LOW-VACUUM GAS-DISCHARGE ELECTRON GUNS ON THE BASIS OF HIGH-VOLTAGE GLOW DISCHARGE

V.A. Tutyk

National Metallurgy Academy of Ukraine, Dnepropetrovsk,
E-mail: tutykva@ua.fm

Investigation results of the proposed methods of rise of pressure in low-vacuum gas-discharge electron guns based on the high voltage glow discharge with a hollow anode are presented. The influence of design parameters, cathode material, and sort of the technological gas on working pressure is considered. The possibility of low-vacuum gas-discharge electron guns operation in the medium and low vacuum at pressure in the range of 10-1000 *Pa* is proved.

PACS: 41.75.Fr; 52.80.Tn

1. INTRODUCTION

The usage of electron beams (EB) at low gas pressure gives the opportunities to obtain coating in the medium of reactive gas (CVD and CPVD technologies), to grow crystals, to modify surfaces, to create plasma-chemical technologies, to carry out active experiments in the ionosphere etc. [1- 4]. Conventional electron guns operate at pressures up to 10 *Pa* and do not allow obtaining EB directly in low vacuum without usage of special extracting devices. In [5] there has been proved the possibility of EB from high-voltage glow discharge (HGD) in the range of pressures of 1-1000 *Pa*. However experimental testing has not been carried out.

The purpose of this presentation is the experimental investigation of methods of rise of working gas pressure in low-vacuum gas-discharge electron gun (LGEG) based on the HGD with a hollow anode for their operation at pressure in the range of 10-1000 *Pa.*

2. TECHNIQUE OF THE EXPERIMENT

Investigations were carried at the upgraded device, described in [3, 6]. The object of the investigation was gas-discharge electron gun EGG-6 of diode type (Fig.1).

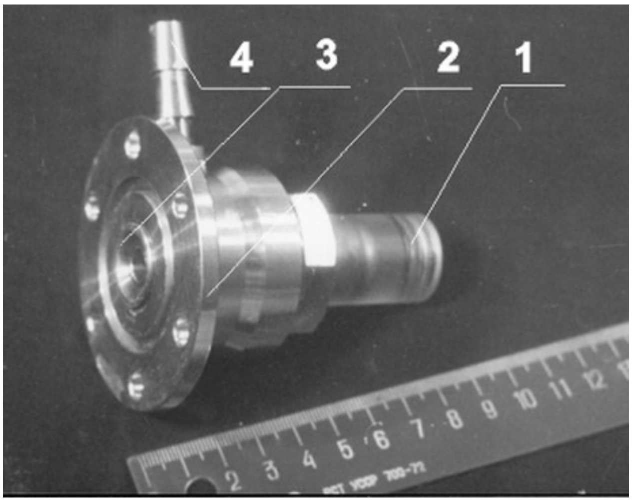

Fig.1. General view of *EGG-6:*
1-high voltage insulator with inserted cold cathode; 2–hollow anode; 3–anode insert; 4–nipple for gas puffing

In the gun construction the exchangeable cathodes of different diameters d_K, anode inserts with different diameters of anode hole d_A, and regulated cathode-anode gap L_{AK} were used. Investigations were carried out in pulsed mode. The amplitude of voltage pulse was U] $40kV$, pulse duration was $t_p = 10^{-5} s$, repetition frequency 100 *Hz.* For measuring parameters of voltage and current pulses the signals were taken from non-inductive resistances and input to the two-channel oscillograph Tektronix TDS-210 with output to the printer. The anode unit of the gun was grounded through a small inductive coaxial shunt, which is used for discharge current measuring. Behind the anode area EB reached the collector. Electron beam current was registered with the help of a shunt, which connected the collector with the ground. The intensity of EB crossover luminescence was measured with a photoelectric multiplier. Power parameters of the gun and EB were measured with the help of a calorimeter [6].

3. EXPERIMENTAL RESULTS

Investigations of LGEG allowed displaying 3 operation modes depending on design sizes of the gun, ion path length, working pressure, and plasma discharge location (see Table 1). At pressures *P*>1000 *Pa* in LGEG HGD turns into diffusion discharge [7].

Working pressure rise $P_2 > P_1$ at constant voltage *U* results in current *I* increase and steepness $S = dI/dU$ growth in volt-ampere characteristics (VAC) ($S_2 > S_1$). Therefore the problem of working pressures rise in LGEG can be solved by decreasing of instant steepness *S* of VAC at rise of *P* only at the expense of *I* decrease, as *U* (power source voltage) does not depend on *P*. Current value in LGEG is the function of many variables $I = f(U, P, \gamma, d_A, d_K, A)$, where γ is coefficient of secondary ionic-electron emission, *A* is sort of gas.

