

Influence of junction temperature on the spectral power distribution of Light Emitting Diodes

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This article describes electrical method for measuring junction temperature of high power LEDs. Measurement system consisting of a temperature controller and a thermostatic chamber was designed and constructed. A number of studies of LEDs in a typical thermal conditions that exist in luminaries were performed. Basing on these results, influence of junction temperature on luminous flux and spectral power distribution of LED was determined. Obtained results allow to optimize the construction of LED lighting fixtures, in the ambient temperature range from 0°C to 100°C, especially in the aspect of improving the photometric properties of the luminaire.

Keywords: LED, junction temperature, spectral power, measurement

Introduction

The spectral power distribution is one of the photometric parameters which allows to characterize the light emitting diode. This parameter is closely related to the material of which has been made *pn* junction, more specifically to the energy gap width of used semiconductor. This relationship is described by the equation:

$$\lambda = \frac{hc}{E_g} = \frac{1,2396}{E_g} \quad (1)$$

where: λ – wavelength, h – Planck's constant, c – light speed.

Figure 1 shows the values of the energy gap and the corresponding wavelength of materials used in LEDs [1].

As can be seen LEDs are made from several basic types of semiconductors, by appropriate doping width of the band gap can be changed, which is equivalent to a change in wavelength of the LED.

Beyond that junction temperature also affect the width of the energy gap. This relationship has been studied by

many researchers [2], [3], [4]. Among the mathematical description of this phenomenon can be indicated the model described by Varshni's equation:

$$E_g(T_j) = E_g(0) - \frac{\alpha_E T_j^2}{T_j + \beta_E} \quad (2)$$

where: $E_g(T_j)$ – width of the energy gap in temperature T_j , $E_g(0)$ – width of the energy gap at absolute zero, α_E , β_E – material constants of the semiconductor.

As can be seen this is a non-linear relationship. However, in the typical temperature range in which LEDs junctions work, non-linearity is small enough that it can be omitted [4]. More than that present in the formula (2) material constants α_E , β_E significantly impede the application of the above-mentioned mathematical model to describe commercially available LEDs. This is mainly due to the fact that LED manufacturers rarely provide full information about the LEDs chip material.

To omit this problem, a method combining forward voltage of the diode, junction temperature and the wavelength of the emitted radiation is proposed.

Measurement system

Figure 2 shows a typical cross-section of high-power LEDs which are commercially available.

Semiconductor crystal is placed on the thermally conductive substrate, and covered protective lens. Such structure makes it impossible to measure the junction temperature using classical temperature sensors such as thermocouples. Removing the protective lens also does not solve the problem, because sensor applied to the diode significantly change the thermal conditions of the junction.

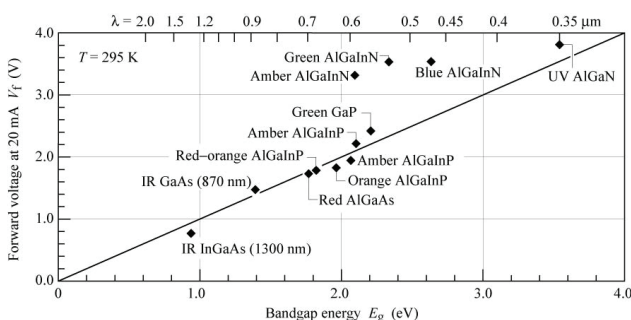


Figure 1. The relation between forward voltage and the width of the energy gap for different semiconductors [1]

