Evaluation of the quality of green InGaN LEDs by values of the threshold current

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Abstract. The article shows the possibility of using the threshold current for evaluating the quality of green InGaN/GaN LEDs. It was determined that the current threshold correlated with the position of the maximum of the current dependence of external quantum efficiency, and a concentration gradient of charge carriers in the heterostructure.

1. Introduction

LEDs based on InGaN/GaN heterostructures are currently widely used in various branches of engineering. In order to improve the reliability of technical devices and systems based on InGaN/GaN LEDs devices and systems of nondestructive testing their quality is actively being developed [1, 2]. One of the least understood, but quite informative parameter, which gives representation about the quality of the LED heterostructure is the threshold current. For lasers this term refers to the current at which the optical radiation from spontaneous enters induced. For LEDs this term refers to the minimum current at which the optical radiation can be registered [3, 4].

It is known that luminescence of an ideal LED comes with an external voltage, compensating the contact potential difference $U_D = E_g/e$, where E_g – band gap, e – electron charge [3]. However, the voltage drop across the base resistance and the ohmic contacts of the LED, the presence of discontinuities of the conduction band and valence band of a semiconductor heterostructure leads to a deviation of the threshold voltage from the U_D value. Thus the current corresponding to the threshold voltage, characterized non-radiative recombination losses in the system of defects penetrating the LED active region [4], therefore, the characteristics of the sampling distributions of the LEDs on the threshold current values can be used to evaluation the quality of the light emitting heterostructure.

2. Experimental details

This article presents the results of a study of green InGaN/GaN LEDs type ARL-5215PGC produced by Arlight in the number of N = 100 pieces, with the following parameters: the wavelength of the maximum of emission spectrum λ_{max} = 525 nm, the maximum constant operating current I_{max} = 30 mA, the crystal size 270x320 μm.

Measurement of threshold current of LEDs made on the automated installation [5], the operation algorithm which is to measure of the LED emission power depending from the current $P(I)$ by highly sensitive photodetector in the current range, corresponding to the beginning of the LED illumination, and subsequent approximation of this dependence by an exponential function of the form $P_0 \cdot (I/I_0)^a$

(figure 1). The current I_{th} at which the approximating function crosses the level of the photodetector dark signal, is taken as the numerical value of the threshold current.

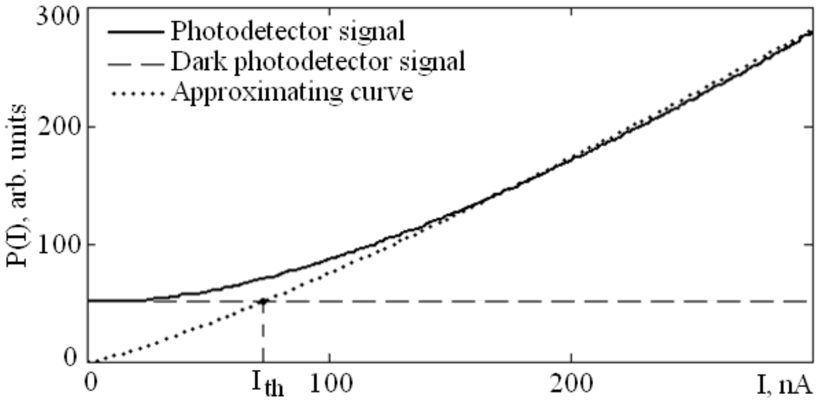

Figure 1. Graphs illustrating the principle of determining the value of the LED threshold current.

Measurement of the external quantum efficiency (EQE) of LEDs was performed using an integrating sphere TKA-KK1.

Measurement of the capacitance-voltage characteristics of LEDs performed in an automated installation [6] in a range of bias voltages +2...–45 V at room temperature. According to the measured capacitance-voltage characteristics was performed calculation of the profile of concentration charge carriers distribution in the heterostructure $n(w)$.

3. Results and discussion

The measurement results showed that the current threshold I_{th} of the researched type LEDs (at an ambient temperature T = 25 °C) are in the range 21...607 nA. 72 LEDs in sampleare the values of threshold current in the range 21...90 nA, while the remaining 28 samples are the values of I_{th} in the range of 90...607 nA. Histogram of LEDs distribution by threshold current values is shown in figure 2. The average value of the threshold current in the sample is 110 nA, the standard deviation is 113 nA. The proximity of the estimation of mathematical expectation value and the estimation of standard deviation indicates the exponential law of distribution of LEDs by threshold current values. We assume that the LEDs are characterized by lower concentrations of defects in the active region, are in the first interval of the distribution histogram, which is marked in figure 2 a gray background, that is, have a threshold current value in the range of 21...90 nA.

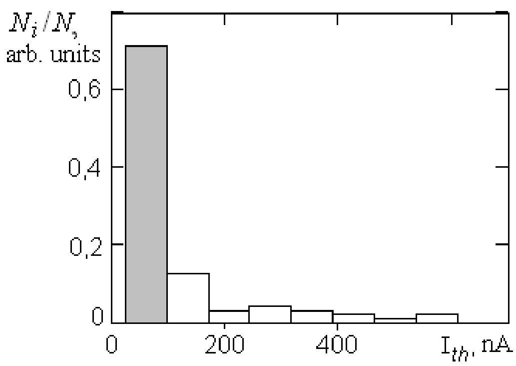

Figure 2. Histogram of distribution of LEDs group of N = 100 pieces by threshold current values.

