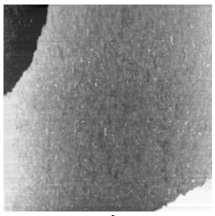
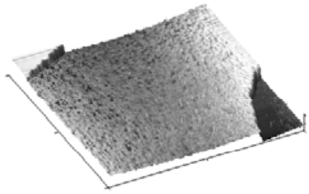


a)



b)

Fig. 7. STM images of the Ge(111) surface.
The image size is 100 nm x 100 nm, sample bias voltage U = 2.5 V, tunnelling current I = 0.5 nA. a) grey-scale representation of the surface topography: brighter areas are closer to the viewer; b) 3D reconstruction of the surface topography.

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НОВІТНЯ СИСТЕМА НАНОПОЗИЦІОНУВАННЯ ДЛЯ СКАНУЮЧОЇ ЗОНДОВОЇ МІКРОСКОПІЇ

Описано новий оригінальний пристрій нанопозиціонування для застосування у скануючій зондовій мікроскопії. Пристрій складається з чотирьох п'єзо-електричних приводів лінійного переміщення, що механічно комбінуються в переміщення зонду скануючого мікроскопу уздовж трьох ортогональних осей у просторі. Така система є надкомпактною, сумісною із надвисоковакуумним обладнанням та не містить компонентів високої вартості. Попереднє тестування проводилося в скаунючому тунельному мікроскопі на поверхнях графіту (0001), у повітряному середовищі та германію (111), у надвисоковакуумному середовищі.

Ключові слова: *скануюча зондова мікроскопія, п'єзоелектричний ефект, нано-позиціонування, надвисокий вакуум.*

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НОВАЯ СИСТЕМА НАНОПОЗИЦИОНИРОВАНИЯ ДЛЯ СКАНИРУЮЩЕЙ ЗОНДОВОЙ МИКРОСКОПИИ

Описывается новое оригинальное устройство нанопозиционирования для применения в сканирующей зондовой микроскопии. Устройство состоит из четырех пьезоэлектрических приводов линейного перемещения, которые механически комбинируются в перемещения зонда сканирующего микроскопа вдоль трех ортогональных осей в пространстве. Такая система является сверхкомпактной, совместимой со сверхвысоковакуумным оборудованием и не содержит компонентов высокой стоимости. Предварительное тестирование проводилось в сканирующем туннельном микроскопе на поверхностях графита (0001), в воздушной среде и германия (111), в условиях сверхвысокого вакуума.

Ключевые слова: *сканирующая зондовая микроскопия, пьезоэлектрический эффект, нано-позиционирование, сверхвысокий вакуум.*

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ANALYTICAL RELATIONS FOR CALCULATION THE ENERGETIC EFFICIENCY OF TRIODE GLOW DISCHARGE ELECTRON GUNS

Dependences of energetic efficiency of triode high-voltage glow discharge electron guns from acceleration voltage, operation pressure and from voltage on additional electrode have been obtained and presented in the article. Obtained mathematical model is formed by analytical solving of algebraic equations, which is a result of consideration of equations of ions balance in anode plasma and equation of discharge self-consistency. Obtained simulation results are shown, that the energetic efficiency of triode glow discharge electron guns is lead in range 80–90%, therefore such type of electron guns can be successfully used in the modern electron-beam technologies.

Keywords: *electron guns, electron-beam technologies, high voltage glow discharge, anode plasma, triode electrode system*

Introduction. Glow discharge electron guns (GDEG) are widely used in industry for providing different technological operations, such as: effective, high-rate and high-quality welding in the soft vacuum; refusing of refractory materials; deposition of high-quality ceramics films and coatings in the soft vacuum; high-rate annealing of items in the soft vacuum [1, 2, 5, 6, 12–15]. Great interest to development and applying in industry of high voltage glow discharge (HVGD) electron guns is caused by many important advantages, which are difference such type of guns from the traditional guns with heated cathodes. Among these advantages most important are follows.

1. GDEG operated in the medium of soft vacuum, range of 1–10 Pa, with acceleration voltage range of 5–30 kV [1, 2, 12, 13]. Therefore, low cost, simple evacuated systems are suitable for providing the operation of GDEG. Usually level of vacuum is defined by the requirement of realised technological process.