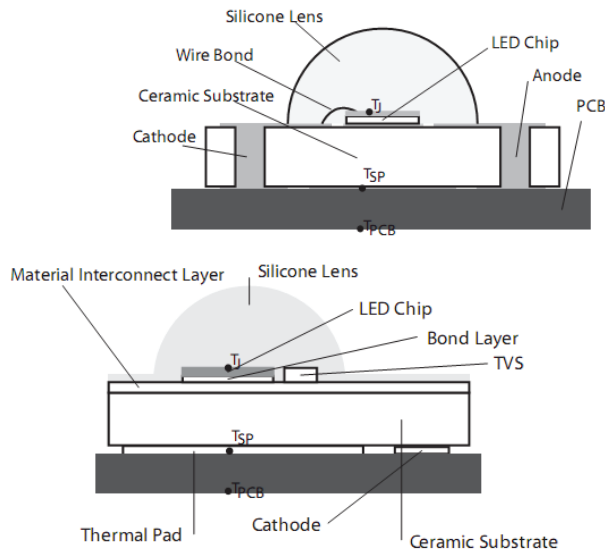


Figure 2. The construction of modern high power LEDs: T_j – junction temperature measurement point, T_{sp} – solder pad temperature measurement point, T_{PCB} – measurement point of printed circuit board temperature

The solution of this measurement problem seems to use the diode chip as the temperature sensor. According to the findings of the EIA standard JEDEC 51-1 [5], the relationship between the junction temperature and voltage conductivity can be described by the following equation:

$$k = \frac{\Delta V_f}{\Delta T_{j-rise}} \quad (3)$$

where: ΔT_{j-rise} – change in junction temperature, ΔV_f – change in forward voltage, k – thermal conductivity coefficient.

By calculating values appearing in formula (3), the actual junction temperature can be determined by following equation:

$$T_j = T_A + \frac{\Delta V_f}{k} \quad (4)$$

where: T_j – junction temperature, T_A – ambient temperature.

Based on the comparative measurements in the calibration oven Fluke 9140 accuracy of the presented method was specified at 2°C

Measurement system

Measurements of the mentioned above values are made on a special test system, whose main elements are the controller implemented on the microcontroller ATmega16 and two thermostatted chamber in which the component responsible for the change in temperature is a 70 W Peltier module. The first, shown in Figure 3, is used to determine the temperature coefficient of forward voltage changes.

The electronic system stabilizes the temperature inside the chamber at a preset level in the range 0°C to 100°C. At

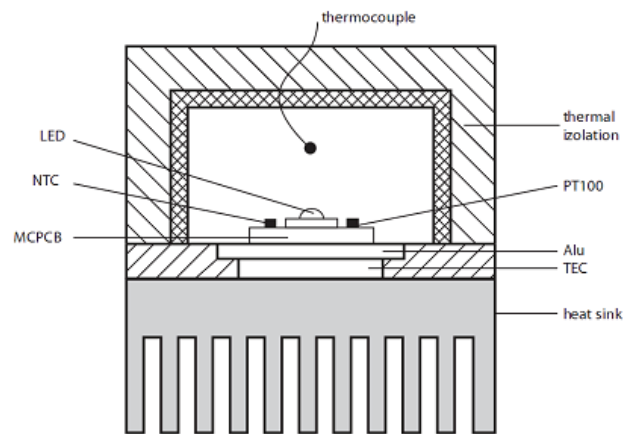


Figure 3. Construction of the thermal chamber used to determine the temperature coefficient of forward voltage changes

this time, the tested LED is turned off. The result is that temperature of the chip is the same as the temperature of the air inside the chamber. After the temperature became stable, the diode is powered by short electric current pulse of known value, measured at the same time a LED forward voltage. The duration of the pulse power is only 2 ms, this allows to assume that in such a short time the junction temperature is the same as the ambient temperature. The whole process is repeated for several levels of temperature in the range 0°C to 100°C and different values of current. Accurate measurement process is presented in [6].

The next step in the process of determining the influence of junction temperature on the spectral power distribution of LED is performed in the heat chamber shown in Figure 4.

The tested LED is placed in a thermal chamber in the shape of a sphere, which on the inside is coated with a high reflectivity white paint. Measurement of the spectral characteristics is performed by CCD spectrometer, to which the signal is transmitted by optical fiber. Setting fiber and assembled inside the sphere shutter make that light reaches the spectrometer after scattered and mixed in the integrating sphere. This eliminates the need to precisely set the LEDs relative to the fiber and also allows the measurement of luminous flux.