Expression for EB current can be written in the form:

$$I_a = \frac{\partial I}{\partial U} U_a + \frac{\partial I}{\partial P} P_0 + \frac{\partial I}{\partial \gamma} \gamma_0 + \frac{\partial I}{\partial d_A} d_{A0} + \frac{\partial I}{\partial L_{AK}} L_{AK} + \frac{\partial I}{\partial d_K} d_{K0} + \frac{\partial I}{\partial A} A_0, \qquad (1)$$

where $I_a, U_a, P_0, \gamma_0, d_{A0}, L_{AKO}, d_{KO}, A_O$ the instantaneous values of variables of the corresponding parameters in the working point. If in expression (1) the partial derivations in the first two terms increase with the pressure increase, then the following ones can be decreased at the appropriate choice of the corresponding parameters.

Table 1. Possible operation modes of LGEG

No.	Mechanism of electrons origination	Ion path length	Range of working pressure ,*Pa*	Plasma discharge location	Operation modes
1	ion bombardment of cathode	$\lambda_i < L_{AK}$	$10^{-2}...10$	cathode-anode space	pulsed continuous
2	ion and fast atom bombardment of cathode	$\lambda_i > L_{AK}$	$10...10^3$	behind anode space	pulsed continuous
3	photoelectron emission	$\lambda_i < L_{AK}$	$>10^3$	cathode-anode and behind anode space	pulsed ($t_p<10^{-9}$ *s*)

It gives the opportunity of working pressure rise in LGEG by decrease of values of derivatives

$$\partial I/\partial \gamma, \partial I/\partial d_A, \partial I/\partial L_{AK}, \partial I/\partial d_K, \partial I/\partial A.$$

Typical experimental VAC of LGEG EGG-6 in pulsed mode (Fig.2) measured for different pressures of helium. Depicted in a double logarithm scale curves represent inclined straight lines and are described with the expression

$$I = f(P) \cdot U^m$$

where *f (P)* is the function of pressure *P,* which shows that for given voltage *U=const* pressure rise leads to growth of current *I* (Fig.2).

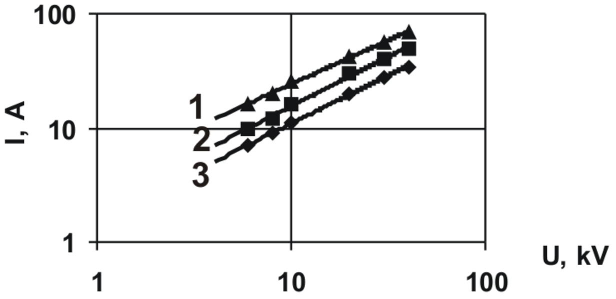

Fig.2. Pulsed VAC for the pressure of helium 1-53 Pa, 2-106 Pa, 3 -133Pa; d_K=8 mm, d_A=9 mm, L_{AK}=1 mm

Exponent *m* can be connected with secondary ion-electron emission coefficient γ . Working pressure can be risen by means of secondary ion-electron emission coefficient decrease. The value of γ depends on a lot of factors, one of which is cathode material. Really it was found that the cathode material influences the incline of corresponding VAC, i.e. through the secondary ion-electron emission coefficient γ determines exponent *m* (see Table 2).

Table 2. Size of exponent m

Cathode material	Aluminium	Low carbon steel	Graphite
m	1,4	0,93	O,43

Small value of exponent m for graphite indicates the appropriateness of graphite usage in LGEG. However the ability to be sprayed under ion bombing should be taken into consideration at the final choice of cathode material.

Carried out experimental researches on the study of influence of L_{AK}, d_A, d_k variations on VAC showed the following results. Decrease of current *I* and steepness S is observed at decreasing of cathode-anode gap L_{AK} and decreasing of the hole diameter in anode d_A (Fig.3).

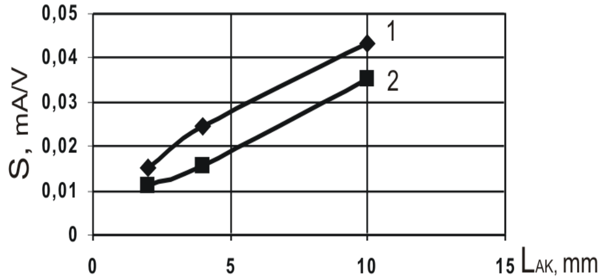

*Fig.3. Dependence of VAC steepness on cathode-anode gap for operation in air at pressure P=*39.9 *Pa and anode hole diameter: 1-d_{A1}=11 mm, 2-d_{A2}=8 mm*

From Fig.3 it is seen that in LGEG electron beam current decreases with L_{AK} decrease. Value of steepness $S \sim L_{AK}$. The latter is connected with the fact that L_{AK} decrease results in growth of the electric field intensity, sagging through the anode hole, increase of nonuniformity of the electric field on the gun axis and reduction of emission area of a cathode. At that current *I* and steepness S decrease.

Decrease d_K results in reduction of emission area of a cathode, emitting electrons and this in its turn decreases beam current *I* and steepness *S*. Thus the steepness is $S \sim \pi d_K^2/4$.