2. GDEG can successfully operate in the medium of different gases, including active and noble ones, dependence on the requirement of technological process [2, 5, 6 12].

3. Relative simplicity of guns' construction and low cost of technological equipment [2, 5, 6, 12].

4. Simplicity of realising control of discharge current, and, as a result, of beam current, by changing the pressure of operation gas in the gun's volume. This control method is simply realised by changing the gas flux in the gun's volume with its uninterrupted pumping [2, 4].

Therefore, elaboration of HVGD electron guns and its applying in industry is the very actual scientific and technical problem for future development of modern electron-beam technologies [2, 6].

Problems and its' discussion. However, well-known gas-dynamic method of gun current control is very slow, usually time constant of current regulation is range of from hundreds millisecond to few second. Such slow regulation is explained by the low speed of gas-dynamic processes [4]. Such high value of time regulation constant is not suitable for modern electron-beam technologies [2, 5, 6, 13–15]. Therefore, many years ago was considered the possibility of fast electric control of HVGD current in more complicated triode electrodes systems by applying relatively small potential to the additional electrode [3]. Provided experimental investigations show, that for electrical control of the discharge current time regulation constant is much smaller, range of tens or hundreds microsecond. Therefore, using of triode GDEG in the modern electron beam technologies is really very promising [6, 14].

However, investigation of complex physical processes in the triode HVGD electrodes systems was provided only in last years and has been considered in papers [7, 9–11]. This advance caused by development of mathematical methods in computer-aided design (CAD) software, such as MatLab and other, which are allow today solving the complex physical problems, such as simulation of discharge systems with located plasma region and with interacted fluxes of charged particles. In the published papers the ion concentration in anode plasma is estimated by solving the algebraic equations of ions balance with taking into account the equation of discharge self-consistency. Firstly was found very important analytical relation for position of plasma boundary relative to the cathode [10]. When position of plasma boundary, and, certainly, plasma volume, is known, was obtained the correspondent simple relations for ion concentration [7, 9, 11], for current of main discharge and for current of additional discharge [9, 11].

Provided theoretical investigations allows to estimate the beam current of triode GDEG and its' energetic efficiency, and, finally, possibilities of its' applying in the modern electron-beam technologies. Complex methodology of estimation of triode GDEG parameters and characteristics was described in paper [7]. The aim of this article is considering of energetic efficiency of triode HVGD electrodes systems for different values of acceleration voltages and pressure of operation gas.

Analyzed physical processes in high-voltage glow discharge. For solving the task of analyzing the anode plasma parameters and for finding the energy distribution in HVGD solving of equation system for ions' balance in the discharge gap with taking into account the condition of discharge self-consistency is necessary [8]. Therefore, writing and analyzing the equation of ion balance in the anode plasma in the first step of simulation is needed. It is well-known fact from HVGD theory, that anode plasma formed as a result of gas ionization by the several groups of electrons, including fast beam electrons and slow electrons, reflected from the anode [12]. In triode electrodes systems gas ionization in additional, non-self-maintaining discharge, also must be taking into account [10]. Among another discharge processes interaction of particles fluxes with themselves and with the electrodes surfaces are also very important and must be analysed [8, 10]. Anode plasma in the physical models of HVGD electrodes systems is usually considered as the source of ions and as transparent to electrons moving electrode with the fixed potential [1, 8, 10]. Among the fluxes interaction processes, the gas ionising by fast and slow electrons and the resonance recharging of accelerated ions' on the molecules of residual gas are very important [1, 7]. Among the processes, taking place at the electrodes surfaces, grate role play the emission of electrons from the cathode surface as a result of its' bombarding by the accelerated ions. Although emission of slow electrons from the anode surface as a results of its radiation by the flux of fast electrons must be also taking into account [1, 7–12].

Structure of investigated HVGD electrodes systems and its parameters. Therefore analyzing of necessary physical processes is very complex, for simplifying the theoretical estimations one-dimensional auxiliary triode HVGD system is considered [7, 9–12]. This is a system with plane cathode, cylindrical anode and with the ring-lake additional electrode for lighting of low-voltage, non-self-maintained discharge. As must be pointed out, that different geometry of electrodes is also possible, but in any case for lighting of additional discharge the condition of hollow-cathode geometry must be fulfilled. For example, the system with the negative cylindrical hollow additional electrode was presented in the paper [3]. Anode plasma, as have been pointed out, considered as the moving virtual electrode with the fixed potential [1, 7–12]. Basic structure scheme of simulated HVGD electrodes system is presented at Fig. 1 [7, 9–11].

