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THEORETICAL ANALYSIS OF THERMAL CONDITIONS AND WAYS OF LED TEMPERATURE STABILIZATION

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Summary. *Thermoelectric model of a light diode was built with a spacial separation of the heat and cold source. The differential equations system was solved, which comprises the stationary equation of the heat-conductivity and the equation of Joule thermogeneration. The temperature distribution in the structural elements of LED was calculated and also the temperature of active zone overheating in dependence on the power of LED and the intensity of the heat exchange with the medium. For the numeral estimation a powerful white light diode was chosen – Gree XR7090WHT. It was found out that the light stream can be increased via current increasing, at simultaneous thermal stabilizing of its active zone.*

Key words: *LED, heterostructure, light stream, thermal mode, thermal resistance, thermalstabilization, radiator.*

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Problem setting. Only the usage of light-emitting diodes sources of light can solve the energy saving problem drastically. Powerful light-emitting diodes (LED) of equal value of light current consume power ten times as less than heating lamps and two times as less than luminescent lamps.

The technical term of heating lamps operation is 1000 hours, luminescent lamps is 5000 hours, light-emitting diodes is from 50 to 100 thousands of hours.

The effectiveness of electric energy conversion into light energy is determined by outer quantum effectiveness. It shows what part of electrical application power is converted into light power. At this day outer quantum effectiveness of the best world models on the basis of gallium nitride in the zone of room temperatures is 15 – 35% [1].

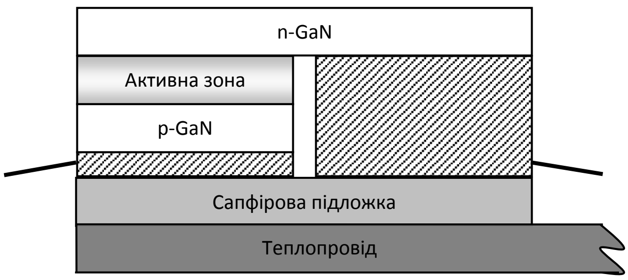

Figure 1. Schematic structure of the LED

However, for practice it is important not only quantum effectiveness but also the emitting value of light current and the colour transmitting quality. For the light current increasing it is necessary to enlarge the quantity of electron hole pairs, which recombinate into time unit in the active zone. It is simple to do while rising the value of working stream via heterojunction. Nevertheless, the current increasing causes the magnification of light-emitting diode heat power. The process of heat emission for light-emitting diodes into medium is complicated enough. In contrast to traditional light sources LED doesn't emit the energy, but conducts it in the direction from active zone towards cathode, which is in thermal contact with the heat conductor situated on the frame. Power supply discontinuity (usually it is the heterojunction work at temperature more than 125…145°*C*) can lead to the reduction of the exploitation term of LED a number of times.

Apart from it the active zone temperature rising leads to light luminance decreasing, to diminution of light-emitting diode quantum effectiveness and the current offset of working

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wave length into spectrum ‘‘blue’’ zone, it influences negatively on the quality of colour transmission.

Under given conditions the supplying of light-emitting diode adequate thermical regime acquires significant actuality. For drastic problem solution it is necessary to improve the quality of material of light-emitting diode heterostructure. At the same time successfully constructed heat conductor at the modern stage of semiconductor technologies development without delay will allow to rise light current of existing LED by the working current extention [2].

The actual investigations and issues analysis.

Joule heat influence on the LED light technic characteristics was researched in many theoretical and experimental works [3-8]. In particular in [3] theoretically was explored the influence of current value on LED heat regime. The overheating temperature dependences of LED active zone on the value of working current and the medium temperature were found. Providing that on the sidelong edges of the heterostructure adiabatic conditions of the second type were given, that considerably simplified LED heat model and led to miscalculations in the evaluation of active zone temperature overheating. In [4-7] experimentally the influence of temperature on light-emitting diode current for different radiator types was investigated. Suggested recommendations concerning thermostabilization of the light-emitting diode working regime. In spite of all this for the active zone temperature estimation the elementary heatelectric model was used.

However, in the mentioned works the opportunity of light-emitting diode arrangement immediately on radiator is considered. At the same time when using light-emitting diodes matrix with tight packaging of powerful elements it is necessary to foresee the space division of the hot source and the cold source. Nevertheless the counting of LED hot regime under this point of view wasn’t realized. That’s why the given work is directed at the solving of this task.