During the test, the LED is powered by a constant current of known value. Then, the system measures the forward voltage of the LED and using the results obtained in the previous step, calculate diode forward voltage at the set temperature. After comparing the forward voltage measured and calculated, the system raises or lowers the temperature inside the chamber until the equalization of the two voltages, which will mean that the junction temperature has reached the set value. At this point, the spectrometer can measure the luminous flux and the spectral distribution of the emitted light.

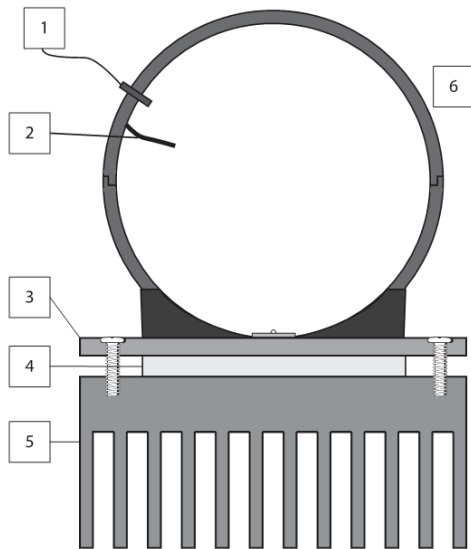


Figure 4. Construction of the thermal chamber used to determine the influence of junction temperature on the spectral power distribution of LED: 1 – an optical fiber connected to a CCD spectrometer, 2 – shutter, 3 – aluminum plate, 4 – Peltier module, 5 – radiator, 6 – integrating sphere

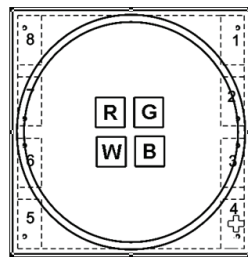
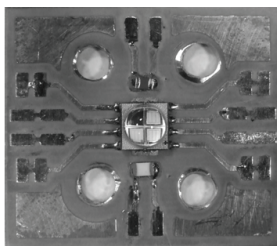


Figure 5. Printed circuit board with soldered LED and temperature sensors and the placement of the chips inside the LED

The division of the measurement process into two main stages is necessary because the CCD spectrometer, though incomparably faster than the classical solution with a monochromator, for precise measurement of the spectrum needs a few to several seconds. During this period, the junction temperature can change dramatically.

Using the developed system was tested thermal performance Cree LED trade name XM-L Color. It is a four-chip LED emitting the color of red, green, blue and white. It has been soldered together with the temperature sensors to the circuit board with an aluminum core – figure 5.

Measurement results

Figure 6 shows the results of measurements of the red, green and blue LED forward voltage as a function of junction temperature.

As can be seen this relationship as predicted is linear, which significantly helps determination of the actual junction temperature in the next stage, which is determine the