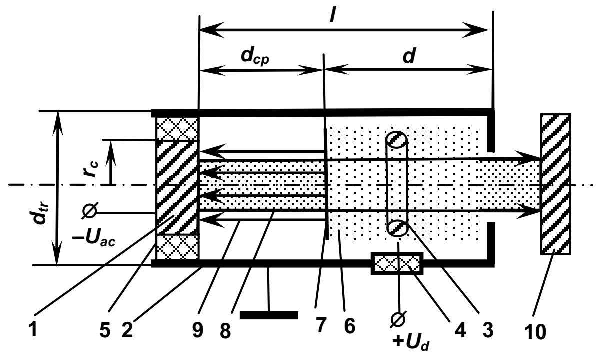

Fig. 1. Scheme of simulated HVGD triode electrodes system.
1 – cathode; 2 – HVGD anode; 3 – electrode for lighting of additional discharge; 4 – low-voltage insulator; 5 – high-voltage insulator; 6 – anode plasma; 7 – anode plasma boundary; 8 – electron beam; 9 – ion flux; 10 – treated item.

As have been pointed out, considered system contains three main electrodes: HVGD cathode 1, HVGD anode 2, which also can be considered as a cathode of additional discharge, and ring-like electrode 3 for lighting of additional discharge. Negative acceleration voltage U_{ac}, which value for real electron guns usual lead in the range from 5 kV to 40 kV, applied to the cathode. Value of positive potential on the additional electrode U_d is significantly smaller, range of from tens to few hundreds V. Main internal parameter of considered HVGD system is the residual pressure in the discharge gap p_{a0}, which, taking into account the additional gas ionization in discharge, is usually in range 0.1 – 10 Pa [7, 9–13]. The low-voltage insulator 4 and high-voltage insulator 5 are established between electrodes for providing the conditions of dielectric strength. Anode plasma 6 is appeared as a result of gas ionization, and plasma boundary 7 in mathematical models is considered as ions' source and as additional virtual electrode with the fixed potential [1, 2, 7–12]. Electron beam 8 is formed as a result of electrons' emission from the surface of cathode 1, which bombarding by the ions flux 9. Finally, beam electrons are collected on the treated item 10.

Main geometric parameters of simulated HVGD electrodes system are also pointed out in Fig. 1. There are: longitudinal length of discharge gap l, its transversal diameter d_{tr}, longitudinal length of anode plasma d_p, distance from cathode to plasma boundary d_{cp}, as well as the cathode radius r_c. All these parameters will be used later for forming complex mathematical model of triode HVGD gap.

Basic equations of mathematical model of triode high-voltage glow discharge gap. For finding the currents of main and additional discharges information about the value of ions concentration in anode plasma and about its volume is necessary. It is clear from Fig. 1, that plasma volume in considered system is defined by transversal diameter of discharge gap d_{tr} and by the longitudinal plasma length d_p.

For defining of ions concentration in anode plasma and its longitudinal length consideration of ionization and diffusion processes in plasma volume is necessary [10, 12]. Therefore, the main equations of forming mathematical model are following.

1. Equation for balance of ions in anode plasma.
2. Equation for describing the discharge self-maintaining and self-consistency.
3. Equations for describing the elementary processes of fluxes of charged particles interactions with themselves.
4. Equations for describing the elementary processes of fluxes of charged particles interaction with electrodes surfaces.

During forming this equations system the main considered physical processes are follows.

1. Gas ionization by the fast beam electrons [7, 10].
2. Gas ionization by the slow electrons, reflected from the anode surface [7, 10].
3. Gas ionization in the additional discharge [7, 9, 10].
4. Diffusion of ions from anode plasma in direction to HVGD anode [7, 9, 10].
5. Resonance recharge of ions on the molecules of the residual gas [7, 10–13].
6. Emission of electrons in the cathode surface, caused by its bombarding by accelerated ions [10, 12].

