account of the substantial influence of the trapping, it should be noted that to produce a uniform volume discharge it is necessary to select the voltage at the accelerator diode so that the transit of the high-energy electrons in the working gas R_E would exceed the discharge dimension during the whole progress of the current pulse. Let us note the prospects of using electric lines as energy storage for the electron accelerator for these purposes.

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CONDITIONS FOR THE MAINTENANCE OF THE CURRENT IN THE CATHODE LAYER OF A SEMI-SELF-MAINTAINING VOLUMETRIC DISCHARGE EXCITED BY AN ELECTRON BEAM

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The distribution of an electric field in a gas gap with the flow of a semi-self-maintaining discharge through the gap is characterized by the presence of preelectrode regions with an increased intensity of the field and the column of the discharge, where the field is approximately homogeneous [1]. With a small rate of generation of electron–ion pairs ψ and small applied voltages U_0, there are strong screening conditions. Under these conditions shock ionization, as a rule, is insignificant [1]. With high values of ψ and U_0, the electrical field in the cathode region rises so much that the principal mechanism of the generation of charged particles can become shock ionization. Then, the processes in the cathode layer of a discharge excited by a beam and of a glow discharge are similar in many respects. Therefore, the use of methods of calculation developed for the investigation of a glow discharge has made it possible (see, e.g., [2-4]) to obtain certain evaluations for the case of large currents.

In the present work, on the basis of a numerical solution of the balance of charged particles and the Poisson equation, an investigation is made of intermediate conditions of the passage of a current in the cathode layer. The transformations of the cathode layer after the beam has been switched off are also discussed.

The system of equations for determining the parameters of the precathode layer has the form

$$(1)\quad -dj_+/dx = dj_-/dx = e\psi + \alpha j_- - \beta j_-(j - j_-)/v_+v_-, \tag{1}$$

$$dE/dx = [(1 + v_+/v_-)j_- - j]/\varepsilon v_+, \quad j_-(0) = \gamma j/(1+\gamma), \quad j_-(d) = j, \int_0^d E(x)\,dx = U_0,$$

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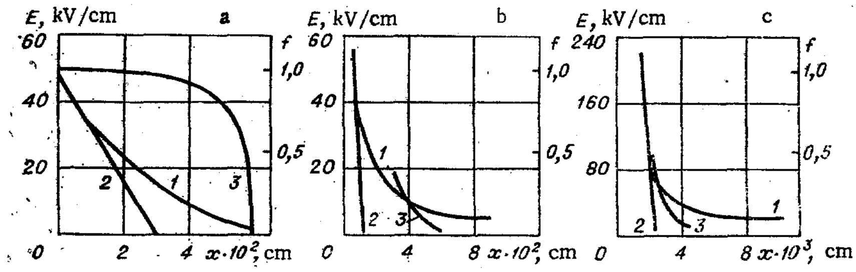

Fig. 1

where $j = eE(\mu_- n_- + \mu_+ n_+)/p$ is the density of the discharge current, defined as the sum of the electronic j_- and ionic j_+ components of the currents; $v_\pm$, $\mu_\pm$, $n_\pm$ are, respectively, the rate of drift, the mobility, and the concentration of the ions and electrons; γ is the coefficient of secondary emission from the cathode; α, β are the coefficients, respectively, of shock ionization and recombination; E is the intensity of the electric field; ε is the dielectric permeability of the medium; d is the interelectrode distance; e is the elementary charge; p is the pressure of the gas.

The calculations were made for nitrogen; the following values of the parameters were taken: $\beta = 2 \cdot 10^{-7}$ cm³/sec; $\gamma = 10^{-2}$; $\mu_- = 2.9 \cdot 10^5$ cm² · mm Hg/(V · sec); $\mu_+ = 2 \cdot 10^3$ cm² · mm Hg/(V · sec). The coefficient of shock ionization was approximated by the formula $\alpha = Ap\exp(-Bp/E)$ with the constants: A = 5.7 1/(cm · mm Hg), B = 260 V/(cm · mm Hg). The method of the numerical solution of system (1) coincided with that described in [5].

