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ON THE MECHANISM OF GLOW DISCHARGE INSTABILITY FOLLOWING THE TURN-OFF A NON-SELF-SUSTAINED IONIZATION SOURCE.

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Instabilities in a non-self-sustained glow discharge which develop when external ionisation pulse is applied have been discussed earlier is many works. According to the present dominating point of view this instability is associated with the growth of the value of self-sustained ionization function. Heating are rarefaction of gas play an important role in this case.

1. This paper reports on the measurements of gas density which were performed to clarify the mechanism of instability when the time τ_{in} exceeds the ionizer pulse duration τ_p. Experiments were carried out in a mixture of CO_2 and N_2 at atmospheric pressure. A pulsed 120keV electron beam with a current density 200 mkA/cm^2 at the anode plane was injected into a discharge chamber through an Al-foil. The voltage across the discharge gap was maintained constant and the velocity of gas flow was 3 m/s. Change in the gas density were recorded by a laser interferometer method. Measurements were carried out with a He-Ne laser which had a three-mirror resonator[1]. The wavelength was 0.63 mkm. Optical axis of simmetry were coincident.

Typical oscillograms of a discharge current pulse and of phase overlapping are presented in Fig.1(200 mks/cm sweep). In this case the non-ionized gas provides the main contribution to the refraction factor. A phase shift 2π corresponds to a relative change in gas density $\Delta N/N_0 = 0.016$ for the mixture CO_2-N_2(1:2) and $\Delta N/N_0 = 0.018$ for the mixture (1:9), where N_0 is the initial gas density and $\Delta N = N_0 - N(t)$. The dependens of the relative density $N(t)/N_0$ on the duration of current pulse for 1:9 mixture is shown in Fig.2. A point in the figure which identifies the development of instability after the termination of current pulse is marked with a cross.

2. An analitical asseasment of gas rarefaction was made on the basis of a two-level model which takes into account the transfer of oscillatory energy away from the discharge zone. The continuity equations for the exited N_2 and CO_2 molecules have the form :

$$\frac{\partial N_N^*}{\partial t} + N_N^* \operatorname{div}\vec{V} = \frac{W_N}{E_N} - K(N_N^* N_C - N_C^* N_N) - \frac{N_N^*}{\tau_N} \quad (1)$$

$$\frac{\partial N_C^*}{\partial t} + N_C^* \operatorname{div}\vec{V} = \frac{W_C}{E_C} + K(N_N^* N_C - N_C^* N_N) - \frac{N_C^*}{\tau_C} \quad (2)$$

Here N_N, N_C are the densities of N_2 and CO_2 molecules in the ground state; W_N, W_C denote the power density used for the exitation of oscillatory levels in N_2 and CO_2; E_N, E_C are the energies of oscillatory levels in N_2 and CO_2, K - constant related to the oscillatory quanta exchange rate between N_2 and CO_2; τ_N, τ_C - relaxation time of oscillatory levels in N_2 and CO_2. Equation (1) and (2) should be supplemented by gas dynamical equations which may be expressed for isobaric expansion of gas as follows :

$$\frac{\partial N}{\partial t} + N \operatorname{div}\vec{V} = 0 \quad (3)$$

$$\frac{\partial E_V}{\partial t} + \left(E_V + \frac{\gamma}{\gamma-1} P\right) \operatorname{div}\vec{V} = W \quad (4)$$

Here N is the total density of molecules in a gas mixture. The solution of system (1)-(4) may be derived with an assumption that due to the high rate of energy exchange between the N_2 and CO_2 oscillatory quanta, the establishment of equilibruim between them is practically a momentary process, i.e. that $N_N/N_C = N_N^*/N_C^* = \delta$.

