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EXPERIMENTAL DETERMINATION OF THE MAIN POSSIBLE STATIC MODEL PARAMETERS OF A DISCRETE SEMICONDUCTOR LIGHT EMITING DIODE

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Abstract

As a fundamental part of every electronic device, semiconductor electronic components possess highly important characteristics. These characteristics must be well understood to correctly determine the operating modes of each electronic component, thereby ensuring the reliability of the device.

In modern electronic equipment, semiconductor light sources namely light-emitting diodes (LEDs) are becoming increasingly widespread. They are used not only as indicator elements, but also for illumination and even for information transmission through the light they emit. In this regard, knowledge of their static and dynamic characteristics is an advantage in the design and implementation of practical electronic circuits employing LEDs.

This report presents the experimentally obtained main static and dynamic parameters of an investigated blue LED. A schematic diagram of the experimental setup, current–voltage characteristics, as well as the experimentally determined static and dynamic resistance, dissipated power, and other parameters are presented, obtained both at room temperature and at elevated temperature.

Keywords: Semiconductor device; semiconductor light source, discrete LEDs; model parameters of semiconductor elements; V-A characteristics of LEDs; investigation of the influence of temperature.

INTRODUCTION

Light-emitting diodes (LEDs) are electronic components that are finding increasingly widespread applications in electronics. Their use both as indicator elements – single and matrix-based (LED displays) – and for information transmission in optical communication channels determines their importance not only for electronics, but also for computer and communication technologies [1].

Particular interest is associated with the application of LEDs as light sources. In this field of optoelectronics, numerous results have been achieved demonstrating the possibilities for improving semiconductor crystals for their use not merely as light indicators, but as actual light sources [1].

In addition, issues related to the use of standard LEDs as converters of light into electrical signals are also considered.

Despite the well-established understanding of solid-state physics related to the processes and phenomena occurring in semiconductor PN junction crystals, there remains significant interest in the possibilities for experimentally measuring and determining the main parameters of discrete semiconductor light sources. Knowledge of these parameters enables optimization in the design of both practical and simulation-based electronic circuits employing LEDs. This, in turn, improves the operating modes of such circuits. To achieve this, it is necessary to understand the influence of ambient temperature on the operation of discrete semiconductor light sources, since their temperature sensitivity is well known [2–8].

The purpose of the present report is to describe the main model parameters of a standard discrete semiconductor light source obtained experimentally during operation at

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both room temperature and elevated temperature.

EXPERIMENTAL INVESTIGATIONS AND RESULTS

1. CURRENT–VOLTAGE CHARACTERISTIC

The schematic diagram of the experimental setup used to conduct the experimental investigations for measuring and plotting the static current–voltage characteristics $I_F = f(U_F)$, $T_0 = \text{const}$, is shown in Fig. 1. The investigated LED, type L-7104QBDL-D, is connected in the forward direction - the positive terminal of the DC power supply U is applied to the anode, while the negative terminal is connected to the cathode.

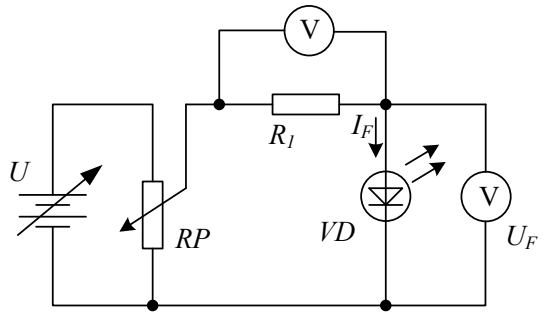


Fig. 1. *Schematic diagram of the experimental setup for measuring the characteristic* $I_F = f(U_F)$, $T_0 = const$

As can be seen from Fig. 1, the DC power supply U is adjustable and can provide a supply voltage within the range $U = (0 - 30)$ V. For finer adjustment, an additional rheostat R_P is used. It should be noted that, to avoid measurement error in the current I_F, the current is not measured directly with an ammeter, but indirectly with a voltmeter by measuring the voltage drop across the measuring resistor R_1. The latter has a resistance value of $1\,\text{k}\Omega$ and a tolerance of ±0.1%. This means that, according to Ohm's law, the reading of the voltmeter connected in parallel to it will be expressed directly in mA.

