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Temperature Measurement Method of the Light-Emitting Diode Chip

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Abstract: The study includes an overview of indirect temperature measurement methods of the Light-Emitting Diode (LED) chip. It is considered the measurement method of thermal performance of the LED chip, based on dependence of the electrical parameters on the temperature. It is described the automated experimental unit for measuring the chip temperature of the working LEDs. There are described the results of measurements of the chip heating and cooling dynamics at various currents. It is carried out the analysis of thermal processes occurring in the chip upon its heating by the flowing current. It is shown that the most simple and fairly accurate temperature measurement method of the chip is the method of direct voltages.

Key words: Light-Emitting Diode (LED), chip temperature, voltage temperature coefficient, temperature measurement method, temperature dynamics, thermal resistance

INTRODUCTION

The light output of the modern LEDs exceeds the value of 300 Lm/W at this point (Cree News, 2014). A further increase in the light flux of the individual LEDs is limited to low power of emitting chip which operates at a relatively low voltage (2-3 V). The only possibility to increase the power of a single chip is to increase the current passing through it, which can be achieved in two ways by either increasing the chip size or increasing the current density through the crystal. At a large chip size, its efficiency decreases by increasing the radiation absorption in the chip, as well as the product cost also increases. An increase in current density also reduces the efficiency due to the chip heating. The maximum current density is limited by the maximum temperature of the chip, at which its significant degradation begins; a destruction of the LED case may occur at high temperatures.

The LED heat sources include the active chip area, current-conducting structure layers and ohmic chip contacts. For small current values, the current main heat source is the active area which is heated by the non-radiative recombination. At the high current values the share of heat, generated at the contacts and in the outer layers of the chip, increases significantly.

The chip temperature affects almost all the LED characteristics: service life, illuminating, electrical characteristics, characteristics of light and energy performance (Chhajed *et al*., 2005; Nikiforov, 2005). The reasons for the temperature change may include the internal and external factors. The internal factors include the chip heating by flowing current and radiation absorption in the chip, the external-change in the ambient temperature and thermal operating conditions of the LED. Based on a large effect of temperature on the LED operation, it is necessary to control the temperature change under the different operating conditions.

MATERIALS AND METHODS

The chip temperature measurement is a difficult task for the LEDs due to the small size and relatively low temperature of the chip. The contact methods are seldom applicable, therefore it is advisable to use the indirect measurement methods. Their brief overview is specified below.

The direct voltage method is based on the dependence of the LED electrical parameters on the temperature of active chip area and enables to determine the chip temperature with an accuracy of ±3°C on the basis of measured Voltage Temperature Coefficient (VTC) (Xi and Shubert, 2004).

According to another method, the temperature of p-n transition is determined by the change in the LED

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emission spectrum, namely by the displacement of spectral emission maximum to short wavelengths with increasing temperature (Schubert, 2006). But this method is less accurate and the measurement is associated with the experiment complication.

Yet another method is based on the use of Raman spectroscopy, by which the temperature of various layers of the structure can be determined. The accuracy is not high and constitutes the value of the order of ±10°C.

For the LEDs, in which the sapphire is used as a substrate, the temperature can be determined by the optical measurement of wavelengths of the lines emitted by chromium (Cr^{3+}) which is located in the substrate as impurity. There are used two red lines for the measurements that are shifted to the long-wave region with increasing temperature (Winnewisser *et al*., 2001).

From the above methods of determining of the LED chip temperature, the most appropriate is the direct voltage method, which enables to carry out the series of experiments on a simple equipment and with a sufficiently high accuracy. This method is based on the change in the electrical parameters of semiconductor structures with the temperature change. Its essence lies in the fact that a calibration is initially made, that is, the pulse voltage-current characteristics of the LED, placed in a thermostat with the fixed temperature, are measured. At the same time the chip is not heated by the flowing current during a short pulse, respectively, the chip temperature is determined by the thermostat temperature. Accordingly, based on the measured voltage and current values at the various temperatures of the LED, it is formed a dependence of electrical parameters on the temperature, which is used to calculate the chip temperature of the operating LED.

The universal expansion board for the Personal Computer (PC) NI PCI-6251 (ADC-DAC) was used as a measuring instrument with a help of which the LED supply currents were set and the measurement of their performance was made. The board is connected to the PC through the PCI slot and contains: 8 differential channels to measure voltage with a maximum digitalization rate of 1.25 MHz, fidelity of 16 bits, measured voltage range of -1...10 V; 2 channels of analog output with a maximum frequency of 2.86 MHz, resolution of 16 bits, voltage range of -10...10 V; 24 channels of digital input/output with a frequency up to 10 MHz; 2 pulse counters with a frequency up to 80 MHz. The board parameters enable to set the voltage of LED power supply and measure it with a high precision. The temperature measurement inside the thermostat is made by the calibrated thermocouple of copper-constantan. Heating is provided by the passage of current regulated based on the measured temperature values. The axial force of LED is measured by a photodiode.

