CALCULATED CHARACTERISTICS OF THE ANODE REGION OF A LONGITUDINAL DISCHARGE INCLUDING DIFFUSION

R. Sh. Islamov

UDC 537.525

The continuing interest in longitudinal discharges at high pressures results from the expanded use of such discharges for pumping the active media of lasers. In this paper we examine a numerical model for the discharge with diffusive fluxes taken into account. Primary attention is devoted to the anode region of the discharge, which serves as the major source of positive ions to the positive column of the discharge. The neglect of diffusion in [1] meant that the calculations were valid for calculating the current–voltage characteristics of the anode layer only at current densities such that $I/p^2 \leq 4$ mA/cm^{2}kPa^2. It has been shown experimentally [2] that at higher pressures a normal current density dependence can be realized for substantially higher values. In this paper a one-dimensional model that includes diffusive fluxes [3] is used to give a more adequate description of the spatial inhomogeneities:

$$\partial\rho/\partial t + \partial\Gamma_0/\partial x = 0,\quad \Gamma_0 = (D_L - D_i)\partial n_i/\partial x - D_L\partial\rho/\partial x - n_i(\mu_e + \mu_i)\times$$
$$\times\,\partial\varphi/\partial x + \rho\mu_e\partial\varphi/\partial x + \rho V,$$
$$\partial n_i/\partial t + \partial\Gamma_i/\partial x = (n_i - \rho)(\nu - \beta n_i),\quad \Gamma_i = -D_i\partial n_i/\partial x - n_i\mu_i\partial\varphi/\partial x +$$
$$+\, n_i V,$$
$$\partial^2\varphi/\partial x^2 = -4\pi e\rho,\ I = e\Gamma_0,$$

where n_i and $e\rho$ are the ion and charge densities; μ_e and μ_i are the mobilities of the electrons and ions; D_L and D_i are their longitudinal diffusion coefficients; φ is the potential of the electric field; V is the gas flow velocity (V > 0 for pumpout from the anode); ν is the ionization frequency; and β is the electron–ion recombination coefficient. At the anode (x = 0) it is assumed that $\varphi|_a = 0$ and $\Gamma_i|_a = 0$ and in the positive column (x = d) the conditions $\rho|_{pc} = 0$ and $\varphi|_{pc} = -U < 0$ are set. Including diffusion raises the order of the equations and two additional boundary conditions are required besides these traditional ones. They are taken in the form $\partial\rho/\partial x|_{pc} = \partial n_i/\partial x|_{pc} = 0$. The following values of the constants were taken for a nitrogen plasma in the following calculations [4, 5]: $\mu_e N = 1.2 \cdot 10^{22}$ cm^{-1}/V·sec, $\hat{\mu}_e = \partial \ln \mu_e/\partial \ln E = -0.14$, $\mu_i N = 5.8 \cdot 10^{19}$ cm^{-1}/V·sec, $D_i N = 1.6 \cdot 10^{18}$ cm^{-1}/sec. $D_L N = 4.0 \cdot 10^{22}$ cm^{-1}/sec, $\beta = 7.5 \cdot 10^{-8}$ cm^3/sec, $\nu = A\exp(-B/E)$, where $A/N = 5.0 \cdot 10^{-9}$ cm^3/sec; $B/N = 8.01 \cdot 10^{-15}$ V·cm^2; $E = -\partial\varphi/\partial x$; and N is the density of the gas.

For numerically solving this system of equations we have used implicit difference schemes of second order in the spatial coordinate and of first order in time. Given the absence of any procedures for smoothing the results of the calculations, this choice of schemes has substantially eliminated the influence of "computational diffusion" on the steady-state solutions found by iteration. At each time step this nonlinear boundary problem was solved by an implicit two-layer iterative method with a choice of the optimum iteration parameter [6].

We analyze the features of the anode region of discharge. The characteristic dimension of the negative space charge between the anode and the electrically neutral plasma in the dc positive column is $\ell_E = \mu_e E^2/4\pi I$ [7]. Diffusive processes in a dc discharge correspond to a length $\ell_u = D_L/\mu_e E$. Thus, for the positive column of a nitrogen plasma, we have $\ell_u/\ell_E \simeq 0.057 I/p^2$ kPa^{2}cm^2/mA. When $\ell_u/\ell_E \ll 1$, the changes in the characteristics are caused by the violation of neutrality over almost the entire layer and a drift approximation (quasineutral equations without diffusive fluxes; [1], for example) is used to describe the electrode layer. The dot–dash curve in Fig. 1 (where D_L is enhanced by a factor of 3.7) shows the relatively weak effect of diffusion on the magnitude of the anode potential drop U_a when this condition is satisfied. The present results are in good agreement with calculations of [1] in the drift approximation for low current densities. When $\ell_u/\ell_E \gtrsim 1$, diffusion causes a noticeable increase in U_a. Nevertheless, when $I/p^2 = 24$ mA/cm^{2}kPa^2, which corresponds to a normal current density at the anode for nitrogen at pressures of $0.7 \leq p \leq 4$ kPa, U_a is 1.5-2 times smaller than the experimental values from [2]. Under these conditions the charac-

---

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 3-5, September-October, 1990. Original article submitted April 10, 1989.