The measurement of the characteristic $I_F = f(U_F)$, $T_0 = \text{const}$ is carried out under strictly controlled ambient temperature conditions by placing the LED in a special chamber with adjustable temperature. The temperature is varied within the range $T_0 = (20–180)°\text{C}$ using a thermostat with an accuracy of ±1°C.

Fig. 2 presents the experimentally recorded family of current–voltage characteristics $I_F = f(U_F)$, $T_0 = \text{const}$, obtained using the setup shown in Fig. 1. Since the diode is forward-biased, its electrical resistance is very low, which enables more precise adjustment of the forward current I_F and accurate measurement of the forward voltage drop U_F.

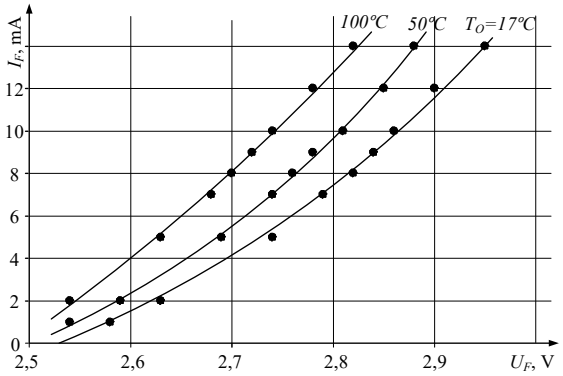


Fig. 2. *Experimental characteristics* $I_F = f(U_F)$, $T_0 = const$

The characteristics $I_F = f(U_F)$, $T_0 = \text{const}$were recorded at three ambient temperature values: $T_0 = 17°\text{C}$, 50°C, and 100°C.

The analysis of the obtained characteristics shows the typical behaviour of a semiconductor device operating at elevated temperatures – a pronounced negative temperature coefficient of the voltage across the LED U_F, and a similar behavior of the static electrical resistance r_S. As can be seen from the graph in Fig. 3, r_S decreases with increasing forward current I_F, and also shows a slight dependence on temperature T_0.

For example, at $I_F = 5\,\text{mA}$, when the LED is already well into forward conduction, the static resistance of the investigated LED at near room temperature ($T_0 = 17°\text{C}$) is $r_S = 548\,\Omega$, while at $T_0 = 100°\text{C}$ it is $r_S = 526\,\Omega$. Therefore, for a temperature change of 83°C, the electrical static resistance of the LED changes by $22\,\Omega$. This corresponds to a temperature coefficient of resistance TCR of $0.265\,\Omega/°\text{C}$.

The values of r_S are obtained from the relationship:

$$r_S = \frac{U_F}{I_F}, \quad (1)$$

and for the temperature coefficient of static resistance:

$$TKr_S = \frac{\Delta r_S}{\Delta T_O}. \quad (2)$$

Fig. 3 shows the dependence $r_S = f(I_F)$, $T_0 = \text{const}$. It illustrates the variation of the static resistance of the discrete LED as a function of the forward current, at room and elevated ambient temperatures.

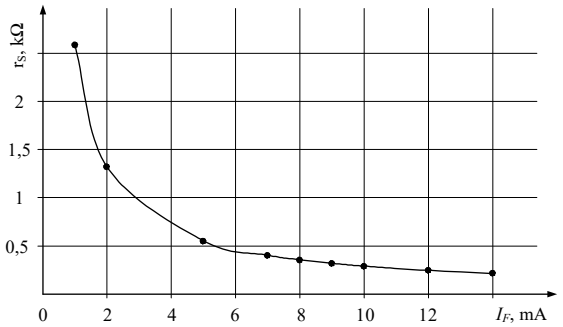


Fig. 3. *Experimental characteristics* $r_S = f(I_F)$, $T_0 = const$

The reason for the observed behavior of the obtained experimental results (characteristics) lies in the processes occurring in the PN junction under conditions of increasing forward current and rising temperature.