All this processes have been described complexly in the pervious section of this paper and must be included to forming mathematical model of discharge gap. It must be pointed out, that in pervious section only the main energetic and geometry parameters of formed mathematical model have been considered. Really described beyond physical processes are very complex and depended from many internal parameters of simulated system, which defined by using electrodes materials and operation gas [7, 10, 12]. All these necessary model parameters will be considered and defined below.

For presented at Fig. 1 triode HVGD electrode system the equation of ions balance in the discharge gap can be written in the following form:

$$z_f + z_s + z_{dis} = z_{dif}, \quad (1)$$

with z_f – efficiency of gas ionization by fast electrons, z_s – efficiency of gas ionization by slow electrons, z_{dis} – efficiency of gas ionization in the additional discharge, z_{dif} – efficiency of leaving the ions from anode plasma as a result of diffusion process [7, 10, 12]. Relations for efficiency of gas ionization z_f, z_s, z_{dis} and of diffusion process z_{dif} can be written in the following form [7, 10]:

$$z_f = \frac{j_{ec} d_p p_{a0} A_i U_c^{-a_i}}{e}\left(1 + \eta\left(1 - f\left(1 - d_p p_{a0} Q_{ep0}\right)\right)\eta_U^{a_i} k_e\right), \quad (2)$$

$$z_s = \frac{d_p p_{a0} n_e}{4}\sqrt{\frac{8kT_e}{\pi m_e}}\,\overline{Q_0}, \quad \overline{Q_0} = N_0 \alpha_i \left(U_i + \frac{2kT_e}{e}\right) e^{-\frac{eU_i}{kT_e}}, \quad (3)$$

$$z_{dis} = \frac{4\pi^3 e^4 n_i \mu_{i0} \gamma_a d_i U_d \ln\left(1{,}5 - \sqrt{\frac{kT_e\left(eU_d + kT_e\right)^3}{\pi p_{a0}}}\right)}{9kT_e d_p\left(eU_d + kT_e\right)}, \quad (4)$$

$$z_{dif} = \frac{\pi^2 n_i \mu_0 k T_e}{d_p p_{a0} e}. \quad (5)$$

where j_{ec} – density of electron current at the cathode surface, T_e – temperature of slow electrons in anode plasma, η_i and η_U – coefficients of electrons reflection from the anode by the current and by the voltage correspondently, f – transparent coefficient for anode plasma, Q_0 – cross-section of ions scattering at the residual gas molecules, k_e – coefficient of electrons' trajectories longitude, n_e – concentration of free electrons in anode plasma, U_i – potential of gas ionization, N_0 – Loschmidt constant, k – Boltzmann constant, A_i, a_i, q – empirical constants for defined operation gas and electrodes material, μ_0 – mobility of ions' in anode plasma, γ_a – secondary ion-electron emission coefficient from anode surface [2, 5–8]. The equation, described the self-consistent conditions of HVGD lighting, can be written in such form [7, 9, 10, 12]:

$$n_i = \frac{j_{ec}\sqrt{\frac{kT_e}{2m_e}}}{e\left(A_i U_{ac}^{-a_i} + 1\right)}, \quad (6)$$

where n_i – ions concentration in anode plasma, e and m_e – electron's charge and mass correspondently.

Equations system (1–6) is full, closed and self-maintained, and it can be solved relative to parameter d_p. With known plasma longitude size d_p ion concentration n_i also can be simply defined from equations (1–6).

Defining the size of anode plasma. With taking into account relations (2–5), equation of ions balance in anode plasma can be written in the form:

$$\frac{\pi^2 \mu_0 \left(kT_e + eU_d\right)}{\left(p_{a0} d_p\right)^2}\left(1 + \frac{\gamma d_{tr}}{\lambda_e}\right) - 3\left(kT_e + eU_d\right)\times$$

$$\times N_0 q \sqrt{\frac{e\left(kT_e+eU_d\right)}{2\pi m_e}} e^{-\frac{U_i}{\frac{kT_e}{e}+U_d}} = \qquad (7)$$

$$= A_i U_{ac}^{-a_i}\left(A_i U_{ac}^{-a_i}+1\right)\sqrt{\frac{kT_e}{2\pi m_e}}\left(1+\eta\left(1-f\left(1-d_p p_{a0} Q_{ep0}\right)\right)\eta_U^{a_i} k_e\right).$$