0021-8944/90/3105-0665$12.50 © 1991 Plenum Publishing Corporation

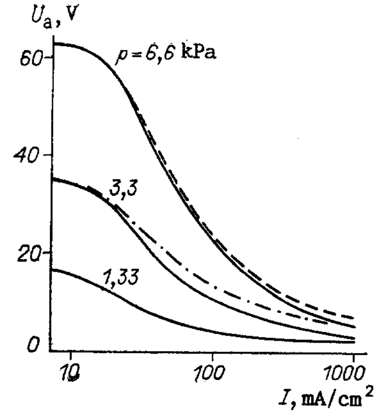

Fig. 1

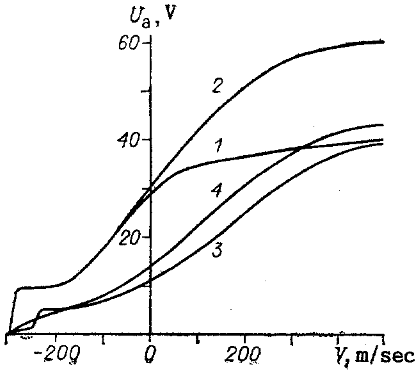

Fig. 2

teristic scale lengths L of the inhomogeneities become comparable to ℓ_u and, in principle, one must also take the nonlocal character of the electron distribution function into account. This greatly complicates the problem under gaseous discharge conditions. An estimate of the influence of the nonlocal character of the distribution function on the plasma coefficients in the linear approximation in the parameter ℓ_u/L leads to the appearance, in the expression for the flux Γ_0, of a diffusive flux $D_E(n_i - \rho)\partial \ln E/\partial x$ [8] and an ionization ambipolar drift at a velocity of $\nu\ \hat{\nu} D_L/\mu_e E$* [9]. According to the calculations of [8], for nitrogen in the range of E/N of interest to us, E/N, $D_E/D_L \lesssim 0.3$. Therefore, the influence of the first term is relatively small. The effect of including the ionization ambipolar drift is indicated by the dashed curve in Fig. 1. According to the calculations, a substantial rise in the electric field strength owing to the violation of quasineutrality sets in at distances much greater than ℓ_E. At low current densities the anode region can occupy almost the entire interelectrode space. Then, determining the anode potential drop from the formula $U_a = U - dE|_{x=d}$ leads to a significant dependence of U_a on the choice of the interlectrode distance d. In the curves of Fig. 1, which were obtained for d = 0.5 cm, this showed up in a saturation effect when the current density was lowered. The effect is especially important when gas is pumped out from the anode [curves 1 (d = 0.05 cm) and 2 (d = 1 cm) in Figs. 2 and 3 for p = 3.3 kPa and I = 20 mA/cm²]. In Fig. 3 the distance at which the field strength is equal to half the sum of the field strengths at x = 0 and x = d was taken to be the thickness of the anode layer D_a. The experiment of Blokhin and Pashkin [10], where U_a was found in an analogous fashion from probe measurements (in air) for I = 9-20 mA/cm², also revealed a weak dependence of U_a on the current density and its growth with increasing interelectrode distance. With gas flow-through at $V = -\mu_i E_{pc}$, the quasineutral positive column extends right up to the anode and there is no anode potential drop in this case. It is interesting to note that because of the ambipolar drift associated with the dependence of the electron mobility on the electric field, there are discontinuities in the velocity dependences of U_a and D_a when gas flows out from the cathode (curve 3 of Figs. 2 and 3 for p = 3.3 kPa, I = 100 mA/cm², and d = 0.5 cm). If we set $\hat{\mu}_e = 0$ (curve 4 of Fig. 2), then the discontinuities vanish. In sufficiently fast flows the flow may become turbulent and have a strong effect on the diffusive processes in the discharge. Including the coefficient of turbulent diffu-

