Accounting the quantum-confined Stark effect on the
determination of the active LED region temperature

M M Romanovich, I A Lamkin and S A Tarasov
Saint-Petersburg Electrotechnical University “LETI”, ul. Prof. Popova 5, St.
Petersburg 197376, Russia

E-mail: mmromanovich@mail.ru, ialamkin@mail.ru, satarasov@etu.ru

Abstract. The article investigates the effect of heating of the LEDs active region (AR) on the luminescence efficiency of LEDs of various spectral ranges. As a result of the work the method for contactless determination of the active LED region temperature with account the influence of the Stark effect was created. The method is based on the analysis of the long-wave part of the spectrum whose behavior primarily depends on the crystal temperature.

1. Introduction
There are a lot of factors that influence on the internal quantum efficiency of LED radiation. One of these factors is the self-heating of the active region of semiconductor LEDs. The temperature value of the crystal active region determines the degree of light output, spectral characteristics, as well as operational reliability, mechanical strength, and service life of the emitters. In optimal conditions the source service life can reach more than 100,000 hours. The most reliable determination of the active region temperature of an LED crystal during its testing and operation is a technically demanding task [1].

The technique [2] was developed earlier, which allows calculating the active region temperature of a crystal. This method contains a significant drawback: the impossibility of using it to study modern LEDs containing quantum wells due to the introduction of a significant error by the quantum-confined Stark effect (QCSE) [3]. In the present work this technique was modernized in such a way that the influence of the QCSE was minimized. The data obtained were in good agreement with the data obtained by directly measuring the heat with an IR camera.

2. Experimental results and discussions
As a result of the work the installation was created. It allows to assess the effect of the active region heating on the LEDs luminescence efficiency based on InGaN solid solutions in a contactless way. The shift of the luminescence spectrum is influenced by two main effects - the QCSE and the heating of the active region itself. The purpose of this work was to determine the dependence of the heating of the active region of a LED on the current. QCSE in this case is a parasitic effect. The effect manifestation can be clearly seen in the pulsed mode of operation since in this case the self-heating of the AR of a LED has a minimal effect which follows from the Joule-Lenz law. It has been established the main factor influencing the peak radiation wavelength of the LED crystal is the active region heating. The active region heating leads to the efficiency decreases of LEDs (figure 1) due to the increase in the
fraction of nonradiative carrier recombination. If the LED operates at high temperatures the lifetime of the device is significantly reduced [4].

Two types of the LEDs based on InGaN solid solution were considered: a blue LED containing nine crystals in the structure (type 1) and a white LED with a phosphor containing one crystal (type 2). The developed method for contactless determination of the active region temperature is based on the analysis of the long-wave spectrum part whose behavior primarily depends on the crystal temperature.

![Figure 1. LEDs efficiencies](image1)

**Figure 1.** LEDs efficiencies

3. **Calculations the active region temperature of the InGaN LEDs**

In this method with a LED temperature grading a set of dependencies of wavelengths on temperature was obtained for selected points in a given long wavelength part of the LED emission spectrum. For different levels of the maximum intensity of 90%, 80%, and 70% the dependences of the long-wave edge of the crystal spectrum on temperature were plotted and their linear dependences were determined. The shift of the long-wave edge of the crystal spectrum is analyzed to minimize the influence of noise on the calculations accuracy and to reduce the error. The dependencies for type 2 LED are shown in figure 2,3.

![Figure 2.](image2)

**Figure 2.** The normalized spectra of the second type LED at different temperatures

![Figure 3.](image3)

**Figure 3.** The temperature dependence of the long-wave part spectral shift
The LED spectra were measured at certain values of direct current. The wavelengths at selected points in a given long-wavelength region of the spectrum were determined from the spectra obtained. At the levels of the maximum intensity of 90%, 80%, and 70% the dependencies of the radiation wavelength on the transmitted current were constructed for each structure. The shift of the wavelength in the emission maximum with increasing current for all samples was determined. It indicates a strong heating of the LEDs active region at high currents. The obtained dependencies for the second type sample are shown in figures 4, 5. In addition to heating the quantum-confined Stark effect (QCSE) makes a significant contribution to the shift of the crystal spectrum to a shortwave wavelength region (as can be seen in figure 5). Internal piezoelectric fields generate the Stark effect, which reduces the internal quantum efficiency. This effect consists of a change in the energy spectrum of atoms, molecules, and crystals in an electric field and manifests itself in heterostructures with quantum wells (QWs) in a blue shift of the exciton absorption line of the QW. The shift of the luminescence spectrum at low currents is due to the influence of elastic stresses which cause the appearance of lattice deformation at the heterojunction and the built-in electric field. The magnitudes of the voltages falling on an active region are very small when small direct currents are passed through the structure. On their background the contribution of the built-in field caused by deformations is especially noticeable. Under it influence the shape of the well is strongly distorted and the QCSE appears. This leads to a decrease in the distance between the levels which causes a shift in the luminescence spectrum to the short-wavelength region. With increasing external voltage, the effect of the built-in field is compensated and the shift decreases [5]. The quantum-confined Stark effect is most pronounced in LEDs based on InGaN and AlGaN heterostructures [6].

To obtain the most reliable temperature values of the LEDs AR this effect was taken into account as follows: to eliminate crystal self-heating and to obtain only the QCSE the spectral characteristics of the LED were measured at selected values of the pulse current at room temperature. And the current dependencies of the wavelengths at different levels on the intensity maximum of the LED radiation was taken into account the influence of the Stark effect, were obtained.

According the calibration dependencies, the average active region temperatures for each selected point were determined. The calculations of the dependencies of the active region temperature on the current were measured for structures in which the QCSE is manifested with and without this effect. The obtained measurement results were compared with the results obtained using an infrared camera. Dependencies for the LED’s of the first and second types are shown in figures 6 and 7, respectively. As can be seen from the dependencies obtained the QCSE introduces a large error in the calculations of the active region temperature from the shift of the electroluminescence spectrum. Using the described technique, the accuracy of temperature calculation was increased. It will further ensure the safe, high-
quality, reliable, non-destructive, and affordable control of ready-made LEDs, lamps, and arrays based on them.

**Figure 6.** The dependencies of the active region temperature for LED type 1.

**Figure 7.** The dependencies of the active region temperature for LED type 2.
4. Conclusions
As a result of the work the quantum-confined Stark effect influence in calculating the temperature of the LEDs active region was minimized. It was confirmed by research using an infrared camera. The presented method of LED research, the purpose of which is to identify defective samples during the production process between the technological operations of obtaining the chip and its packaging, will improve the yield and reduce the excess costs associated with installing low quality crystals in the casing. Also, the technique will allow pre-detecting low-quality chips that can fail at the beginning of operation due to the poor quality of the epitaxial layers, as well as due to an increase in the temperature of the active region to an unacceptable level due to the insufficient heat removal.

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