Equation (7) is the cubic equation relatively to parameter d_p, therefore it can be solved analytically by using famous Cordano relations. Corresponded solution is [10]:

$$R_1 = A_i U_{ac}^{-a_i}\left(A_i U_{ac}^{-a_i}+1\right)\sqrt{\frac{kT_e+eU_d}{2\pi m_e}},\ R_2 = f\eta\eta_U^{a_i} k_e,$$

$$R_3 = 3\left(kT_e+eU_d\right)N_0 q\sqrt{\frac{kT_e+eU_d}{2\pi m_e}} e^{-\frac{U_i}{\frac{kT_e}{e}+U_d}},$$

$$R_4 = \mu_0\left(kT_e+eU_d\right)\left(\frac{\pi}{p_{a0}}\right)^2\left(1+\frac{\gamma d_{tr}}{\lambda_e}\right), \qquad (8)$$

$$R_5 = R_1 R_2 p_{a0} Q_{ep0},\ C_{eq} = -\frac{R_1+R_3+R_1R_2}{R_5},\ D_{eq} = \frac{R_4}{R_5},$$

$$p = -\frac{C_{eq}^2}{3},\ q = \frac{2C_{eq}^3}{27}+D_{eq},\ D = \left(\frac{p}{3}\right)^3+\left(\frac{q}{2}\right)^2,$$

$$u = \sqrt[3]{-\frac{q}{2}+\sqrt{D}},\ v = \sqrt[3]{-\frac{q}{2}-\sqrt{D}},\quad y = u+v,$$

$$\lambda_e = \frac{2.25kT_e\left(eU_d+kT_e\right)^2}{\pi e^4 p_{a0}\ln\left(1.5-\sqrt{\frac{kT_e\left(eU_d+kT_e\right)^3}{\pi p_{a0}}}\right)},$$

$$d_p = y-\frac{C_y}{3},\qquad d_{cp} = l-d_p,$$

where λ_e – free path of electrons in anode plasma, R_1, R_2, R_3, R_4, R_5, p, q, u, v and y – additional variables, C_{eq} and D_{eq} – coefficient of solved cubic equation, obtained form (7), D_{eq} – discriminate of this equation.

Equations (8) are writing for obtaining two geometry parameters of simulated electrodes system, which are strongly interconnected, namely: longitudinal size of anode plasma d_p and distance from cathode to plasma boundary d_{cp} (see Fig. 1). Such approach in this case is very important, because volume of anode plasma and ion concentration defined by its longitudinal length, but cathode-plasma distance also used in HVGD theory for defining processes in the discharge gap and electron-optical properties of elaborated electron gun [7, 8, 10, 12].

Clear, that plasma boundary position relatively to the cathode surface d_{cp} is depended from acceleration voltage U_{ac}, voltage of additional discharge U_d and from residual pressure in the discharge gap p_{a0}. But also all coefficients of proposed model depended from using electrodes materials and operation gas, therefore defining the conditions of HVGD lighting is necessary. In this work calculation with using equation system (8) was provided for aluminium cathode and cooper anode, the nitrogen was considered as operation gas. Such conditions of HVGD lighting are often used in industrial electron guns and they are very suitable for many technological processes. In conformity with this physical conditions such values of coefficients were choose: $U_i = 18$ V; $T_e = 800$ K; $\eta = 0.7$; $a_i = 0.343$; $q = 1.452$; $\eta_U = 0.95$; $\gamma = 4.6$; $f = 0.99$; $\mu_0 = 1.27\cdot 10^{-4}\,\frac{\text{m}^2}{\text{V}\cdot s}$; $A_i = 3.8\cdot 10^{-6}$; $\overline{Q_0} = 5.3\cdot 10^{-19}\,\text{m}^{-2}$ Considered range of operation pressure was $p_{a0} = 0.1-1$ Pa, range of acceleration voltage $U_{ac} = 5-30$ kV, and range of the voltage of additional discharge is $U_d = 30-100$ V. At the same time the geometrical dimensions of simulated discharge gap was: $l = 0.07$ m, $d_{tr} = 0.035$ m and $r_c = 0.025$ m [10]. The results for another geometry sizes also have been obtained and analysed [7].