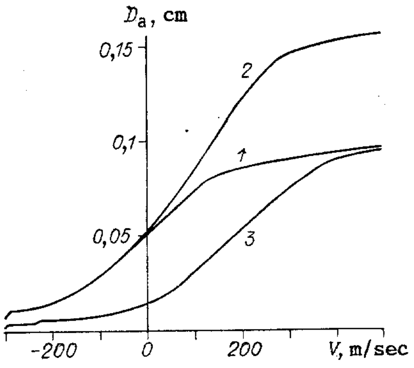

Fig. 3

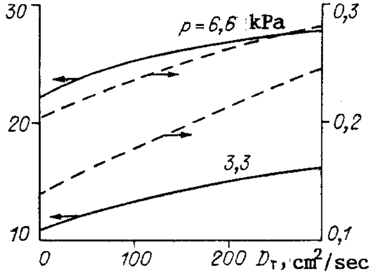

Fig. 4

---

*As in Russian original — Editor.

sion D_T, which was added to D_L and D_i in the calculations, leads to a growth in the anode potential fall and the thickness of the anode layer (Fig. 4, I = 100 mA/cm², d = 0.5 cm).

LITERATURE CITED

1. Yu. S. Akishev, F. I. Vysikailo, A. P. Napartovich, and V. V. Ponomarenko, Teplofiz. Vys. Temp., 18, No. 2 (1980).
2. Yu. S. Akishev, A. P. Napartovich, P. I. Peretyat'ko, and N. I. Trushkin, Teplofiz. Vys. Temp., 18, No. 4 (1980).
3. Yu. P. Raizer, Foundations of the Modern Physics of Gas Discharge Processes [in Russian], Nauka, Moscow (1980).
4. A. M. Dykhne, A. P. Napartovich, T. V. Taran, et al., A Numerical Study of a Two-Dimensional Electrical Discharge [in Russian], Preprint No. 164, Inst. of Applied Mathematics, Academy of Sciences of the USSR, Moscow (1981).
5. L. Huxley and R. Crompton, Diffusion and Drift of Electrons in Gases [Russian translation], Mir, Moscow (1977).
6. A. A. Samarskii and E. S. Nikolaev, Methods for Solving Equations on a Grid [in Russian], Nauka, Moscow (1978).
7. V. I. Blokhin, V. V. Breev, S. V. Dvurechenskii, and S. V. Pashkin, Teplofiz. Vys. Temp., 19, No. 5 (1981).
8. N. L. Aleksandrov, A. M. Konchakov, A. P. Napartovich, and A. N. Starostin, Plasma Chemistry [in Russian], Vol. 11, Moscow (1984).
9. F. I. Vysikailo, Fiz. Plazmy, 13, No. 2 (1987).
10. V. I. Blokhin and S. V. Pashkin, Teplofiz. Vys. Temp., 14, No. 2 (1976).

TWO FORMS OF DISCHARGE IN ARGON PLASMAS WITH AN EMISSION-ACTIVE POTASSIUM ADDITIVE

V. O. German and V. S. Uspenskii

UDC 533.9

There are currently a substantial number of papers devoted to research on the stability of distributed discharges in gases with different assumptions about the character of the flow in the interelectrode gap, the external electrical circuit, the electrode potential falls, etc. ([1-6], for example). The loss of stability by a discharge can lead a priori to a transformation of the solutions that describe the flow of current in the discharge to a new stationary state or to quenching of the discharge. It turns out that a nonuniqueness in this type of transformation can be observed in a number of cases. For a given total discharge current one can have both a distributed discharge regime with diffusive coupling to the anode and a contracted discharge with an anode spot.

In this paper we obtain experimentally the current—voltage characteristic of a discharge in a high-temperature argon plasmotron with distributed and contracted branches. The distinctive feature of the experimental apparatus lies in supplying a small amount of emission-active potassium additive to the cathode to ensure a high thermal-emission current [7] under atmospheric and higher pressure conditions, so that the discharge is coupled diffusively at the cathode independently of the behavior of the discharge in the plasma volume. In this way we exclude the cathode's having a significant effect on the discharge in the plasma volume, as happens in most other devices where a transition to field emission takes place at the cathode with the appearance of a cathode spot when the discharge contracts. We believe that ensuring diffusive coupling of the discharge to the cathode prevents the streamer formation in the plasma volume from the cathode side observed during the transition from thermionic emission to field emission as the mechanism for current flow at the cathode. Shifts into distributed and contracted stationary discharge regimes corresponding to a single val-

---

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 5, pp. 6-8, September-October, 1990. Original article submitted February 24, 1989; revision submitted April 20, 1989.

0021-8944/90/3105-0667$12.50