In the first case, with an increase in forward current, the injection of electrons across the PN junction increases, which leads to a reduction in resistance. In the second case, with increasing temperature, the donor and acceptor energy levels in the semiconductor PN junction become depleted – the number of electrons and holes associated with these impurity levels gradually decreases. Consequently, the activation energy of the donor and acceptor levels increases. With a further rise in temperature (up to approximately $T_0 \approx 100°C$), electrons begin to be thermally excited from the valence band into the conduction band, i.e., intrinsic charge carriers are generated. At this point, as long as the concentration of intrinsic carriers remains lower than that of impurity carriers, the total carrier concentration in the semiconductor remains approximately constant. This behavior is typical for doped semiconductors, which exhibit impurity conduction at low temperatures and intrinsic conduction at higher temperatures.

When the PN junction operates in forward bias, both positive and negative charge carriers pass through its depletion region in opposite directions. In some cases, they meet and recombine, forming a recombination current that adds to the diffusion current, and their sum determines the total current through the LED.

The influence of the recombination current on the current–voltage characteristic of the PN junction is easily accounted for by introducing the emission coefficient m (the so-called m-factor) into the original equation:

$$I_F = I_S.\left(\frac{U_F}{e^{\frac{U_F}{m.\varphi_T}} - 1}\right). \quad (3)$$

From the obtained current–voltage characteristics, it is possible to easily determine the static model parameters: the saturation current I_S, the emission coefficient m, and the base differential resistance r_B:

$$I_S = \frac{I_F}{e^{\frac{U_F}{m.\varphi_T}}}, \quad (4)$$

where $\varphi_T = \frac{273{,}5 + T_O}{q}$ is the thermal potential, which is determined by the ambient temperature T_0 expressed in absolute (Kelvin).

The emission coefficient accounts for the various physical effects that occur in a real PN junction:

$$m = \frac{U_{F2} - U_{F1}}{\varphi_T.\ln\left(\frac{I_{F2}}{I_{F1}}\right)}. \quad (5)$$

Table 1 presents the numerical values of the described parameters, obtained at low

currents through the LED. They were calculated according to the equations described above by substituting the experimentally measured data.

Tab. 1

T_O, ºC	φ_T	m	I_S
17	0,025	2,75	$1{,}08.10^{-15}$
50	0,028	3,41	$2{,}61.10^{-15}$
100	0,032	3,07	$1{,}39.10^{-14}$

2. DIFFERENTIAL RESISTANCE

It is well known that both rectifier diodes and LEDs exhibit nonlinear resistance when a nonlinear voltage is applied to their terminals. This effect becomes particularly pronounced in cases where high-power LED matrices are used for lighting applications.

The experimental setup shown in Fig. 4 allows the differential resistance r_B of the LED to be determined experimentally. This measurement reveals the possible nonlinear resistance that will be present in the LED when it is driven by a nonlinear supply signal.

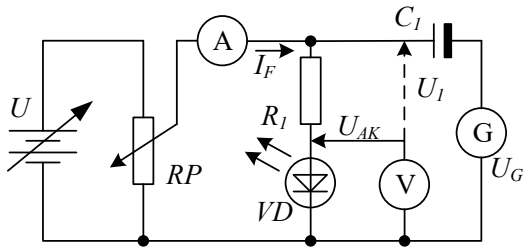


Fig. 4. *Schematic diagram of the experimental setup for determining the differential resistance*

The measurements are performed by simultaneously applying a DC forward current $I_F$through the LED and a sinusoidal signal from a low-frequency generator U_G. The current I_F is smoothly adjusted using the DC power supply U and the rheostat R_P, and is measured with an ammeter.

To determine r_B, a measuring resistor $R_1$with a known resistance is connected in the anode circuit of the LED. Using an AC voltmeter, two voltage drops are measured sequentially: across the LED U_{AK} and across the entire circuit consisting of the LED and the measuring resistor R_1, denoted as U_1 (Fig. 4).

The generator signal has an amplitude $U_G = 1$ V and a frequency $F_G = 1$ kHz. It should be noted that the measurements are carried out under the same temperature conditions as described above.

