. Thus, besides reaching high efficiency and meeting photometric targets, the proper thermal management of the power LED devices is gaining importance. The lifetime of an LED can be defined as the time during which the LED emits at least 70% of its initial light output. Since the power of LED's used in lighting ranges from 1 to 10 Watts, severe overheating problems may occur and in case of semiconductor devices, this overheating may destroy, or reduce their lifetime[4].

A. *Heat Transfer Path for LED*

The ambient temperature and the drive current both affect the junction temperature of LED. Other influences are the nature of the light output, whether it is steady state or pulsed, and the LED wattage per unit area of surface that dissipates heat. The key factor is the thermal path from the LED junction to ambient i.e. the outside of the package as seen in Fig. 2. Heat should be conducted away from the LED in an efficient manner, and then removed from the area by convection. Power LEDs are often mounted on metal-core printed circuit boards (MCPCB), which will be attached to a heat sink. Heat conducted through the MCPCB and heat sink is dissipated by convection and radiation.

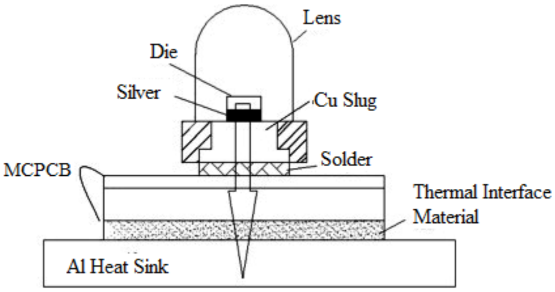

Fig. 2: Heat transfer path for an LED [8]

The junction temperature of an LED is given by the equation [6],

$$T_j = T_a + (R_{thja} P_d) \quad (1)$$

where,

T_a - Ambient temperature (˚C)

T_j - Junction temperature for a given input power (˚C)

R_{thja}-Thermal resistance between LED junction and surroundings (˚C/W)

Pd - Power to be dissipated (W)

B. Junction Temperature Measuring Methods

Accurate temperature measurements are required to appropriately design a thermal system and to evaluate and assess an existing design. Whether for a final design or a prototype, the measurement process is the same and requires due diligence to make sure realistic and accurate measurement are made. LED reliability is a major advantage compared to traditional light sources, so proper and realistic measurement procedures should be used so this benefit is not jeopardized. When performing thermal measurements, it is critical to set up the test subject as close as possible to the real-life, worst-case scenario to which the system may be subjected. Ensure that the measurement setup accounts for similar airflow, material properties, orientation, ambient conditions and any additional heat sources such as power supplies or contributory heat loads. This ensures that the temperature’s measured correspond to real-world, worst-case scenarios and could identify potential problems that best-case scenarios may miss.

The first technique for measuring an LED's junction temperature electrically dates back to 1977. It is based on the linear relationship between forward voltage and junction temperature at constant-current bias. Although it does not require an extra sensor, this technique requires a calibration at two temperatures, making it still quite expensive to implement on a large scale. One of the method is based on the differential voltage/current measurement techniques extensively used in bipolar transistor-based thermometers and, in principle, this require calibration at one temperature only. Here the junction is consecutively biased with two currents, I1 and I2 and the resulting voltage difference is proportional to absolute temperature. This method needs a climatic chamber to place the LED [9].

Another method for measuring junction temperature is forward voltage method. In this method, the LED is kept in an oven whose temperature is controlled and initial temperature is set to 10˚C and then the LED street light is allowed to reach thermal equilibrium. Then voltage is applied to constant current LED driver and is changed in steps. At each step of increment, drive current and forward voltage is recorded. These steps of obtaining VI chara is completed within a short span of time(30 seconds or less) to avoid self heating of LED junction due to drive current and it can be assumed that junction temperature is the same as the oven temperature[6].

The above mentioned method requires climatic chamber/oven and other expensive equipment's. Even though various methods to measure temperature exist, for LED systems the most common methods are simple thermocouples, infrared (IR) microscopes, and pulsed voltage/transient response monitoring. The latter two methods require expensive, accurate and specific tools that are beyond the scope of this document. Simple thermocouples are the most common and simplest method to obtain accurate data and are recommended for precise absolute LED system measurements.