Figure 1a-c gives the distributions of the electrical field near the cathode (curves 1) and a linear approximation (curve 2) with the following conditions: a) $\psi = 10^{18}$ 1/(cm³ · sec); j = 0.04 A/cm²; p = 300 mm Hg; E(0) = 47 kV/cm; b) $\psi = 10^{18}$ 1/(cm³ · sec); j = 0.7 A/cm²; p = 760 mm Hg; E(0) = 169 kV/cm; c) $\psi = 10^{18}$ 1/(cm³ · sec); j = 13 A/cm²; p = 760 mm Hg; E(0) = 441 kV/cm. Curves 1 confirm the presence of three sets of conditions of the maintenance of the current in the cathode layer, which are conveniently characterized by the parameter $\delta = \alpha j_- / e\psi$. With a small current density (Fig. 1a) we have $\delta \ll 1$, i.e., the cathode layer is formed due to the generation of charged particles under the action of a beam, and the process of shock ionization is insignificant. With high current densities and large voltages, on the contrary, the parameter δ is great (Fig. 1c). Under intermediate conditions, for which the distribution of the field is shown in Fig. 1b, both shock ionization and ionization of the gas by an electron beam play a role in the maintenance of the current in the cathode region. In the region adjacent to the cathode we have $\delta \gg 1$ and in the transitional region between the column of the discharge and the cathode layer $\delta \lessgtr 1$. The presence of a transitional region in a discharge excited by a beam was also shown in [5, 6]. In this work an investigation was made of the case where, depending on ψ, there is a considerable redistribution of the field between the column of the discharge and the cathode layer, makes it difficult to interprete the results from the point of view of a consideration of the mechanism of the conductivity of the cathode layer. In the present calculations the rate of ionization of the gas ψ and the voltage drop in the column varied independently. This makes it possible to isolate the range of conditions under which there hold one set of conditions or another for the flow of the current in the cathode layer.

For definiteness in the subsequent analysis, the determination of the limit l_c of the cathode layer must be stipulated. The criterion for the selection must, in the first place, distinguish the region where shock ionization plays a small role; in the second place, it must not contradict the known method for determination of the limit of the precathode region using a linear approximation of the curve of E(x), used in the theory of a glow discharge; [7]; in the third place, since the real limit of the region is washed-out, the value of the cathode potential drop $U_c = \int_0^{l_c} E(x)\,dx$ should vary only slightly with a variation near the adopted provisional value. It is expedient to determine l_c from the values of the ratio $f = (n_+ - n_-)/n_-$, varying within the limits 0-1. In the region of the column, in practice f = 0. Graphic dependence of f(x) is shown in Fig. 1, a-c (curve 3). If the limit is determined from the condition $f(l_c) = \xi$, it is found that, with a change in ξ within the limits 0.05-0.2, the cathode potential drop changes very little. Under these circumstances, for the first two sets of conditions the cathode layer is determined taking account the transitional region, while, under the third set of conditions, the difference in the determination of U_c in comparison with the method adopted in the theory of a glow discharge is not more than 10%. In our calculations of the volt–ampere characteristics (VAC) it was everywhere assumed that $\xi = 0.1$.

Figure 2 gives the volt–ampere characteristics of the cathode layer of a discharge excited by an electron beam, and of a glow discharge. The calculation was made with d = 1 cm, $\psi = 10^{-2}$. For curve 2, $\psi = 10^{18}$

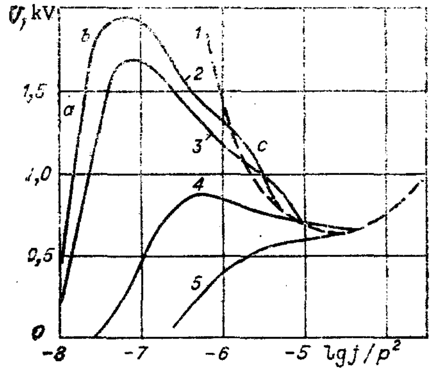

Fig. 2

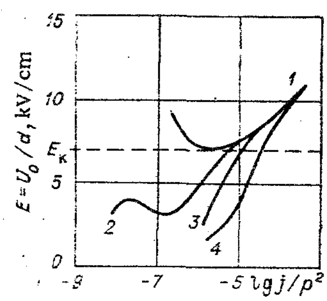

Fig. 3

1/(cm^3 · sec), p = 760 mm Hg; for curves 3-5, p = 300 mm Hg and ψ is equal respectively to 10^{17} 1/(cm^3 · sec), 10^{18} 1/(cm^3 · sec), and 10^{19} 1/(cm^3 · sec). The conditions of the burning of a normal glow discharge correspond to a minimum of curve 1. Correspondingly, the right- and left-hand branches give the volt–ampere characteristics of an anomalous and a subnormal discharge. Using the example of the typical curve 2, let us follow the variation in the conditions of the formation of the cathode layer.