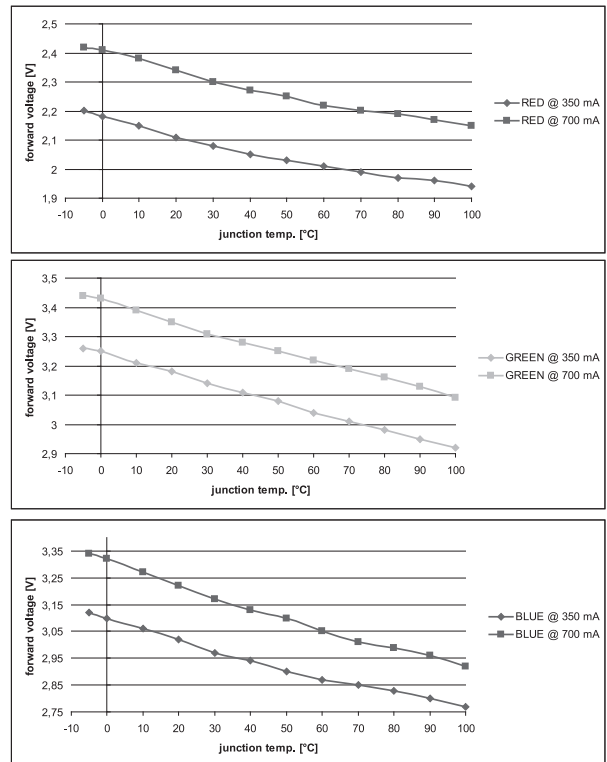


Figure 6. Forward voltage depending on the junction temperature of red, green and blue LED

Table 1. Summary values of thermal conductivity coefficient for different LEDs

LED	supply current [mA]	temperature coefficient [mV/°C]
RED	350	2,5
	700	2,6
GREEN	350	3,3
	700	3,4
BLUE	350	4,0
	700	4,3

relationship between temperature and spectral distribution for power.

After approximating the results by linear function can be determined a thermal conductivity coefficient for each LED. Its values for different light emitting diodes are presented in Table 1. As can be seen the junction temperature least affect the forward voltage of the red LED, the most blue. On this basis it can be concluded that the semiconductor with a wide band gap demonstrate an increased response to the temperature in which they work.

Although the temperature coefficient of forward voltage changes seem small, have a significant impact on power electronic systems used to supply LED light fixture. This is because LEDs are connected in series after several pieces. In this case, the decrease in voltage of 2 mV - 4 mV per degree Celsius for each diode leads consequently volts drop across the single-chain – results in a decrease in efficiency and a greater load of the electronic system.

