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The Aspects Of Increase Of Luminous Efficacy Of The Low Voltage Sodium Vapor Lamp Dnao-85

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Abstract- Prospective area in modern energetics is further development of low voltage sodium-vapor lamps (LPSL).Theoretical limit of luminous efficacy of LVSLmakes 478 lm/W,that is, 80 % of approached electric energy discharge to plasma columncan be converted to visible radiation.Radiation of LVSLwith wavelengthof 589,0–589,6 nm is close to maximumsensitivity of the eye. Monochromatic orange light is conductive to high visibility of objects. It penetrates through dust, fogandprocesses small dazzle.
Currently, LVSLwith U – shapeddischarge tube (DT) is produced by the companies«Osram», «Philips», «Thorn», «Toshiba» and «Sylvania». Luminous efficacy of LVSL being serially turned out abroadmakes 160–200 lm/W, which 1,6times higher than luminous efficacy of high voltage sodium-vapor lamps (HVSL) and 1,5–2 times higher than sodium-vapor lamps. Life ofLVSLaccounts for 18000 hours.
Direct sodium-vapor lamps in comparison with U – shaped lampsare simpler in construction and more practically feasible in fabrication. They may have fitting dimensions identical with those of luminescent lamps.
It is shown that increase of luminous efficacy of the lamp DNaO-85 may be achieved by reduction of temperature emission of discharge tube in ambient space anddecrease anode-cathodicvoltage drop.
It is noted thatlamp luminous efficacyincreases with decreased coefficient of transmission of sodium line by glass shell of discharge tube in infrared region. Reduction of DT infrared radiation share can be realized with deposition of thin filters onto DT surface.In the capacity of filter it is reasonable to use indium-tin oxide film. Such filters reflect more than 90 % of infrared radiation and take up only 3 % of yellow spectral region, which enables to raiseluminous efficacy of the lamp 1,6 times.
Further increase of luminous efficacy of the lamp can be reached by means ofdecrease anode-cathodic voltage drop (U_{AK}). It is determined thatminimal value of oxide cathode work function and U_{AK}can be reached at the temperature of cathode, less than 800 K. In this case decrease of work function is conditioned by sodium dipole formation on cathode. Minimal magnitude of anode-cathodic voltage drop may account for from 7 to 9 V. it is shown that in decrease $U_{AK}$from 18 to 8 V, lamp luminous efficacy increase by 25 %.
Optimal working temperature of cathode 600–700 Kmay be reached by using hollow oxide cathode of cylindrical shape.
With the help of computer simulation we have calculated the parameters of oxide cathode.It has been determined via calculation that the work function of hollow cylindrical cathode of the lamp DNaO-85 is 1,33 eVat the working temperature 650 K, whichis lower by 22 %, than in trispiral cathode of the lampDNaO-85 atT = 1100 K. It leads to reduction of anode-cathodic voltage drop from16 to 8 V.
Thus, modernization of the lampDNaO-85M, connected the use of hollow cylindrical cathode in it and deposition of heat-reflective coating based on indium oxide onto DT, will enable to increase luminous efficacy of the lamp by 2 times. Its value of 160–165 lm/W will correspond to the level of luminous efficacy of serially produced foreign lamps, in particular, of the type SOX-E of Philips, close by power.

Keywords: radiation, sodium-vapor lamp, luminous efficacy, potential gradient, plasma column, emissiveactivity of cathode.

Introduction

Prospective area in modern energetics is further development of low voltage sodium-vapor lamps. Low voltage sodium-vapor lamps (LPSL) are the most efficient gas-discharge light source among the known.

Theoretical limit of luminous efficacy ofLVSL makes 478 lm/W, that is, 80 % of approached electric energy discharge to plasma columncan be converted to visible radiation. Radiation of LVSL with wavelength of 589,0–589,6 nm is close to maximum sensitivity of the eye. Monochromatic orange light is conductive to high visibility of objects. It penetrates through dust, fog and processes small dazzle. Therefore, LVSL are widely used abroad for lightingof superhighways, airports, shipyards, tunnels, undercrossings, building sites.

Currently,LVSLwith U – shapeddischargetube(DT) are produced by such companiesas «Osram» (Germany), «Philips» (the Netherlands), «Thorn» (Great Britain), «Toshiba» (Japan) and «Sylvania» (the USA). Luminous efficacy of LVSL being serially produced abroad makes 160–200 lm/W, which 1,6 times higher than luminous efficacy of high voltage sodium-vapor lamps (HVSL) and 1,5–2 times higher than sodium-vapor lamps [1]. Life of LVSL accounts for 18000 hours. Such lamps meet European nature conservation standards WEEE on utilization.