The issue aim is the creation of the LED heatelectric model and the temperature over heating counting of LED active zone on its base with space divided hot source and cold source under different radiator models.

Task stating. By the theoretical analysis to determine analytical connections between LED power, heat conductor and radiator parameters, medium temperature, and the temperature of LED active zone, that gives the ability of reasonable choice of LED cold scheme with the aim to supply necessary light current and the exploitation term.

Main materil exposition. Under exploitation of powerful light-emitting diodes often occurs necessity to separate in space the hot source and the the cold one. Such situation arises, for example, when the LED is the constituent part of LED matrix with tight package of powerful elements (figure 2). In this case it is necessary to foresee the possibility of LED arrengement on the specific thermal conductor which could bear the warm energy from the zone of warm and light generation into cold zone.

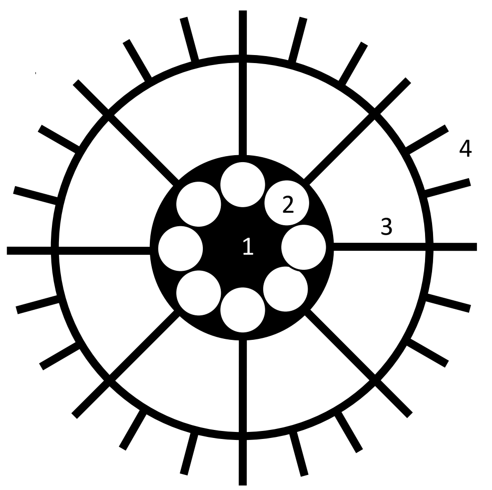

Figure 2. Chart of light-emitting-diode lamp. 1 – light-emitting-diode matrix with LED – 2, 3 are the hot-explorer, 4 – radiator

For the calculation of LED heat regime as basic we’ll analyse heatelectric model of semiconductor structure GaN on the sapphire substratum arranged on metal heat conductor. Structure geometric sizes are taken on figure 3. LED on the GaN base is chosen as basic model, as long as, such structures for the modern light technics are long-term [2].

Let heat conductor transversal section has rod side-view of arbitrary geometric configuration. Let's consider the warm distribution in the heat explorer with constant transversal section on length. It is supposed that heat conductor is connected with radiator and is in the medium with constant temperature T_0. Also we consider that

$$\kappa_1 << \kappa_2,\ p_1 l_1 << S_1,\ S_2 << p_2 l_2,\ l_1 << l_2 \tag{1}$$

where κ_1 – the coefficient of heat conductivity of heterostructure, κ_2 – the heat conductivity coefficient of heat conducter , S_1 i S_2 and $p_1 l_1$ i $p_2 l_2$ the area of diametrical crosscut and the area of lateral surface of heterostructure and heat explorer orrespondingly. Indicated inequalities allow to neglect the temperature changing in the diametrical crosscut and consider that it changes only lengthwise of heat conductor axis.

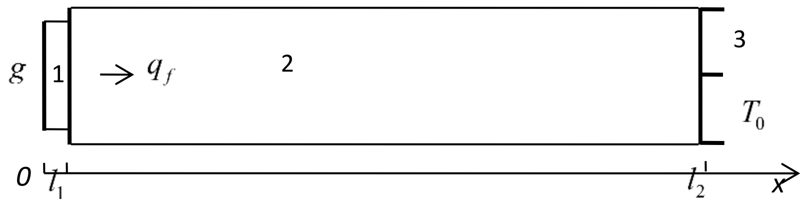

Figure 3. Heatelectric model LED: g – *GaN* heterostructure *GaN* with active zone, 1 – sapphire substrate with a metal base, 2 – heat removal, 3 – radiator

Heat distribution is described by stationary equation of heat conductivity [9]

$$\nabla^2 \Theta_i - \gamma_i^2 \Theta_i = 0, \tag{2}$$

And by the equation of thermogeneration

$$q_g = (1 - \eta_e) j_g U_g, \tag{3}$$

where

$$\gamma_i = \sqrt{\frac{\alpha_{pi} p_i}{\kappa_i S_i}}, \tag{4}$$

$i = 1,\ 2$ the number of diode structure T_i – the temperature of i-тої diode structure, $\Theta_i = (T_i - T_0)$ – the overheating temperature, T_0 – the medium temperature, α_{pi} – the coefficient of heat exchanging between lateral surface of i-тої diode structure and the medium, q_g – the heat current density, η_e – outer quantum effectiveness, U_g – direct tension on LED, j_g – current density.