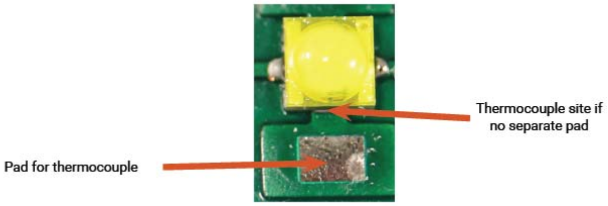

Fig. 3: Soldering point temperature measurement location [10]

While using a thermocouple, the general guideline for thermocouple attachment is to place the thermocouple as close to the LED as possible, mounted directly on a metal pad connected to the neutral thermal trace, if possible. Fig. 3 is an image showing the proper location for a thermocouple. Thermally conductive epoxy or solder is recommended to ensure good heat transfer from the board to the thermocouple. All thermocouples must be out of the optical light path or photons will interfere with the readings, giving extremely inaccurate results [10].

IV. EXPERIMENTAL STUDY AND RESULTS

The LED’s chosen for experimental study was Edison C series 1W cool white power LED. Six such LED’s were chosen in which three were connected in series and two such branches were connected in parallel to form 6W LED. All the six 1W LED's are identical. The characteristics of Edison LED is shown in the below table.

Table I

Parameter	**Value**
DC Forward Current	350 mA
Reverse Voltage	5V
Drive Voltage	5V
Forward voltage	3.4V
Viewing Angle	130˚
CRI	68
LED Junction Temperature	125˚C

The VI chara for the 6W LED string is shown in Fig. 4. The LED string starts conducting from 6.2V.

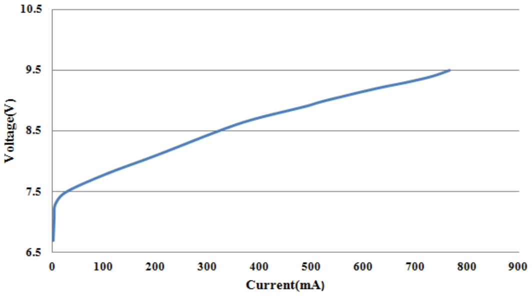

Fig. 4: VI chara of 6W LED string

For finding the effect of junction temperature over LED current and light intensity, the LED string without heat sink was tested inside a photometric integrator for a time period of two hours. DC voltage of about 9.3V was given to the string and the current, lux, voltage and temperature readings were noted continuously with a time gap of 10 minutes. For measuring junction temperature, a thermocouple is attached on the metal part of the LED. The other end of the thermocouple was connected to the digital multimeter which gives the temperature readings in degree celsius. The experimental setup is shown in Fig. 5.

Fig. 5: Experimental setup for finding the effect of junction temperature on 6W LED string without heat sink

The photometric integrator is of diameter 1.5 meter. The internal surface of the integrator is coated white to avoid the absorbance of light. A luxmeter is placed in the slot provided for it on the integrator. The LED string is placed 1.25 meters away from the luxmeter. The variation of junction temperature with time is shown in Fig. 6.

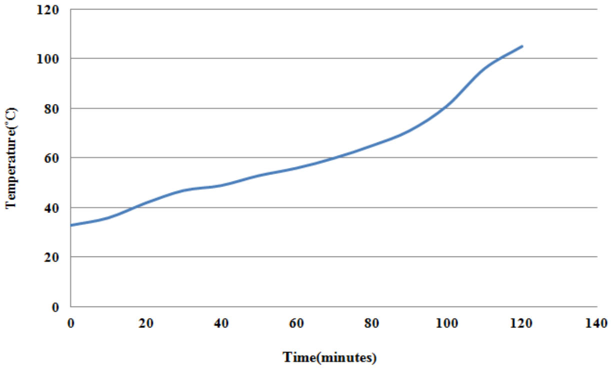

Fig. 6: Time versus Junction temperature chara for 6W LED string without heat sink

LED forward current variation with respect to junction temperature was shown in Fig. 7. It is clear from the figure that as junction temperature increases the current is getting reduced.

