Journal of Engineering and Applied Sciences 12 (7): 1931-1934, 2017
ISSN: 1816-949X

Temperature Measurement Method Development for Light-Emitting Diode Crystal

Myshonkov Alexander Borisovich and Zheleznikova Olga Evgenievna
Federal State Budgetary Educational Institution of Higher Education,
"National Research Mordovia State University Named after N.P. Ogarev", Bolshevistskaya St. 68,
430005 Saransk, Mordovia Republic, Russia

Abstract: The study is devoted to the method development concerning the measurement of a light-emitting diode crystal temperature based on the method of direct stresses. An automated experimental device is described to perform crystal temperature measurements among working LEDs. The results of indirect measurements are presented for heating and cooling dynamics of crystals at various currents. They presented the analysis of thermal processes occurring in a crystal during its heating by a flowing current. It was confirmed experimentally and theoretically that the developed method of a light-emitting diode crystal measurement can be used to evaluate the heating of a light-emitting diode crystal under real operating conditions during the design of light devices.

Key words: LED, crystal temperature, temperature coefficient of voltage, temperature measurement technique, temperature dynamics, thermal resistance

INTRODUCTION

Currently, the light output of modern LEDs makes 300 Lm/W. Further increase of the light flux among individual LEDs is limited by the low power of a radiating crystal which is operated at a relatively low voltage (2-3 V). The only possibility of a single crystal power increase is the increase of current passing through it which can be achieved in two ways: by increasing the crystal size or by increasing the current density through a crystal. At large crystal sizes its efficiency decreases due to the increase of radiation absorption in a crystal. Besides, the cost of the product increases. The current density increase also leads to the efficiency decrease due to a crystal heating. The maximum value of the current density is limited by the extreme temperature of a crystal at which its considerable degradation begins. A LED housing may be destroyed at high temperatures.

An active region of a crystal, the conducting layers of a structure and ohmic contacts to a crystal are the heat sources in LEDs. At low current values, the main source of heat is an active region which is heated by nonradiative recombination. At high current values, the fraction of heat released on contacts and in the outer layers of a crystal increases significantly. The temperature of a crystal influences on almost all LED characteristics: service life, lighting, electrical characteristics, the characteristics of light and energy efficiency (Chhajed *et al*., 2005; Nikiforov, 2005). Internal and external factors may act as the reasons of temperature change. Internal factors may include the heating of crystals with a flowing current, the absorbing of radiation in a crystal, external factors may include the change of the ambient temperature and the thermal conditions of a LED operation. According to a large influence of temperature on the operation of LED, it becomes necessary to control the temperature change under different operating conditions.

MATERIALS AND METHODS

The measurement of the LED crystal temperature is a difficult task due to the small sizes and relatively low temperature of a crystal. Contact methods are of little use, so indirect measurement methods are advisable.

The method of direct stresses is based on the dependence of LED electric parameters on the temperature of a crystal active region of the crystal and on the basis of the measured Temperature Voltage Coefficient (TVC) it is possible to determine the temperature of a crystal with an error of ±3°C (Xi and Shubert, 2004).

According to the method described by Schubert (2006), the temperature of the p-n-junction is determined

Corresponding Author: Myshonkov Alexander Borisovich, Federal State Budgetary Educational Institution of Higher Education, "National Research Mordovia State University Named after N.P. Ogarev", Bolshevistskaya St. 68, 430005 Saransk, Mordovia Republic, Russia

according to the change of LED emission spectrum, namely according to the shift of the radiation spectral maximum to the region of short wavelengths at temperature increase. But this method is less precise and the measurement is related with the experiment complication.

Another method is based on the use of Raman spectroscopy by the means of which the temperature of various layers of a structure can be determined. The accuracy is a low one and amounts to about ±10°C (Chitnis *et al*., 2002).

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

From the abovementioned methods of LED crystal temperature determination, the most suitable one is the direct stress method which makes it possible to carry out a series of experiments on simple equipment and with a sufficiently high accuracy. It is based on the change of semiconductor structure electrical parameters at temperature change. The essence of the method lies in the fact that calibration is carried out initially the pulsed volt-ampere characteristics of the LED are measured. This LED is placed in a thermostat with the set temperature. At that, the crystal is not heated by a flowing current during a short pulse, therefore, the temperature of the crystal is determined by the thermostat temperature. Proceeding from this, according to the measured values of voltage and current at different LED temperatures, the dependence of electrical parameters on the temperature is designed which is used to calculate the temperature of an operating LED crystal (Cree News, 2014).