The work was carried out with the use of LabView Software package which distinctive feature laid in the fact that it had been designed for research purposes, so the appearance of applications is very similar to the appearance of conventional measuring instruments. The programs and subprograms in this package are called the virtual appliances. To conduct the researches of the LED chip temperature, it was developed the program, consisting of multiple virtual appliances, interconnected with each other by the: LED temperature calibration; pulse generator; measurement of the voltage-current characteristics; measurement of the LED electrical performance at pulsed supply (Ashryatov *et al*., 2011).

The LED temperature calibration is performed by changing the temperature inside the thermostat and by measuring the pulse voltage-current characteristics of the LED. The temperature varies from 20°-120°C in increments of 10°C. The preliminary studies have shown that the temperature stabilization occurs within 15 min upon its change for 10°C. To reduce inaccuracies the measurements are carried out during the temperature increase and decrease with the following averaging of the results. The results are recorded to the file. The result is a creation of the calibration diagram of the LED voltage dependency (U) on the chip Temperature (T) for a given current. This dependence is well approximated by a straight-line equation. The calibration results are used to calculate the chip temperature under the measured value of LED voltage at a given current.

RESULTS AND DISCUSSION

By using the described unit, it is made the indirect measurements of the dynamics of chip self-heating by passing through it the direct and pulse current of various duty ratio (q) with a frequency of 1 kHz. There were used the blue LEDs in a standard plastic case with a diameter of 10 mm in the studies. The results of experimental studies of the chip heating by a flowing current (30 mA) for the time interval of 60 sec are shown in Fig. 1, for the initial time interval (up to 5 sec) in Fig. 2.

The approximation of these curves using the exponential function shows that the coefficients in the formula are different at different times, i.e., they describe the heating of various sections of the LED structure. This is because initially the temperature gradient has not been established at initial time and the chip outgoing power has been used to heat the structure elements. Since, the heat

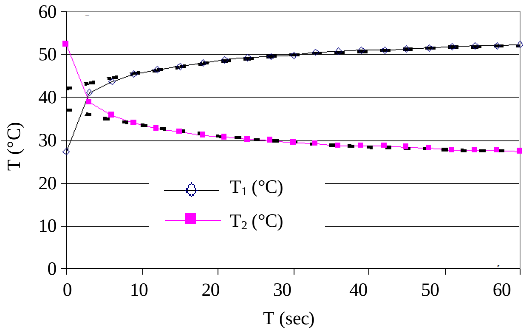

Fig. 1: Approximation of chip heating and cooling curves

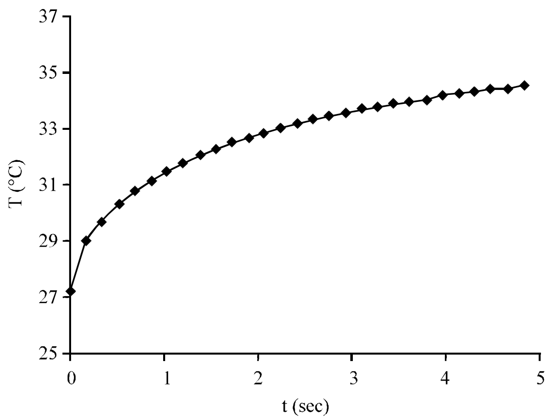

Fig. 2: Chip self-heating curve at the initial time

flow is not distributed instantaneously, the chip temperature increase at the initial time is at a higher rate, as the chip heat capacity is much smaller than the heat capacity of the entire LED structure. After some time, when the thermal energy is spread throughout the LED structure (in this case after 10 sec from power on), the exponential dependence describes the LED heating with the participation in the heat elimination to the whole structure, at that, the heating time constants satisfy the obtained relations for the thermal resistance and heat capacity (Shybaykin and Myshonkov, 2011).

The experimental studies and theoretical modeling of the thermal processes in the LED with a pulsed current power (Shybaykin and Myshonkov, 2012) showed the chip active area is heated to a lesser degree at the higher frequencies upon the equal duty ratios. Thus, in order to reduce the local overheating of the chip active area under pulsed current, it is necessary to increase the pulse repetition frequency.

The above method of the LED chip temperature measurement can also be used to evaluate the LED chip heating in actual use upon the design of lighting devices (Kositsyn and Myshonkov, 2013). For mass measurements in the production of lighting devices, it may be used a typical temperature coefficient value of the LED voltage which varies but the inaccuracy introduced by the technological spread of the parameters may be taken as allowed. To obtain more accurate measurements, it is necessary to calibrate each LED.

The most simple and fairly accurate temperature measurement method of the chip is the method of direct voltages. The unit developed on the basis of application of modern automated measuring devices will enable to conduct the experimental researches of thermal processes in the LED with a high accuracy. The obtained results of the experimental studies are the basis for the modeling of thermal processes in the LEDs in actual use.

CONCLUSION

The conducted measurements showed good agreement between the experimental and theoretical data, which may indicate the possibility of applying this method to measure the temperature and electrical characteristics of the LEDs on the described equipment and using the developed program.

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