The set of equations (1)-(4) may now

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now be reduced to a single non-linear second-order differential equation for gas density :

$$\frac{\partial^2 \ln n}{\partial t^2} - \left(\frac{\partial \ln n}{\partial t}\right)^2 + \left[1 - B(1-\eta)\right]\frac{\partial \ln n}{\partial \tau} + B = 0$$

$$\left.\frac{\partial \ln n}{\partial \tau}\right|_{\tau=0} = B(\eta - 1);\ n = \frac{N}{N_0};\ \tau = \frac{t}{\tau_c^*(1+\delta)} \quad (5)$$

$$\eta = \frac{W_N + W_c}{W};\ \frac{1}{\tau_c^*} = \frac{1}{\tau_c} + \frac{\delta}{\tau_N};\ B = \frac{W\tau_c^*(1+\delta)}{P\gamma}(\gamma - 1)$$

Solution of (5) is as follows :

$$n = \frac{2A\exp\left[1 + A - B(1-\eta)\right]\frac{\tau}{2}}{\left[1 + A + B(1+\eta)\right]\exp(A\tau) - \left[1 - A + B(1-\eta)\right]} \quad (6)$$

$$A = 2\sqrt{B + \frac{1}{4}\left[1 - B(1-\eta)\right]^2}$$

If $B \ll 1$, expression (6) may be simplified as follows :

$$n \approx \frac{1 + B(1+\eta)}{1 + B + B\eta\cdot\exp\left[-1 - B(1+\eta)\tau\right]}\exp(-B\tau) \quad (6a)$$

In another limiting case when $B(1-\eta) \gg 1$ we obtain from (6) :

$$n \approx \exp\left[B(\eta - 1)\tau\right]$$

In both cases the solution does not depend on τ_c^*. It should be noted that after termination of the pumping pulse, the gas concentration decreases for some time due to oscillatory energy relaxation. The solution of equations (1)-(4) at $W = 0$ yields :

$$n(\tau) = \frac{n^2(\tau_p)}{n(\tau) - n'(\tau_p)\left[1 - \exp(\tau_p - \tau)\right]},\ (\tau > \tau_p) \quad (7)$$

$$n'(\tau_p) = \left.\frac{\partial n}{\partial \tau}\right|_{\tau = \tau_p}$$

To allow comparison with experimental data of $n(t)$ was computed from formulas (6a),(7) for mixture CO_2-N_2(1:9) at V_d=3 kV and V_d=5 kV (curves 3 and 2 respectively in Fig.2). Note, that with the increase of V_d and at earlier moments of observation, the deviation from the conditional P=const which is the basic approximation of the theoretical model becomes greater. Also, the discrepancy between calculation and experiment increases.

3. Discussion of results. From Fig.2 it may be seen that at V_d=6 kV and 310mks duration current pulse, instability develops at 375 mks ($\tau_{in} > \tau_p$). By this time the gas density decreases approximately by a factor of 2.5. Comparision between the applied voltage and the static breakdown voltage of this discharge gap shows that at n =0.4 the latter is three times as high as V_d.

A simular situation is true for the (1:2) mixture.

Thus the rarefaction of the gas is not a sufficient factor for the development of a static breakdown (direct Townsends ionisation). The development of instability may be associated with the growth of stepped self-sustained ionisation in the decaying plasma in an external field. In this case the increase of E/N due to gas rarefaction plays a significant role.

[1] - D.E.Ashby,D.F.Jephcott, Appl.Phys. Lett.,3,13,1963.

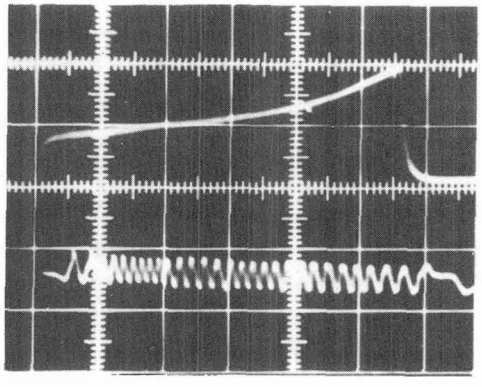

Fig.1

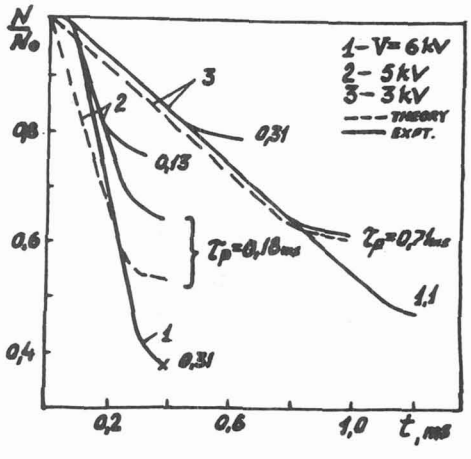

Fig.2