Dependences of plasma boundary position from the acceleration voltage, voltage of additional discharge and from the residual pressure in the discharge gap are presented in Fig. 2. These dependences are very important, its' allows to make necessary conclusions about the singularity of operation of GDEG.

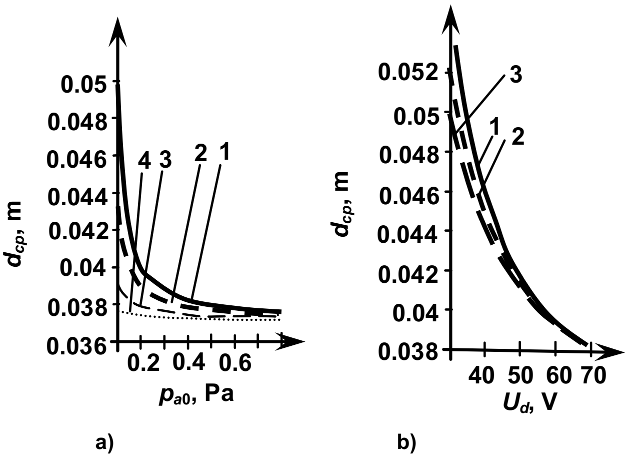

Fig. 2. Dependences of cathode-plasma distance from residual pressure in the discharge gap (a) and from the voltage on additional electrode (b):
a – U_{ac} = 10 kV; 1 – U_d = 30 V, 2 – U_d = 50 V, 3 – U_d = 80 V, 4 – U_d = 100 V; b – p_{a0} = 0.5 Pa; 1 – U_{ac} = 30 kV, 2– U_{ac} = 15 kV; 3 – U_{ac} = 5 kV

First conclusion is, that cathode-plasma distance d_{cp} is decreasing with increasing the residual pressure in discharge gap p_{a0} and with increasing the voltage of additional discharge U_d. These conditions are corresponded to increasing of plasma volume, and therefore ions' concentration in plasma and the current of main discharge are also increased. The current of additional discharge is defined by concentration of charged particles in anode plasma and by the square of surface of plasma boundary. However, the simulation results shown, that increasing of plasma volume takes place only to the defined limits, and the minimum value of cathode-plasma distance $d_{cp}^{\min}$ defined by simple relation:

$$d_{cp}^{\min} \approx d_{tr}. \qquad (9)$$

The second conclusion is, that anode plasma position relative to the cathode d_{cp} is strongly depended from the residual pressure in discharge gap p_{a0}, but the dependence of d_{cp} from the acceleration voltage U_{ac} is, in contrary, very weak. Since d_{cp} is strongly influence to the current of formed electron beam and to the self-maintained electron-ion optic in HVGD [1, 8, 12], it is clear, that in control systems, where HVGD current stabilized by changing the potential on additional electrode, the pressure in discharge gap also must be precisely stabilized.

With known size of anode plasma d_p ions concentration, as well as the currents of main and additional discharges also can be defined from equations (6, 7).

Defining the currents of main and additional discharges, as well as efficiency of electron gun. Since the longitudinal length of anode plasma d_p is known from the relations (8), ions concentration of ions in plasma can be calculated from following equation, which are obtained from the equation of discharge self-maintained (6) [7, 9, 11]:

$$C_1 = A_i U_{ac}^{-a_i}\left(1 + A_i U_{ac}^{-a_i}\right)\left(1 + \eta\eta_i^{a_i}\left(1 - f\left(1 - d_p p_{a0} Q_{ep0}\right)\right)\right),$$

$$C_4 = 3N_0\alpha_i\sqrt{\frac{e\left(kT_e + eU_d\right)}{2\pi m_e}},\quad C_2 = \frac{\pi^2\mu_0}{\left(d_p p_{a0}\right)^2}\left(1 + \frac{\gamma d_{tr}}{\lambda_e}\right) - C_4,$$

$$C_3 = C_2\left(kT_e + eU_d\right)e^{-\frac{U_i}{\frac{kT_e}{e} + U_d}},\quad n_i = \frac{C_1}{C_3}, \qquad (10)$$

where C_1, C_2, C_3 and C_4 is the additional variables.