Tab. 2

T_O,°C	I_F, mA	0,5	1	1,5	2	3
17	U_1, mV	58,4	55	54	52	51,5
	U_{AK}, mV	18	12,8	10	9,3	8,4
	$r_{B,\Omega}$	98	66,7	50	47,9	42,9
50	U_1, mV	56	52,8	52	51	50,5
	U_{AK}, mV	17,9	11,3	8,95	8	6,9
	$r_{B,\Omega}$	103	60	45,7	40,9	34,8
100	U_1, mV	50	53,5	52,2	51	50
	U_{AK}, mV	17,8	11,2	8,7	7,9	6,8
	$r_{B,\Omega}$	121	58	44	40,3	34,6

Table 2 presents the actual experimental data recorded using the described methodology and experimental setup. The measurements were carried out for three values of T_0. In this case, the value of the differential resistance is obtained using the following relationship:

$$r_B = \frac{U_{AK}}{I_F} = \frac{U_{AK}.R_1}{U_1 - U_{AK}}. \qquad (6)$$

Fig. 5 shows graphs of the dependence $r_B = f(I_F)$, $T_0 =$ const. Their analysis indicates that $r_B$decreases with increasing I_F, which is expected. However, it is noteworthy that two distinct regions can be identified in the characteristics, each exhibiting a different rate of change.

The variation of r_B ($S_{r_B} = \Delta r_B / \Delta I_F$) is greater at higher temperatures (T_0) and at lower LED current values (I_F). For example, at $T_0 = 100$°Cand $I_F = 0.5$–1 mA, the value is S_{r_B}=126 Ω/mA, while at $I_F = 1$–1.5 mAit decreases to $S_{r_B} = 28$ Ω/mA.

A similar behavior is observed at lower temperatures, close to room temperature, where at $T_0 = 17$°Cand $I_F = 0.5$–1 mA, S_{r_B} = 64 Ω/mA, while at $I_F = 1$–1.5 mAit decreases to $S_{r_B} = 32$ Ω/mA.

The greatest change in differential resistance occurs at $T_0 = 100$°C, but only

within the interval $I_F = 0.5–1$ mA; beyond this range, the characteristic recorded at 17°C becomes dominant.

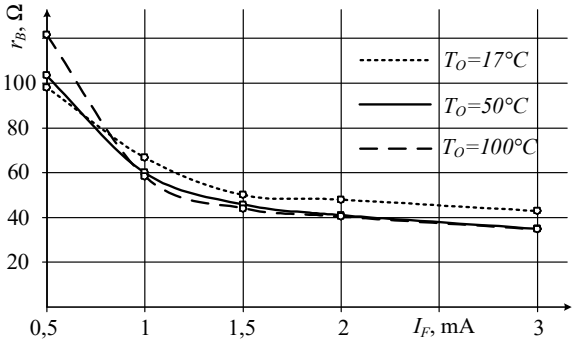


***Fig. 5**. Experimental characteristic $r_B = f(I_F)$, $T_0 = const$*

For higher currents ($I_F > 1.5$ mA), the characteristics are almost parallel, with a slope of approximately 5–6 Ω/mA.

The analysis of the obtained results and the nature of the characteristic variations confirm the presence of a heterojunction. When forward biased, the potential barrier for electrons decreases significantly, while for holes it decreases much less. Therefore, the current in such junctions is predominantly carried by electrons.

With increasing forward voltage in heterojunctions, the phenomenon of superinjection is observed, in which the concentration of injected electrons in the P-region becomes much higher. This unipolar injection is the fundamental principle underlying the operation of light-emitting diodes.

CONCLUSION

The schemes and methodologies for the experimental determination of the main static and dynamic parameters of standard discrete semiconductor light sources are presented and described.

Experimental investigations were carried out, and the current–voltage characteristic $I_F = f(U_F)$, $T_0 =$ const of a blue LED, type L-7104QBDL-D, was obtained at three ambient temperature values – 17°C, 50°C, and 100°C. From this characteristic, the static resistance r_S, the saturation current I_S, and the emission coefficient m (the so-called m-factor) were determined. The characteristic $r_S = f(I_F)$, $T_0 =$ const, describing the dependence of the static resistance of the discrete LED on the variation of forward current at room and elevated ambient temperatures, was also constructed.