Further development of LVSL is reasonably to carry out on the basis of priordirectlampDNaO-85 [2] (Fig. 1). The lamps with U – shapeddischarge tube are the optimal variant of packaging, at which it is achieved maximal luminous efficacy.

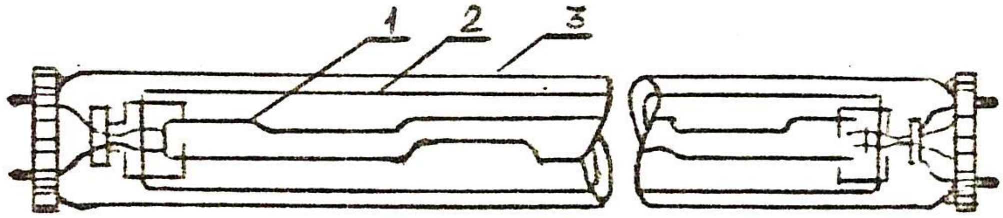


Figure 1.Construct of the lamp DNaO-85: 1 – discharge tube, 2 – thermal shield, 3 – vacuum jacket

Direct sodium-vapor lamps in comparison with U – shaped ones are of simpler construction and easier produced. They can have fitting dimensions being identical with those of luminescent lamps, which opens up opportunity to use fittings, produced for installations with luminescent lamps, in LVSL lighting units.

Lighting units can be meant for joint use of LVSL and luminescent lamps in them.

Methods of increasing luminous efficacy of LVSL DNaO-85 are considered below. Luminous efficacy increase reserve is deposition of heat-reflective film onto discharge tube. It has been shown that the use of hollow cylindrical cathode with internal oxide coating in the lamp will allow to increase its luminous efficacyby 25 % and increase light flow stability in the process of lamp usage.

Reserves of increase ofluminous efficacy of sodium-vapor lamp DNaO-85

Increase of luminous efficacy ofthe lamp DNaO-85 can be reached with reduction of heat emission of discharge tube (DT) in ambient space and decrease of anode –cathode voltage drop.

Consider the influence of each of the mentioned factors on light efficacy of the lamp DNaO-85. Using the ratio for$W_p$for specific electric power of discharge [3],fraction of electric power $a_W$converted to heat [4], and also taking into account thatpower$W_p$consumed by the lamp equals:

$$W_Л = I_p K_Л (E_c h_{ст} + U_{АК}), \quad (1)$$

where$W_Л$ – lamp power, I_p – discharge current of the lamp, $K_Л$ – power factor, E_c – plasma potential gradient, $h_{ст}$ – the length of plasma column of discharge, $U_{АК}$ – anode –cathode voltage drop.

The derived expression for determination of luminous efficacy H:

$$H = \frac{475}{\tau_1}\left(1 - \frac{1{,}7\pi\delta_B h_{kk}\left(T_T^4 - T_p^4\right)}{K_Л(W_Л - U_{АК} I_p)\left(1/R_T + 1/R_э + 1/R_p\right)} - \tau_2 F_t\right). \quad (2)$$

Hereδ_B – Stefan-Boltzmann constant,h_{kk} – distance between cathodes,T_T,T_p –temperatures of vacuum jacket anddischargetube, respectively,$U_Л$– tube voltage, τ_1= 0,95 andτ_2 = 0,90 – coefficient of transmission of sodium line by glass shell of discharge tube in infrared region, respectively, F_t = 0,12 – power fraction, radiated with sodium vapors in infrared region, $R_T, R_э, R_p$ –radius of discharge tube, heat shield and vacuum jacket, respectively.

It follows from (2) thatlamp luminous efficacy increases with decrease of $\tau_2$coefficient of transmission of sodium lines by glass shell of discharge tube in infrared region.

Figure 2 demonstrates the calculated dependence of luminous efficacy of the lampDNaO-85 on $\tau_2$coefficient of transmission of discharge radiation by glass shell of DTin infrared region.

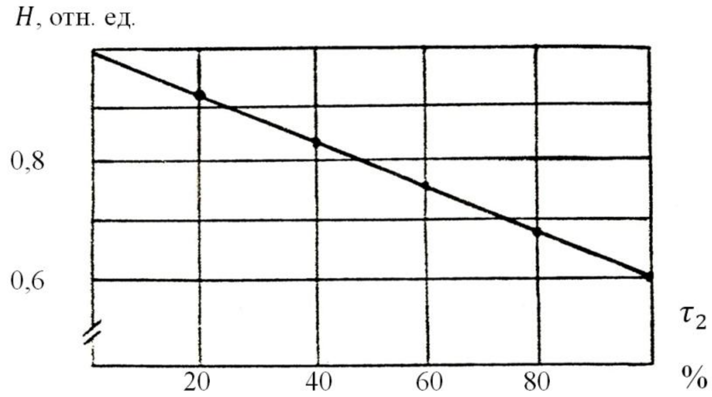


Figure 2.Dependence of luminous efficacy of the lamp DNaO-85 on of transmission of sodium lines by glass in infrared region

It follows from figure 2 thatluminous efficacy of the lamp can be increased more than by 1,6times.