To confirm this statement, we investigated the relationship between the values of the threshold current and character of the EQE versus current density depending $\eta(j)$ of the LED. Figure 3 shows plots of EQE versus current density for three investigated LEDs samples having different values of the threshold current I_{th}. It can be seen that the most noticeable variation of the EQE values is reveals at the low current density range, corresponding to rise range of function. At current densities corresponding to range of decrease of EQE, LEDs have similar external quantum efficiency values. According to the model described in [7], it is explained as follows. At low current densities the non-radiative recombination centers present in the LED active region can efficiently trap the injected carriers, thus reducing the probability of radiative recombination, and consequently, the radiation power. At high current densities the injection of a large number of charge carriers leads to a saturation of non-radiative centers, so differences in the radiation power and therefore the EQE of LEDs at high measurement currents is much smaller than for low current.

Statistical analysis of the sample measurement results showed that the value of the threshold current is correlated with the value of the EQE of LEDs at low current densities, corresponding to rising of the current dependence of EQE. The dependence of the external quantum efficiency $\eta(j)$ from the LEDs with a low threshold current value I_{th} = 22 nA reaches a maximum at 0.1 A/cm^2 current density, while the LEDs with a high threshold current value I_{th} = 607nA – at 0.6A/cm^2, while absolute value of EQE according to maximum of $\eta(j)$ is the greater, the smaller the value I_{th} (figure 3).

These results suggest that the greater the threshold current of the LED, the higher the probability of tunneling non-radiative recombination, and hence the higher the concentration of defects in the active region of the LED.

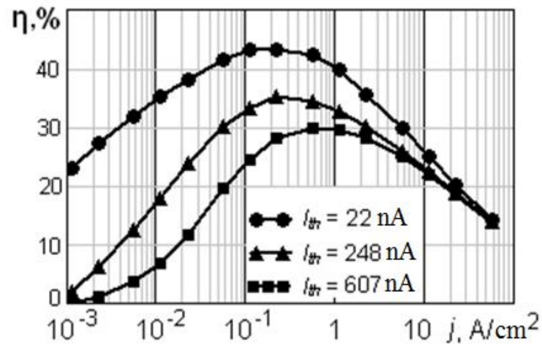

Figure 3. The current density dependence of the external quantum efficiency for three LEDs with different values of the threshold current.

It is known that the defect concentration is largely determined by the degree of ordering of the structure [4]. Evaluation of ordering of the structure can be performed by profile of concentration charge carriers distribution in the heterostructure is obtained by measuring the capacitance-voltage characteristics of the LED.

In [8] the correlation between the value of the LED light power and the character of the concentration profile is shown: the wider the area of increase of charge carriers concentration from the minimum to the maximum, the higher the power of the LED light. The authors explain this effect to the improvement of injection and distribution of charge carriers in the active region of the LED.

We propose to use to assess the of ordering of the active region of LEDs concentration gradient of charge carriers in the heterostructure [9], defined according to the formula:

$$\frac{\Delta n}{\Delta w} = \frac{\int_{w_{min}}^{w_{max}} n(w)dw}{(w_{max} - w_{min})^2}, \tag{1}$$

where w_{min} and w_{max} – the borders of measured profile concentrations.

As aresult of research of LEDs sample we have found that LEDs with a low threshold current value (about 21...50 nA) have a more uniform concentration profile (figure 4, curve 1) than the LEDs with a high threshold current (of the order of 200...607 nA) (figure 4, curve 2). The correlation coefficient between the values of the threshold current I_{th} and the concentration gradient of charge carriers $\Delta n/\Delta w$ is 0.7. Thus, LEDs with a more uniform concentration profile have less defects in the active region and are characterized by small values of the threshold current.

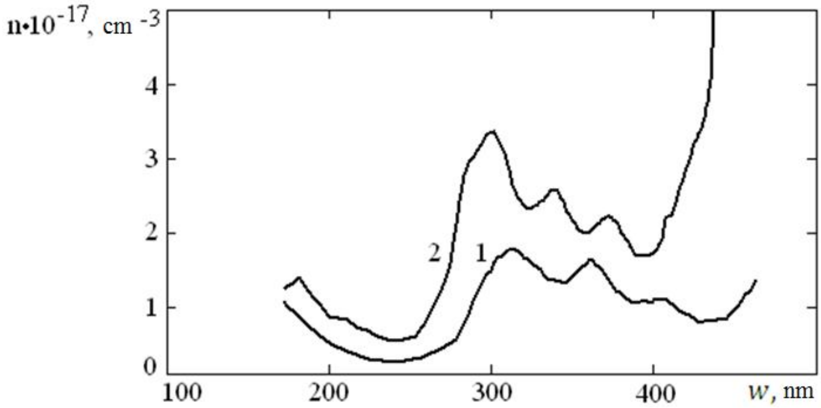

Figure 4. Profiles profile of concentration charge carriers distribution in the LEDs heterostructure with a small (1), and large (2) value of the threshold current.

4. Conclusions

The results of the studies showed that the threshold current can be used to assess the quality of the LEDs based on InGaN/GaN nanoheterostructure. The distribution of LEDs by values of threshold current has a form close to exponential, indicating the correlation between this parameter and defect density in the active region of the heterostructure [10]. The threshold current values is correlated with the value of the EQE of the LED at low current densities range corresponding increase external quantum efficiency with increasing current, and with a charge carrier concentration gradient value. The more uniform concentration profile and the higher the quantum efficiency of the LED, measured at low currents, the less defects in the active region of LEDs, which are non-radiative recombination centers, and thus, the lower the threshold current. LEDs that are less than the threshold current average value in the sample, characterized by lower concentrations of defects in the active region, thus their quality is higher. Thus, the threshold current of the LED is an important informative parameter that can be used to evaluation of the light-emitting heterostructures quality.

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