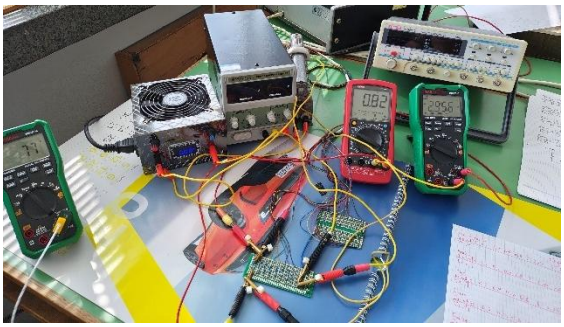


***Fig. 6.** Experimental setup*



***Fig. 7.** Mounting of the investigated LED in the thermal chamber*

The analysis of the obtained results shows that with increasing thermal potential φ_T, and correspondingly with increasing ambient temperature T_0, a decrease in the emission coefficient m is observed. This is explained by the properties of heterojunctions and their characteristic electron-dominated current behavior, which with increasing applied forward voltage leads to a growing asymmetry of the injected charge carriers in the *p*-region.

It should be noted that the nature of the variation of the differential resistance r_B is also negative, similar to that of the static

resistance r_S. However, the key difference is that the static resistance is almost independent of temperature variations T_0, whereas the dynamic resistance shows a weak dependence on temperature.

The obtained results, as well as the described and analyzed parameters and characteristics of the investigated discrete LED, contribute to expanding the database related to the study and application of standard discrete light-emitting diodes.

These data can provide the necessary information for the design of electronic circuits using LEDs and for the correct determination of their operating modes.

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REFERENCE

[1] Aleksandrov, A. Semiconductor elements and integrated circuits. Publishing house EKS-PRESS Gabrovo, 2012, ISBN: 978-954-490-317-6.

[2] Mashkov, P. Methods for LED`s thermal loading estimation. Proceeding of University of Ruse, Vol.60, Book 4.1, 2021

[3] Dziarski Kr., Ar. Hulewicz. Measurement of the junction temperature of light-emiting diodes based on the thermographic measurement of the case temperature. Pomiary Automatyka Robotyka. ISSN 1427-9126, R.29, Nr4/2025, p-p117-126, doi:14313/PAR_258/117

[4] S.Chhajed, Y.Xi, Th. Gessmann, J.-Q.Xi, J.M.Shah, J.K.Kim, E.F.Schubert. Junction temperature in light-emitting diodes assessed by different methods. Light-emitting diode: Research, Manifacturing and Applications IX, edited by Steve A. Stockman, H. Walter Yao, E. Fred Schubert, Proc of SPIE Vol.5739 (SPIE, Bellinghamm, WA, 2005).0277-786X/05/$15, doi:10.1117/12.593696

[5] Saikat Sena, Soni Kumari, Vijay Kumar, Azamal Husen. Light emitting diode (LED) lights for the improvement of plant performance and production: A comprehensive review. Current Research in Biotechnology 7(2024):100184, February 2024, DOI:10.1016/j.crbiot.2024.100184, License: CC BY-NC-ND 4.0

[6] Dziarski K, Hulewicz A, Kuwałek P, Wiczyński G., Methods of Measurement of Die Temperature of Semiconductor Elements: A Review, “Energies”, Vol. 16, No. 6, 2023,DOI: 10.3390/en16062559.

[7] Cheng H-Ch., Lin J.-Y., Chen W.-H., On the thermal characterization of an RGB LED-based white light module,“Applied Thermal Engineering”, Vol. 38, 2012, 105–116, DOI: 10.1016/j.a plthermaleng. 2012.01.014

[8] Lee D., Choi H., Jeong S., Jeon C.H., Lee D., Lim J., Byon C.,Choi J., A study on the measurement and prediction of LED junction temperature, “International Journal of Heat and Mass Transfer”, Vol. 127 (B), 2018, 1243–1252, DOI:10.1016/ j.ijheatmasstransfer. 2018.07.091.