Further increase of luminous efficacy can be reached by means of decrease of anode-cathode voltage drop$U_{АК}$. Its rate depends on the construction and emissive cathode properties.

Table 1 presents the dependence of the calculated luminous efficacy of the lamp DNaO-85 on magnitude of anode-cathode voltage drop by formula (2).

Table 1.Dependence of luminous efficacy of the lamp on magnitude of anode-cathode voltage drop

$U_{АК}$, B	6	8	10	12	14	16	18
H, rel. unit	1	0,95	0,90	0,85	0,8	0,75	0,7

It follows from table 1 that by decrease$U_{АК}$from18 Bto 8 Bluminous efficacyincreases by 25%.

Thus, increase of luminous efficacy of the lamp DNaO-85can be reached by means of modernization of discharge of tube of the lamp connected with the decease of heat emission into ambient space and increase of emissive activity of cathode.

Modernization of Discharge Tube Construction

Discharge tube is a basic element of the sodium-vapor lamp(Fig. 3).

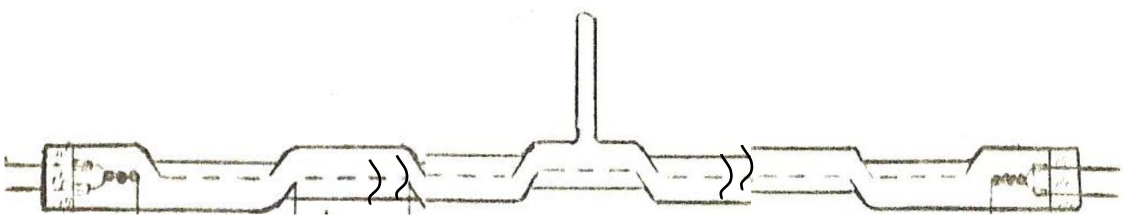
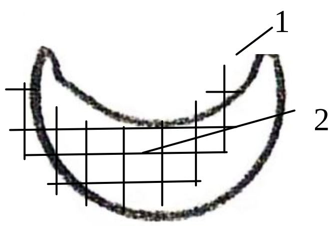


Figure 3.Construction of discharge tube of the sodium-vapor lamp DNaO-85
1 – bifilar shaped trispiral cathode, 2 – chute, 3 – exhaust tube

The results of the work [2] allow to conclude that the most appropriate is chute CTwithcrescent shape of cross section. With such shape of cross section, sodium is concentrated in relatively cool capillary hollows (Fig. 4).



Figue 4.Crescent shape of cross section of discharge tube:
1 – sodium, 2 – plasma of sodium discharge

Cathodes represent bifilar-shaped trispiral and, when produced, are coated by triple barium, strontium and calcium carbonates. The cover of CT is produced from sodium-resistant glass. CTis filled with the mix of 99 % neon + 1 % argonat pressure 8-14 mmof mercury column and redundant quantity of sodium with the indicated fill with neon-argon mix, it is provided the optimal temperature of CT, where the optimal pressure of saturated sodium vapors accounts for $(4 – 5) \cdot 10^{-3}$mm of mercury.

Decrease of CT infrared radiation fraction for the purpose of luminous efficacy of the lamp is realized by means of deposition of thin filters onto external surface of CT. In [5, 6] it has been performed the studies on application of fluorine-down tin oxide films, or indium oxide with tin additive agent as selective filters; such filters reflect more than 90 % of infrared radiation and absorb only 3 % of yellow, which allows to raise luminous efficacy of the lamp by1,6 times.

Further increase of luminous efficacy can be achieved by means of decrease of anode-cathode voltage drop. In the lamp DNaO-85 with bifilar-shaped trispiral cathodes,the anode-cathode voltage drop makes 16-18 V [2].

We have determined that minimal value of work function of oxide cathode andU_{AK}can be obtained at the temperature of cathode less than 800 K [7]. In this case the decrease of work function will be conditioned by formation of stratum of sodium dipole on cathode.Providing that in cathode region of sodium discharge only sodium $U_{AK}$is ionized, close to sodium ionization potential, and amounts to 5,14 V. Anode voltage drop in sodium discharge will change from 1 to 3 V, sominimal magnitude of anode-cathode voltage drop can be from 7 to 9 V.