It is considered that current is uniformly distributed in the plane of heterojunction. After that for current density we'll gain

$$j_g = \frac{I_g}{S_g}, \tag{5}$$

where I_g – working LED current, $S_g = S_1$ heterostructure diametrical crosscut.

Written equations should be supplemented with limiting conditions. On the limits of structure division we'll set conventional conditions of adjoint (temperature and heating currents equality)

$$
\begin{aligned}
&-\kappa_1 \frac{d\Theta_1}{dx}\big|_{x=0} = q_g, \ -\kappa_1 \frac{d\Theta_1}{dx}\big|_{x=l_1} = -\kappa_2 \frac{d\Theta_2}{dx}\big|_{x=l_1} \\
&\Theta_1\big|_{x=l_1} = \Theta_2\big|_{x=l_1}, \ -\kappa_2 \frac{d\Theta_2}{dx}\big|_{x=l_2} = \alpha_l \Theta_2\big|_{x=l_2}
\end{aligned}, \tag{6}
$$

where α_l – the coefficient of heat exchanging between radiator and medium.

Misprising of heat loss via lateral surface of the LED first structure in comparison with the heat current through transversal section in one-dimensional geometry the solution of equation system (2-6) we'll have like:

$$\Theta_1(x) = C_{11}x + C_{12}, \quad \text{when} \quad 0 \le x \le l_1 \tag{7}$$

$$\Theta_2(x) = C_{21}e^{\gamma_2 x} + C_{22}e^{-\gamma_2 x}, \text{ when} \quad l_1 \le x \le l_2 \tag{8}$$

where C_{11}, C_{12}, C_{21}, C_{22} constant integrations, which are determined by limiting conditions.

As the result of the solution of the equation system the following temperature distribution was gained:

$$\Theta_1(x) = P_g R_1^t \left(\frac{R_2^t}{R_1^t} \frac{\delta\, th\,(\sigma) + \sigma}{\sigma[\sigma\, th\,(\sigma) + \delta]} - \frac{x}{l_1} + 1 \right), \qquad \text{when } 0 \le x \le l_1 \tag{9}$$

$$\Theta_2(x) = P_g R_1^t \left(\frac{R_2^t}{R_1^t} \frac{\delta\, sh\,[\sigma(1 - x/l_2)] + \sigma\, ch\,[\sigma(1 - x/l_2)]}{\sigma\,[sh\,(\sigma) + \delta\, ch\,(\sigma)]} \right), \quad \text{when } l_1 \le x \le l_2 \tag{10}$$

where $R_1^t = l_1/\kappa_1 S_1$ – heat resistance between active zone and LED metal base, $R_2^t = l_2/\kappa_2 S_2$ – heat resistance of heat conductor, $P_g = (1-\eta_e)\, U_g I_g$ – LED heat power, $\sigma = \gamma_2 l_2$ – given heat conductor length, $\delta = \alpha_l l_2/\kappa_2$ unlimited parameter, which value is determined by the intensity of radiator heat exchange with medium.

Let's find the overheating temperature of the hottest active zone area. When $x = 0$ with (9) we'll have

$$\Theta(0) = \Theta_1(0) = P_g R_1^t \left(\frac{R_2^t}{R_1^t} \frac{\delta\, th\,(\sigma) + \sigma}{\sigma\,[\sigma\, th\,(\sigma) + \delta]} + 1 \right). \tag{11}$$

As we see after received relation, the overheating temperature depends on radiator nonlinearly, that's why it isn't correctly to use the linear theory of heat conductivity [10].

In the case of traditional cooling standart scheme, when light-emitting diode is attached immediately on radiator, and heat conductor isn't available (11) is turned into known relation [10]

$$\Theta(0) = P_g\left(R_1^t + R_2^t + R_3^t\right), \tag{12}$$

where $R_3^t = 1/\alpha_l S_2$ – heat resistance between radiator and medium.

For numerical realization we'll choose powerful white light-emitting diode Gree XR7090WHT which parameters are presented in the table 1 [1]. When its quantum effectiveness is $\eta_e = 0.25$, direct tension $U_g = 3.43\,V$, nominal current $I_g = 350\,mA$, heat resistance $R_1^t = 8.0\ K/W$.