We used a universal expansion board for the personal computer NI PCI-6251 (ADC-DAC) as a measuring instrument. It set the LED supply currents and their characteristics were measured. The board is connected to a personal computer via a PCI slot. The board has 8 differential channels for voltage measuring with a maximum digitization frequency of 1.25 MHz, the accuracy of 16 bits and the range of measured voltages -1, ..., 10 V; 2 channels of analog output with the maximum frequency of 2.86 MHz, the resolution of 16 bits, the voltage range of -10, ..., 10 V; 24 channels of digital I/O with the frequency up to 10 MHz; 2 pulse counters with the frequency up to 80 MHz. The board parameters allow to set the LED supply voltage and to measure it with a high accuracy. The temperature measurement inside a thermostat is performed by a calibrated copper-constant an thermocouple. Heating is carried out by passing the current controlled on the basis of the measured temperature values. The axial light intensity of a LED is measured with a photodiode.

LabView Software was used in the research, the distinctive feature of which is that it was designed for research purposes so the appearance of applications is similar in many respects to the appearance of conventional measuring devices. Programs and subroutines are called virtual devices in this complex. In order to study the temperature of a LED crystal, the program was developed consisting of several virtual instruments interconnected with each other: the temperature calibration of the LED; pulse generator; the measurement of the current-voltage characteristic; the measurement of LED electrical characteristics under pulsed power (Ashryatov *et al*., 2011).

The temperature calibration of a LED is carried out by changing the temperature inside a thermostat and by the measuring of LED impulse volt-ampere characteristics. The temperature varies from 20-120°C with the step of 10°C. Preliminary studies showed that the temperature stabilization occurs within 15 min when it changes by 10°C. In order to reduce errors measurements are performed with temperature increase and decrease, followed by the averaging of results. The results are recorded in a file. The result is the creation of a calibration graph concerning the dependence of LED (U) voltage on the crystal Temperature (T) at a certain current. This dependence is well approximated by the equation of a straight line. The calibration results are used to calculate the crystal temperature according to the measured value of LED voltage at a given current.

RESULTS AND DISCUSSION

Main part: The device described above made it possible to make indirect measurements of a crystal self-heating dynamics when a constant and pulsed current of various pulse ratios (q) is passed through it with the frequency of 1 kHz. The studies used blue LEDs in a standard plastic housing with the diameter of 10 mm. The results of experimental studies concerning a crystal heating by a flowing current (30 mA) for the time interval of 60 sec are shown on Fig. 1 for the initial time interval (up to 5 sec) on Fig. 2.

The approximation of these curves using an exponential function shows that at different moments times the formula coefficients are different ones that is they describe the heating of LED structure different sections. This is explained by the fact that the temperature