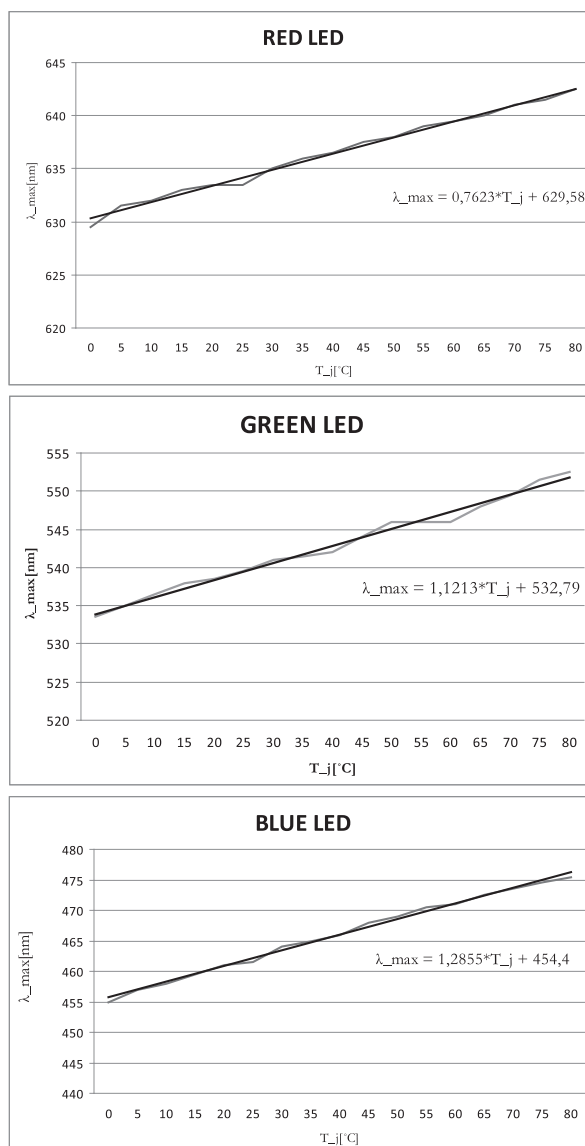
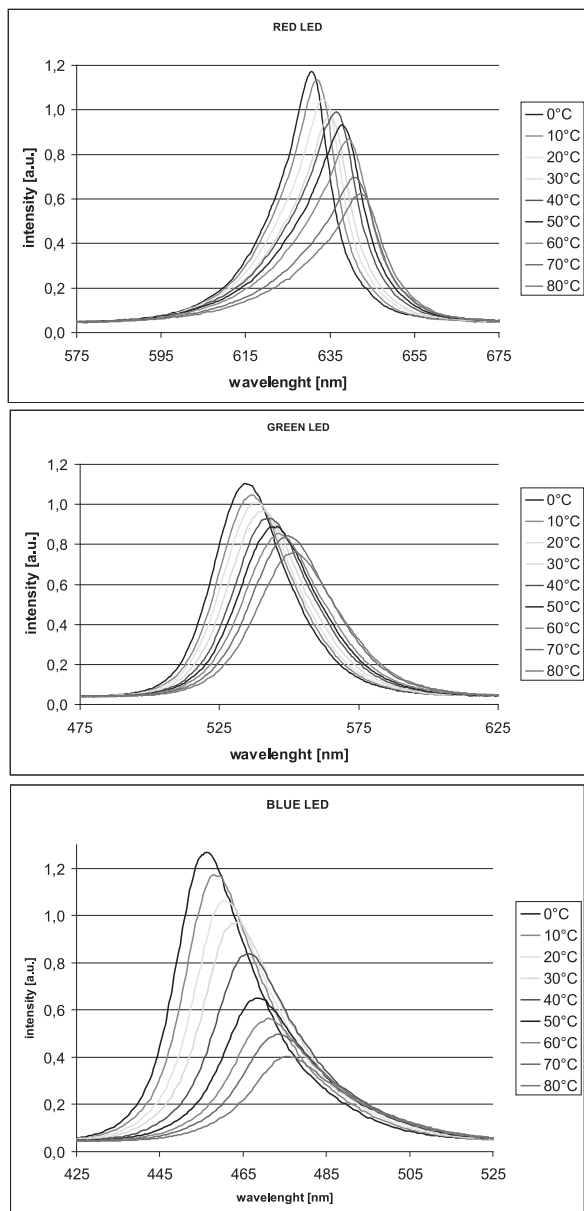


Figure 8. Influence of junction temperature on the maximum of the light wave emitted by a red, green and blue LED

temperature fluctuations may lead to a change in the color of

Temperature influence on the spectral parameters of the diodes is shown in Figure 7 - the results are normalized relative to the values obtained at 25°C. As can be observed with the increase of junction temperature the LED optical power decreases and the maximum of wavelength shifts toward long wavelengths. This is consistent with the relationship described by the formulas (1) and (2), beyond that figure 8 confirms that the non-linearity characteristics of $E_g(T_j)$ in the typical temperature range in which LEDs work can be neglected.

After analyzing the slope of the characteristics of the graphs in Figure 8, it can be seen that the light-emitting diodes of different colors react differently to a change in temperature of the *pn* junction. Comparing the directional

factor of the line approximating obtained characteristics can be seen that the greatest shift of the maximum of the emitted light was observed in the case of blue LED, the smallest in the case of the red. This fact is particularly important in the case of luminaires using multi-color LEDs, because the large temperature fluctuations may lead to a change in the color of the emitted light.

Conclusions and Future work

Developed and manufactured measurement system is used to measure the real LED junction temperature, and to determine its impact on the basic electrical and photometric LED parameters. The results can be used for optimizing the design of lighting fixtures, especially for lamps operating under extreme temperature conditions.

Currently, works are carried on the impact of the above-mentioned phenomena in the colorimetric parameters of luminaires using multi-colored LEDs. The result of this work will be a lighting fixtures control algorithm which reduces fluctuations of chromaticity coordinates of the emitted light.

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