Table № 1

Manufacturer	Line	Nominal current I_g (mA)	Light efficiency (lm/W)	Heat resistance R_1^t (K/W)	Active zone the highest temperature (C°)
Luxeon	LXHL-BW02	350	30	15	125
Luxeon	LXHL-PW09	700	25	13	125
Nichia Corp.	NCCW023S-P12	350	32	17	100
Nichia Corp.	NCCW023S-P13	350	37	17	100
Gree	XL7090WHT	350	60	17	125
Gree	XL7090WHT	350	110	17	125
Gree	XR7090WHT	350	60	8	145
Gree	XR7090WHT	350	110	8	145

We'll apply cupric heat conductor with the coefficient of thermal conductivity $\kappa_2 = 3.9\ W\,cm^{-1}K^{-1}$. length $l_2 = 10\ cm$ and diametral crosscut $S_2 = 0.62\ cm^2$. Its heat resistance is $R_2^t = 5.1\ K/W$. After relation analysis (11) it follows that active zone overheating temperature decreasing forward heat conductors with low heat resistance R_2^t. For this short heat conductors of huge diametral crosscut made of high heat conductivity material should be chosen.

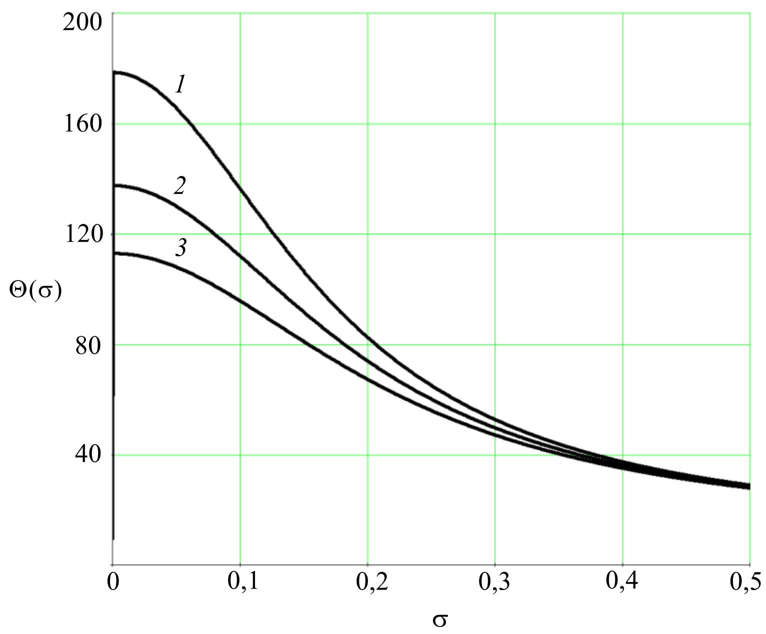

Figure 4. Dependence of overheating temperature on the length of heat removal for LED power $P = 1.2\ W$ in different models of heat removal. Solid line – $\delta = 3\ 10^{-2}$, dashed – at $\delta = 4\ 10^{-2}$, bar-dotted – $\delta = 5\ 10^{-2}$

On figure 4 is shown temperature dependence of overheating of given heat conductor length when different parameters values δ. It is shown on the figure that the overheating temperature is decreasing with the increasing of heat conductor given length, and when $\sigma \to \infty$ the overheating temperature is approximating asymptotically to *0*. It is obviously that the value σ is augmenting under product extending $l_2\sqrt{\alpha_{p2} p_2}$, which is responsible for heat distribution via lateral heat conductor surface.