From equations (8) and (10) can be obtained the simple relations for the currents of main and additional discharges. The current of additional discharge is defined as [11]:

$$I_d = en_i\pi r_{tr}\left(1 + \gamma\right)\left(r_{tr} + 2d_p\right)\sqrt{\frac{2eU_d}{m_i}},\qquad r_{tr} = \frac{d_{tr}}{2}, \qquad (11)$$

where m_i – mass of the ions of operation gas. And the current of HVGD is defined as [7, 9]:

$$I_e = r_c^2 n_i\left(1 + A_i U_{ac}^{-a_i}\right)\sqrt{\frac{\pi e d_p\left(kT_e + eU_d\right)}{2m_e}}. \qquad (12)$$

With known currents of the HVGD and of additional discharge from equations (11, 12) the energetic efficiency of triode GDEG can also be estimated. In the book [12] by analyze of energetic balance in the electrodes and in the diode discharge gap was shown, that energetic efficiency of diode GDEG can be defined by the following equations:

$$\eta_d = 1 - \frac{2 + k_d\left(1 + 2k_d\gamma\mu_{i0}\right)}{2k_d\left(1 + \gamma k_d\right)},\qquad k_d = lp_{a0}\overline{Q_0}. \qquad (13)$$

Provided theoretical estimations and experimental researches of energetic efficiency of diode GDEG are shown, that the energy loses in the volume of discharge gap is very small, and it is caused by the low value of the residual pressure p_{a0}. Therefore the volume loses can be neglect, and total loses at the cathode and the anode in diodes high voltage glow discharge electrodes' systems are usually nearly 10% [12]. In such conditions, with known currents of main and additional discharges, which are defined by equations (8, 10–12), and considering also equations (13), energetic efficiency of triode glow discharge electron guns can be simply defined from following relation [7]:

$$\eta = \frac{\eta_d}{1 + \frac{\eta_d U_d I_d}{U_{ac} I_e}}. \qquad (14)$$

Obtained simulation results and its discussion. Obtained theoretical dependences of triode GDEG energetic efficiency from acceleration voltage, from the voltage on the additional electrode and from the residual pressure in the discharge gap are presented at the Fig. 3.

It is clear, that GDEG energetic efficiency is increased with increasing of acceleration voltage, with increasing the voltage on the additional electrode, and with decreasing of operation pressure. In any case, the energetic efficiency of triode GDEG is very high value and lead in range 80–90%. That value is closed to corresponded parameter for the similar diode electrodes systems [8], therefore the energy loses in additional discharge really is not very high, its estimation level is few percent. It caused by the low voltage of additional discharge and by the high efficiency of gas ionization in it. Furthermore, reducing of pressure in the discharge gap in triode GDEG given the advanced possibilities of its applying in the modern electron-beam technologies, in such technological processes, where the high level of vacuum is necessary. For example, deposition of complex compositions from metals and dielectrics films in the microelectronic and nanoelectronic production is possible.

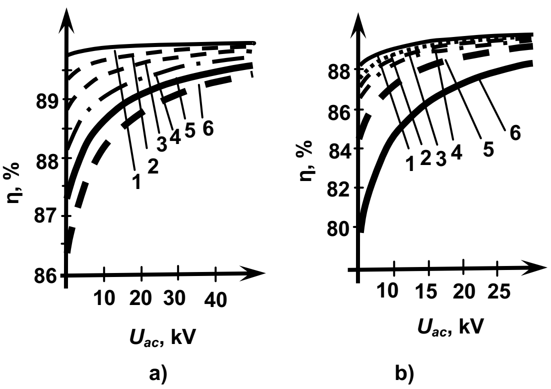

Fig. 3. Dependences of GDEG efficiency from acceleration voltage, voltage on additional electrode (a) and residual pressure (b):
a – p_{a0} = 0.5 Pa; 1 – U_d = 80 V, 2 – U_d = 70 V, 3 – U_d = 60 V, 4 – U_d = 50 V, 5 – U_d = 40 V, 6 – U_d = 30 V;
b – U_d = 50 V; 1 – p_{a0} = 0.2 Pa, 2 – p_{a0} = 0.4 Pa, 3 – p_{a0} = 0.5 Pa, 4 – p_{a0} = 0.6 Pa, 5 – p_{a0} = 0.8 Pa, 6 – p_{a0} = 1 Pa

Since the plasma size and the current of formed electron beam are strongly depended from the residual pressure in the discharge gap, with realizing of electric control and stabilization of beam power stabilization of residual pressure is also necessary. But in any case regulation time constant for HVGD systems with electric control is in range of tens' or hundreds microsecond, and this small value of time regulation constant is very suitable to thermal processes of modern electron-beam technologies [2, 5, 6, 14, 15].