The segment a–b reflects the first set of conditions $\delta \ll 1$. This case is described in [1]; here

$$U_c \approx [\mu_-^2 E^2(l_c)/2p^2](e/\varepsilon\mu_-\psi\beta)^{1/2}, \quad E(0)/E(l_c) = (e\mu_-^2 p/\varepsilon\mu_+)^{1/2}. \tag{2}$$

Further, with a rise in the current density of the discharge, there is a rise in the intensity of the field at the cathode and in this region the parameter δ becomes greater than unity. It must be noted that, under these transitional conditions (segment b–c), the condition of self-maintenance

$$\theta = \gamma\left[\exp\left(\int_0^{l_c} \alpha\, dx\right) - 1\right] = 1.$$

adopted in the theory of glow discharge, is not satisfied. For example, in the region of a maximum of the curve 3 we have $\theta = 0.75$. With a further rise in the current density of the discharge, the cathode layer goes over to the conditions of a glow discharge; in this case, both curves come together; the parameter $\delta \geq 1$ in the whole interval.

However, not all the curves of the volt-ampere characteristics of a discharge excited by a beam have a maximum. Thus, with a rise in ψ, the curve with a maximum goes over into curve 5, having a point of inflection. With a further rise in ψ, we obviously obtain a monotonically rising curve. For the attainment of one or another volt-ampere characteristic, it is essential to know with what value and given external parameters a layer appears in the cathode region, where the condition $\delta \geq 1$ is satisfied; the value of U_c' can be approximately evaluated using formula (2). With $U_c' > U_{c.n}$ ($U_{c.n}$ is the voltage drop in the cathode layer of a normal glow discharge) the volt–ampere characteristic has a clearly expressed maximum, and the transition to self-maintaining conditions takes place in the subnormal region. With a rise in ψ the cathode potential drop U_c' decreases and becomes comparable to $U_{c.n}$; the curve of the volt–ampere characteristic therefore has a point of inflection. With a further rise in the rate of generation of pairs of carriers, U_c becomes less than $U_{c.n}$ and the volt–ampere characteristic is found to be monotonically rising. The smaller the value of ψ, the smaller the region of a non-self-maintaining discharge (with respect to the parameter j/p^2). It is obvious that, at the limit, where the rate of generation ψ becomes comparable to the rate of generation of pairs by the action of natural sources, the non-self-maintaining form goes over into the volt–ampere characteristic of a glow discharge with an ignition potential corresponding to the breakdown voltage.

Let us consider the transformation of the cathode layer and the volt–ampere characteristic of a discharge maintained by a beam of fast electrons after the beam has been switched off. Such a problem arises with an examination of the work of commutators, where the initial concentration of carriers is generated by a beam of small duration. An exact solution is possible only on the basis of a non-steady-state system of equations. However, in a majority of cases, after the beam has been switched off, the time required for the establishment of the cathode layer is far less than the time of the decomposition of the plasma of a positive column. With such a quasi-steady-state appraoch, a comparison of the volt–ampere characteristic of a self-maintaining glow discharge and the volt–ampere characteristic of a discharge maintained by a beam makes it possible to answer the question of whether a transition from a non-self-maintaining discharge to self-maintaining conditions after the beam has been switched off is possible or not. An analysis of the results given in Fig. 3 shows that such a transition is possible. The calculation was made for $d=1$ cm, $p=300$ mm Hg, $\gamma=10^{-2}$. The ionization rates for curves 2-4 are, respectively, equal to 10^{16}, 10^{17}, and 10^{18} 1/(cm$^3\cdot$sec); curve 1 relates to a discharge. With a constant applied mean field $E_0=U_0/d$ greater than some critical value E_c, the parameter j/p^2 will decrease with time, and the intersection of the volt–ampere characteristics of such a discharge with the volt–ampere characteristic of a glow discharge is inevitable. In accordance with the new parameter j/p^2, determined at the point of intersection, the value of the cathode layer can be evaluated from Fig. 2.

If the condition $E_0<E_c$ is satisfied for the corresponding parameters of a glow discharge, then, the volt–ampere characteristic of the broken discharge and the volt–ampere characteristic of a glow discharge have no common point; therefore, on the basis of the classical mechanism of shock ionization, a transition to self-maintaining conditions is impossible.

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