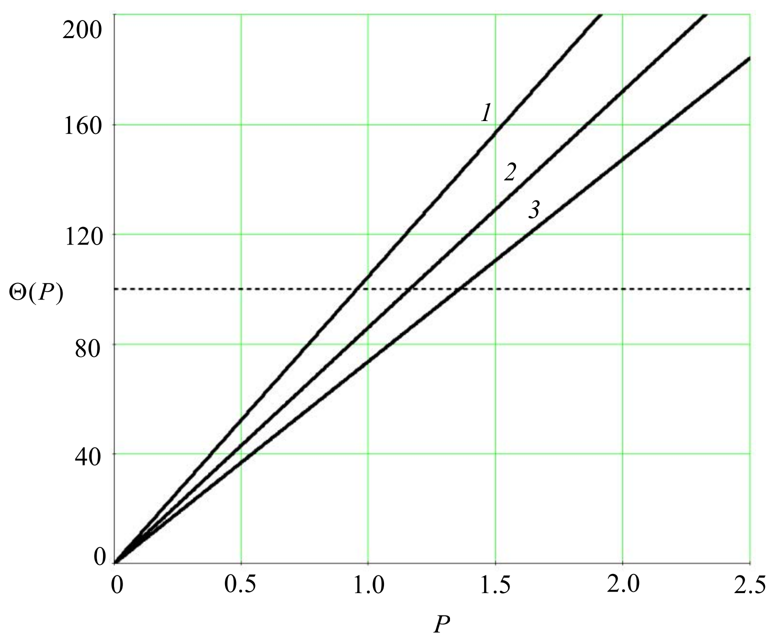

Figure 5. Dependence of temperature overheating of active zone LED on the power at different models of heat conducter, η_e = *0.2,* and *σ=01.* Line 1– δ = 0.01, line – δ = 0.02, line 3– δ = 0.03

When $\alpha_{p2}/\kappa_2 = const$ effective heat conducter from active zone long heat conductors with large-scale relation $l_2^2 p_2/S_2$ further. Attached to fixed heat conducter length the increasing of coefficient α_l forwards decreasing of active zone temperature the coefficient range depends on the heat exchange intensity between radiator and medium. The easiest way of heat exchange intensification is the air ventilator application. Such version is the cheapest one, nevertheless owing to supplementary sound generation has limitted usage. Given problem can be solved by means of application of air- cooling stream technology by turbulent air current [11], or when using thermoelectric cooling [12].

On figure 5 the dependency of overheating temperature on LED power is shown at different heat conducter models. When $\delta = 0.01$ and LED heat power P_g *=0.9W* the active zone overheating temperature is $\Theta = 100\ K$ and when $\delta = 0.03$ without overheating temperature changing the LED heat power can be increased to P_g *=1.4W.*

Conclusions

To direct the thermal energy beyond the boundaries of LED matrix, which has a dense package of powerful elements the system of metal heat conductors can be used, that are connected with the radiator radially. The usage of the offered cooling scheme will allow to increase the nominal thermal capacity on the LED (the increase of the nominal current) under the condition of the preserving of the lumen efficiency. This will lead to the reduction of the number of LEDs in the matrix and the price of the lamp without the reduction of the exploitation time.

The temperature of the overheating of the LED active zone can be defined either with its thermal power or general thermal resistance between heterojunction and radiator. The value of the active zone overheating of the LED will be decreasing with the growth of the effective length, of the cross-section area and heat conductivity of heat conductor.

High values of the thermal exchange of the heat conductor and radiator with the medium is leading to the decrease of the active zone temperature. The cooling process can be emphasized through the usage of stream technology of the blowing with turbulent air blasts or by using of thermoelectric cooling.

The value of the maximal overheating of the LED active zone can be higher than the achieved value as a result of: heating with Joule heat of the passive heterostructure areas;

dependence of the quant efficiency of the LED on the current, temperature, sizes and material of the heat-conductor; thermal dependence on the heat conductivity coefficients of the heterostructure materials and the construction of the LED.

Taking into consideration described facts are separate tasks, which can be solved with the help of the offered heat-electric model.

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ТЕОРЕТИЧНИЙ АНАЛІЗ ТЕПЛОВОГО РЕЖИМУ СВІТЛОДІОДА З ПРОСТОРОВО РОЗДІЛЕНИМИ ДЖЕРЕЛОМ ТЕПЛА ТА ДЖЕРЕЛОМ ХОЛОДУ

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Резюме. *Побудовано теплоелектричну модель світлодіода (СД) з просторово розділеними джерелом тепла та джерелом холоду. Розв'язано систему диференціальних рівнянь, яка включає стаціонарне рівняння теплопровідності та термогенерації Джоуля доповнених тепловими граничними умови третього роду. Розраховано розподіл температури в структурних елементах СД та температура перегріву активної зони залежно від його потужності та параметрів теплопроводу і радіатора. Проведено числовий розрахунок температури активної зони потужного білого світлодіода Gree XR7090WHT.*

Ключові слова: *світлодіод, гетероструктура, світловий потік, тепловий режим, тепловий опір, термостабілізація, радіатор.*

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