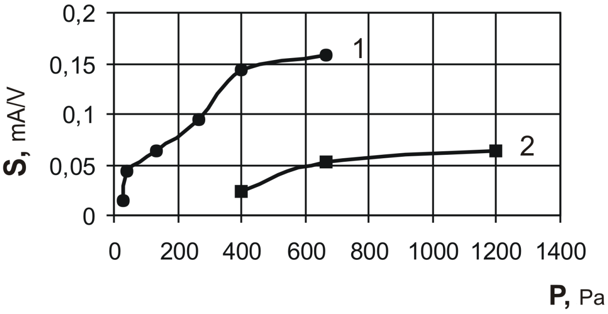

Fig.4. Dependence of VAC steepness on pressure P for d_A=8 mm, L_{AK}=1 mm; 1= air, 2= helium

As researches showed for LGEG there is a strong dependence of VAC steepness on the sort of puffing gas

(Fig.4). Helium *He* and hydrogen H_2 have the lowest value of steepness *S* (in particular for pressure *P=399 Pa* in helium *S*=0.023 *mA/V*, whereas in air *S*=0.144 *mA/V*, i.e. six times more). It is connected with their minimum molecular weight so that during cathode bombardment ions of these gases knock out less of secondary electrons, and as a result, they give low values of coefficient γ . For *He* and H_2 a higher electric breakdown strength of gas gap in the range of left branch of Paschen's curve is also characteristic.

Revealed behaviors were laid in the base of methods of working pressure rise in LGEG. Their integrated use allowed creating a number of LGEG of different functional purposes, which operates in pressure range 10-1000*Pa*. In continuous mode of LGEG operation the similar behaviors of influence L_{AK}, d_A, d_k and sort of gas on VAC steepness were observed as in pulsed mode. However, values of steepness *S* were much lower because of limited power of an energy source.

Investigations of LGEG EGG-6 showed the possibility of its operation in pulsed mode in working pressure range 10-1000 *Pa* and accelerating voltage up to 40 *kV*. Maximum power of an injected electron beam in an impulse was $P_{pused} \approx 9 \cdot 10^5 W$.

4. CONCLUSIONS

Working pressure rise of gas-discharge electron guns with a hollow anode was accomplished at the expense of the VAC steepness decrease. Methods of working pressure rise based on the revealed behaviors of influence of design parameters of LGEG on VAC and on the choice of the sort of puffing gas were proposed and experimentally proved. As a puffing gas it is advisable to use helium *He* or hydrogen H_2. Complex usage of the proposed methods has given the possibility LGEG to operate in pulsed mode in pressure range of 10-1000 *Pa*.

REFERENCES

1. Z. Schiller, U. Gajzig, Z. Panzer. *Electron beam technology*. M.: "Energy", 1980 (in Russian).
2. A.A.. Novikov. *Radiant's electron of a high-voltage glow discharge with anode plasma.* M.: "Energoatomizdat", 1983 (in Russian).
3. V.A. Tutyk. Research of the mode of plasma-beam discharge at gas-discharge electron gun operation // *Problems of Atomic Science and Technology. Ser: "plasma Electronics and New Methods of Acceleration" (6).* 2008, N 4, p.184-188 (in Russian).
4. Yu. Ya. Ruzhin., V.N. Oraevsky., V.A. Tutyk. The active experiments in the stratosphere with the electron beams injection // *Adv. Space Res.* 1993, v.13, N10, p. 122-124.
5. K.N. Ulyanov. Theory of the high-voltage glow discharge // *High Temperature. 1978*, v.16, N 6, p. 1121-1129 (in Russian).
6. V.A. Tutyk, M.I. Gasik. Energy parameters of the gas-discharge electron guns for surface modification// *Electrometallurgy*. 2007, N 10, p. 24-30 (in Russian).
7. A.P. Bohan., P.A. Bohan., D.E. Zakrevsky. Effective oscillation of electron beams in the abnormal discharge with the increased photoemission of the cathode // *Journal of Technical Physics Letters*. 2003, v. 29, N 20, p. 81-87 (in Russian).

Article received 10.10.08.

НИЗКОВАКУУМНЫЕ ГАЗОРАЗРЯДНЫЕ ЭЛЕКТРОННЫЕ ПУШКИ НА ОСНОВЕ ВЫСОКОВОЛЬТНОГО ТЛЕЮЩЕГО РОЗРЯДА

В.А. Тутык

Приведены результаты исследования предложенных методов повышения рабочего давления в низковакуумных газоразрядных электронных пушках, основанных на высоковольтном тлеющем разряде с полым анодом. Экспериментально доказана возможность работы низковакуумных газоразрядных электронных пушек при давлениях в диапазоне 10...1000 Па.

НИЗЬКОВАКУУМНІ ГАЗОРАЗРЯДНІ ЕЛЕКТРОННІ ПУШКИ НА ОСНОВІ ВИСОКОВОЛЬНОГО ТЛІЮЧОГО РОЗРЯДУ

В.А. Тутик

Наведено результати дослідження запропонованих методів підвищення робочого в низьковакуумних газорозрядних електронних пушках, заснованих на високовольтному тліючому розряді з порожнистим анодом. Експериментально доведена можливість роботи низьковакуумних газорозрядних електронних пушок при тисках у діапазоні 10...1000 Па.