Provided theoretical investigations and estimations are shown the high level of energetic efficiency of triode GDEG. Therefore these investigations confirmed that elaboration of industrial constructions of such guns and its applying in modern electron-beam technological equipment is very promising.

Conclusion. Proposed mathematical model of triode HVGD electrodes systems based on solving of analytical equations for defining plasma boundary position, its volume and the concentration of ions in it. All main physical processes are taking into account. Therefore, in spite of the simplified one-dimensional model of discharge gap, obtained results are very adequate. Experimental measurements of discharge current also have been provided, and disagreement between theoretical and experimental data was in range 15%. Therefore proposed model is very suitable to providing preliminary calculations in the first step of designing of industrial guns.

In any case, numerical simulation shown, that energetic efficiency of triode GDEG is in range 80–90% for different acceleration voltage, voltage on the additional electrode and the residual pressure in the discharge gap. Therefore, taking into account the small time constant for electrical method of beam current control, such guns are very promising to application in modern electron-beam technological equipment. Creating of novel up-to-date technologies with using high-effective and cheap triode GDEG is also possible.

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АНАЛІТИЧНІ СПІВВІДНОШЕННЯ ДЛЯ РОЗРАХУНКУ ЕНЕРГЕТИЧНОЇ ЕФЕКТИВНОСТІ ТРІОДНИХ ГАЗОРОЗРЯДНИХ ЕЛЕКТРОННИХ ГАРМАТ

Отримані та представлені у даній статті залажності енергетичної ефективності тріодних електронних гармат високовolтного тліючого розряду від прискорювальної напруги, тиску залишкового газу у разрядному проміжку, та від напруги на керувальному електроді. Запропонована математична модель зформована шляхом аналітичного розв'язування алгебраичніх рівняннь, отриманих як результат аналізу рівняння балансу іонів в анодній плазмі та рівняння самоузгодження розряду. Отримані результати показали, що енергетична ефективність тріодних газорозрядних електронних гармат лежить в діапазоні 80–90%, тому такі гармати можуть успішно використовуватися у сучасних електронно-променевих технологіях.

Ключові слова: *електронна гармата, електронно-променеві технології, високовольтній тліючий розряд, анодна плазма.*

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АНАЛИТИЧЕСКИЕ СООТНОШЕНИЯ ДЛЯ РАСЧЕТА ЭНЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ ТРИОДНЫХ ГАЗОРАЗРЯДНИХ ЭЛЕКТРОННЫХ ПУШЕК

Получены и представлены в данной статье зависимости энергетической эфффективности триодных электронных пушек высоковольтного тлеющего разряда от ускоряющего напряжения, остаточного давления в разрядном промежутке и от напряжения на управляющем электроде. Предложенная математическая модель получена путём аналитического решения алгебраических уравнений, полученных в результате анализа уравнения баланса ионов в анодной плазме и уравнения самосогласованости горения разряда. Полученные результаты показали, что энергетическая эффективность триодных газоразрядных электронных пушек лежит в диапазоне 80–90%, поэтому такие пушки могут успешно использоваться в современных электронно-лучевых технологиях.

Ключевые слова: *электронная пушка, електронно-лучевые технологии, высоковольтный тлеющий разряд, анодная плазма.*

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MAIN PROBLEMS OF ANTICANCER DRUGS' MODIFICATION

Limit capabilities and low efficiency in the treatment of locally advanced and disseminated forms of cancer shows that anticancer drugs are need to be modified. This modification needs solving some special tasks. So there was created the program of their realization. There are main tasks and results, shared at this moment, shown in this article.

Keywords: *cancer, oncodrugs, modification, radiation, bubstones.*

The experience of anticancer chemotherapy has shown limit capabilities and low efficiency in the treatment of locally advanced and disseminated forms of cancer. One of the most actual problem of modern pharmacology and oncology practice is an identification of new biologically active materials, studding of their physical-chemical and