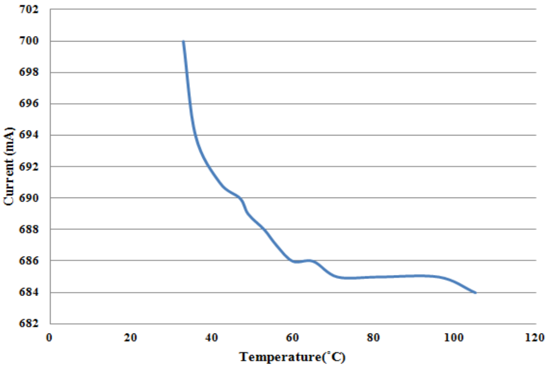

Fig. 7: Junction temperature versus Forward Current chara for 6W LED string without heat sink

The variation of lumen output with respect to junction temperature was shown in Fig. 8.

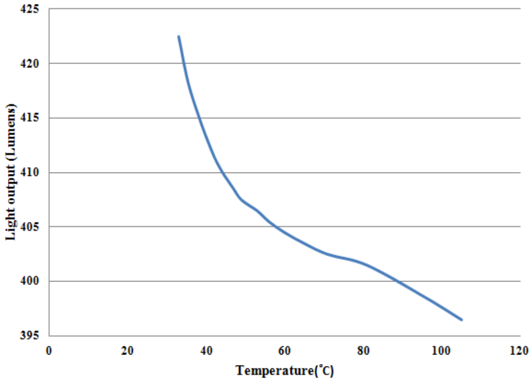

Fig. 8: Junction temperature versus Lumen output chara for 6W LED string without heat sink

As the junction temperature increases the light output is getting reduced. This is because as current reduces, lumen output also get reduced. The decrease in light output cause decrease in life time of LED.

V. CONCLUSIONS

In this paper, the effect of junction temperature on power LED's were discussed. Various methods of measuring junction temperature were also mentioned. From the experimental study of six 1W Edison C series cool white LED's, it is clear that, as LED is turned on for more time its junction temperature increases with time. As junction temperature increases LED's current decreases which inturn cause decrease in light output. As part of future work the thermal model of LED can be studied in detail and proper heatsink can be designed to dissipate the junction temperature so as to improve the life and light output of LED.

REFERENCES

[1] W. Paul and T. Tanishima, Light's Labour's Lost - Policies for Energy-efficient Lighting, International Energy Agency, Paris, 2006.

[2] J. Byun, I. Hong, B. Lee, and S. Park, "Intelligent household LED lighting system considering energy efficiency and user satisfaction", IEEE Transactions on Consumer Electronics, vol. 59, no. 1, pp. 70-76, February 2013.

[3] R. Kathiresan, Y.J. Kenneth, S. K. Panda, T. Reindl and P. Das, "An interactive LED lighting interface for high energy savings", IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia), pp. 508-513, May 2014.

[4] E. M. Sa, F. L. M. Antunes, and A. J. Perin, "Junction temperature estimation for high-power light-emitting diodes", Proceedings of IEEE International Symposium on Industrial Electronics, pp. 30303035, August 2007.

[5] L. Ron, L. Carol, Practical Lighting Design with LED, John Wiley & Sons, Canada, 2011.

[6] K. R. Shailesh, C. P. Kurian and S. G. Kini, "Junction temperature measurement of a LED street light using forward voltage method", International Conference on Advances in Electronics, Computers and Communications (ICAECC), pp. 1-6, October 2014.

[7] S. Tanuja, K. R. Shailesh, C. P. Kurian and S. G. Kini, "A review of existing methods for study and analysis of thermal design of LED lighting products", Green Computing, Communication and Conservation of Energy (ICGCE), pp. 404-408, June 2013.

[8] L. Dongjing, Y. Haiying and Y. Ping, "Experimental and numerical approach on junction temperature of high-power LED", Microelectronics Reliability, vol. 54, no. 5, pp. 926-931, May 2014.

[9] F. D. Roscam Abbing and M. A. P. Pertijs, "Light-Emitting Diode Junction Temperature Sensing using Differential Voltage/Current Measurements", Sensors, IEEE, pp. 861-864, October 2011.

[10] Cree, "Thermal Management of Cree® XLamp® LEDs- Application note", USA, May 2012.