Optimal working temperature of the cathode 600-700 K [8] may be reached by using hollow cylindrical oxide cathode (Fig. 5)

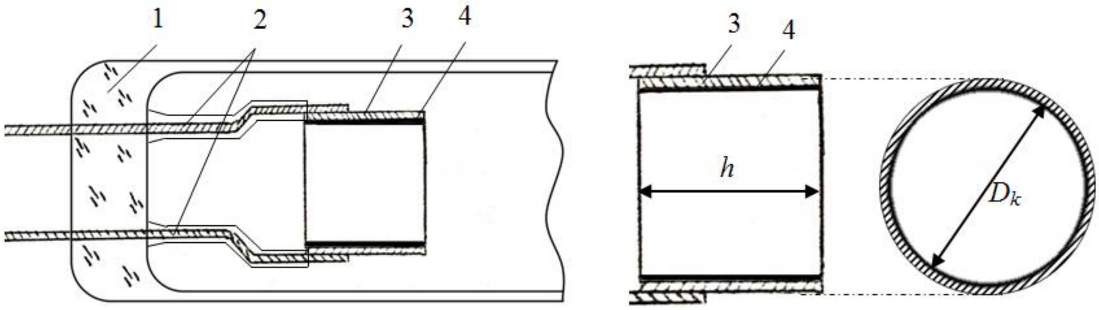


Figure 5.Hollow cathode of sodium-vapor lamp:
а) cathode assembly: 1 – discharge tube cover, 2 – leads-in,
3 – cathode base, 4 – oxide coating, б) cathode magnitude

The base of cylindrical cathode can be produced from molybdenum foil. As emissive coating of cathode, it is used triple carbonate: 60 % $BaCO_3$, 20 % $CaCO_3$, 20 % $SrCO_3$ [2].

Parameters of oxide cathode for the sodium-vapor lamphave been calculated via computer simulation, [8] and summarized in table 2.

Table 2.Parameters of oxide cathode for the sodium-vapor lamp DNaO-85

I, A	T, K	Work function, eV	Electroconductivity, $o^{-1}m^{-1}$	h, m	D_k, m	S_k, m^2
0,75	650	1,33	$1{,}7\cdot10^{-3}$	$5{,}15\cdot10^{-3}$	$5{,}15\cdot10^{-3}$	$8{,}36\cdot10^{-5}$

It follows from table 2 that the work function of hollow cylindrical oxide cathode of the lamp DNaO-85 consists 1,33 eVat the working temperature 650 K, which by 22 % lower, than in trispiral cathode atT = 1100 K. It leads to decrease of anode-cathode voltage drop from 16 to 8 V, so to increase of luminous efficacy of the lamp.

Table 3 compares characteristics of the lampDNaO-85 with trispiral cathodeto be produced beforeandcalculated characteristics of the updated lampwith hollow cylindrical cathode.

Table 3 – Comparison characteristics of the lampDNaO-85 with calculated characteristics of the updated lamp DNaO-85M.

Characteristics	Lamp type	
	DNaO-85	DNaO-85M (updated)
Power, W	85	85

Luminousflux, lm	6800-7225	12800-14025
Luminousefficacy , lm/W	80-85	160-165
Discharge current, A	0,74-0,75	0,74-0,75
Lamp voltage, B	115	111
Firing voltage, B	500	340

It follows fro table 6 thatmodernization of the lamp DNaO-85M, connected with the use of hollow cylindrical cathodein it and deposition of indium oxide-based heat reflecting coating onto CT, will allow to increase luminous efficacy of the lamp by 2 times. Its value of160–165 lm/W will correspond to the level of luminous efficacy of serially produced foreign lamps, for example SOX-E of Philips, identical in power [1].

Summary

1. LVSL are the most efficient sources of light among the known. Characteristic monochromaticradiation of sodium-vapor lamps in yellow spectral region is close to maximal sensitivity of the eye and can be widely used in economics.
2. Increase of luminous efficacy of the lamp УвеличениесветовойDNaO-85 can be reached by deposition of heat reflecting film onto discharge tube and use of hollow cylindrical cathode in the lamp instead of trispiral cathode.
3. Application of hollow cylindrical cathode in the lamp DNaO-85 will make it possible to decrease work function and anode-cathode voltage drop.
4. Parameters and characteristics of the updated direct sodium-vapor lamp DNaO-85Mwill correspond to the level of the best foreign serially produced sodium-vapor lamps with low voltage and U –discharge tube.
5. The direct sodium-vapor lamp in comparison with U – shaped discharge tube is simpler constructed and easier produced. They may have fitting dimensions identical with the luminescent lamp, which makes it possible to usefittings in lighting installations with LVSL, produced for units with luminescent lamps.
6. Lighting installations are aimed at joint application of the low voltage sodium-vapor lamps and luminescent lamps in them.

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