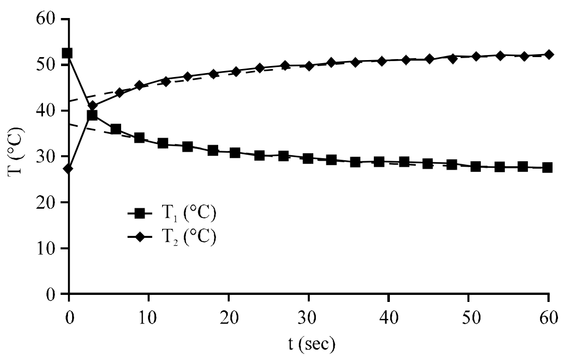

Fig. 1: Approximation of crystal curves heating and cooling

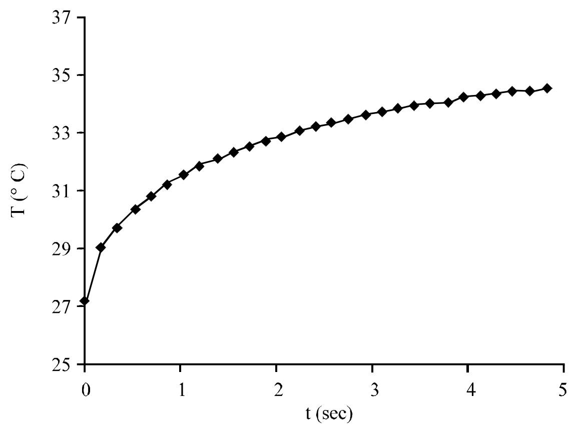

Fig. 2: Crystal self-heating curve at the initial instant of time

gradient was not established at the initial moment of time and the power diverted from a crystal was used to heat the structural elements. Since the heat flux does not spread instantaneously, the increase of the crystal temperature at the initial moment of time proceeds at a higher rate, since the heat capacity of a crystal is much less than the heat capacity of the entire LED design. After a certain time, when the thermal energy spread throughout the entire LED design (in this case after 10 sec from the moment of turning on), the exponential dependence describes the LED heating with the participation of the entire structure in heat removal. At that the heating time constants satisfy the obtained ratios for thermal resistance and heat capacity (Shibaykin and Myshonkov, 2011).

Experimental studies and theoretical modeling of thermal processes in a light-emitting diode with pulse current (Shibaykin and Myshonkov, 2012) showed that at equal relative pulse duration with higher frequencies, an active region of a crystal is heated to a lesser degree. Thus, in order to reduce the local overheating of a crystal active region with a pulsed current, it is necessary to increase the pulse repetition rate.

The developed method of a crystal temperature measuring for light-emitting diodes can also be used to evaluate the heating of light-emitting diode crystal in real operating conditions during the design of light devices (Kositsyn and Myshonkov, 2013). They can use a typical value of LED voltage temperature coefficient of the LED voltage for mass measurements during the production of lighting products. This coefficient varies, but the error introduced by the technological spread of parameters can be accepted as an acceptable. It is necessary to calibrate each LED for more accurate measurements.

Summary: The simplest and most accurate method of a crystal temperature measurement is the method of direct stresses. The developed device based on the use of modern automated measuring devices will allow to conduct experimental studies of thermal processes in a LED with a sufficiently high accuracy. The obtained results of experimental studies are the basis for thermal process modeling in light-emitting diodes under real operating conditions.

CONCLUSION

The conducted measurements showed a good agreement between experimental and theoretical data which may indicate the possibility of the developed technique use to measure the temperature and electrical characteristics of LEDs using the described equipment and the researchers program.

REFERENCES

Ashryatov, A.A., A.B. Myshonkov and S.A. Mikaeva, 2011. Measurement of crystal temperature among low-power LEDs. Autom. Mod. Technol., 3: 10-13.

Chhajed, S., Y. Xi, Y.L. Li, T. Gessmann and E.F. Schubert, 2005. Influence of junction temperature on chromaticity and color-rendering properties of trichromatic white-light sources based on light-emitting diodes. J. Appl. Phys., Vol. 97,

Chitnis, A., J. Sun, V. Mandavilli, R. Pachipulusu and S. Wu *et al*., 2002. Self-heating effects at high pump currents in deep ultraviolet light-emitting diodes at 324 nm. Appl. Phys. Lett., 81: 3491-3493.

Cree News, 2014. Cree first to break 300 lumens-per-watt barrier. Durham, Carolina. www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier

Kositsyn, A.A. and A.B. Myshonkov, 2013. Development of a device and a technique to determine the temperature of the LED P-N-junction in real operating conditions. Educ. Exp. Educ., 3: 51-52.

Nikiforov, S.G., 2005. Temperature during the life and work of light-emitting diodes. Compon. Technol., 9: 48-54.

Schubert, E.F., 2006. Light-Emitting Diodes. Cambridge University Press, Cambridge, UK., Pages: 431.

Shibaykin, S.D. and A.B. Myshonkov, 2011. Approximation of self-heating curves of a LED crystal by a flowing current. Branch Aspects Eng. Sci., 12: 23-24.

Shibaykin, S.D. and A.B. Myshonkov, 2012. Modeling of thermal processes in a LED. Branch Aspects Eng. Sci., 8: 29-35.

Winnewisser, C., J. Schneider, M. Borsch and H.W. Rotter, 2001. In situ temperature measurements via ruby R lines of sapphire substrate based InGaN light emitting diodes during operation. J. Appl. Phys., 89: 3091-3094.

Xi, Y. and E.F. Schubert, 2004. Junction-temperature measurement in GaN ultraviolet light-emitting diodes using diode forward voltage method. Appl. Phys. Lett., 85: 2163-2165.