Experimental and theoretical study of the influence of nitrogen admixture on characteristics of dc glow discharge in rare gases at intermidiate pressures

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The influence of nitrogen admixture on characteristics of diffuse glow discharges in rare gases at intermediate pressures (20-80 Torr) was studied both experimentally and theoretically. It was shown that in the case of argon the addition of nitrogen leads to the noticeable decrease in discharge voltage (electric field in the positive column). Contrary, in the case of neon and helium the increase in discharge voltage with nitrogen admixture was observed. The numerical modeling of discharges in argon-nitrogen and neon-nitrogen mixtures was performed and explanation of observed effects was given.

The influence of nitrogen admixture on characteristics of diffuse glow discharge in pure argon was studied in detail in our recent paper [1]. The discharge was excited in a cylindrical molybdenum glass tube with an inner diameter of 2.8 cm and interelectrode distance of 75 cm. It was shown that, at relatively low pressures ($P < 10$ Torr), the current–voltage characteristic of a discharge in the Ar+1%N_2 mixture lies higher than that in pure argon. In contrast, at intermediate pressures ($P > 15$ Torr), the current-voltage characteristic of a discharge in the mixture lies lower than that in pure argon (see Fig.1). To calculate discharge characteristics a zero dimensional model was developed. In this model the equations describing the kinetics of the excited states of Ar atoms, vibrational kinetics of nitrogen molecules in the ground state, kinetics of the electronic states of N_2 molecules, kinetics of the electronic states of N atoms, charged particle kinetics; the Boltzmann equation for electrons; and the equation for the electric circuit are solved self-consistently. The gas temperature at the tube axis was estimated from the experimental data and used as the parameter of the model. Detailed calculations performed for Ar and Ar+1%N_2 mixture showed that model reproduces effects found out in experiments. It follows from simulations [1] that at intermediate pressures production of electrons in Ar:N_2 mixture is provided mainly by processes of associative ionization of excited nitrogen atoms

$$N(^2D, ^2P) + N(^2P) = N_2^+ + e$$

and (to a lesser extent) by processes of associative ionization of excited nitrogen molecules

$$N_2(A^3\Sigma_u^+, a'^1\Sigma_u^-) + N_2(a'^1\Sigma_u^-) = N_4^+ + e.$$

Losses of electrons are provided mainly by electron-ion recombination processes. Due to charge transfer ($N_2^+ + Ar \leftrightarrow N_2 + Ar^+$) and ion conversion ($Ar^+ + 2Ar = Ar_2^+ + Ar$) processes the major ion in argon-nitrogen discharge appeared to be Ar_2^+, i.e. the same as in pure argon discharge. Ionization mechanism is rather efficient, so the discharge voltage in gas mixture is lower than that in pure argon. It was also shown that, under considered conditions, a high degree of vibrational excitation of nitrogen molecules is achieved and production of nitrogen atoms is provided by processes with participation of vibrationally excited molecules.

To understand whether the effect of discharge voltage decrease (at intermideate pressures) is universal with respect to the sort of rare gas, experiments with pure Ne and Ne:N_2 mixtures were performed. Experimental setap was exactly the same as in [1]. It was found out that the effect is absent in this case: in the whole range of gas pressures under consideration the addition of nitrogen to neon led to the increase in the electric field strength in the positive column (see Fig. 2). To clarify the situation self-consistent kinetic model (similar to that for Ar:N_2 mixtures) was developed, and calculations for pure Ne and Ne+1%N_2 mixture were performed. Results of the electric field calculations are shown in Fig. 2. One can see that theoretical results are in agreement with experimental data. According to calculations, ionization mechanism in Ne:N_2 mixture at intermideate pressures is the same as in Ar:N_2 mixture. On the other hand, since the ionization energies of Ne atoms and N_2 molecules are appreciably different the charge transfer processe from N_2^+ ion to Ne atom is absent. For this reason, the addition of nitrogen to neon leads to the replacement of major ion in plasma from Ne_2^+ (in pure neon) to N_4^+ (due to N_2^+ ion conversion processes). And the rate constant for the process of electron recombination with N_4^+ ion is one order of magnitude higher than that with Ne_2^+ ion. The increase in the rate of electron losses due to recombination with N_4^+ ions appeared to be more significant factor than the increase in the ionization rate, so the electric field needed for the glow discharge maintenance increases with the addition of nitrogen to neon.

The ionization energy of He atoms is essentially higher than that of N_2 molecules, and the rate constant for the recombination of electrons with He_2^+ ions is about two orders of magnitude lower than that for the recombination with N_4^+ ions. That is, in the case of helium the situation is the same as in the case of neon. Really, performed experiments showed that the addition of nitrogen to helium leads to the increse in the electric field (see Fig. 3).

In the case of Xe:N_2 mixture situation is similar to that in Ar:N_2 mixture. Really, the ionization energy of Xe atoms is lower than the ionization energy of N_2 molecules, and charge transfer processes (from N_2^+ ions to Xe) take place. So, one can expect that the addition of nitrogen admixture to xenon at intermediate pressures will lead to the decrease of discharge voltage. We did not perform experiments with Xe:N_2 mixtures, but in the literature there are evidenses that effect takes place [2].

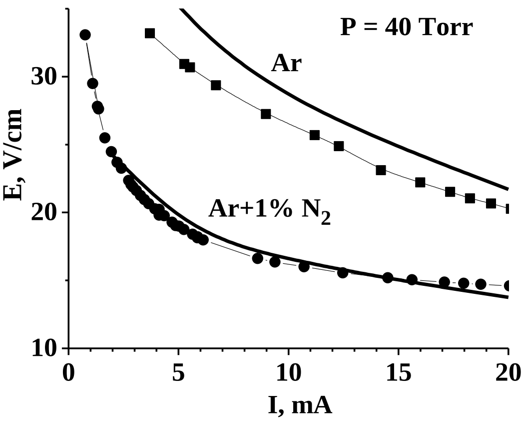

Fig. 1: Measured (symbols) and calculated (thick lines) dependences of the electric field in the positive columns of discharges in pure argon and the Ar + 1% N_2 mixture on the discharge current for P = 40 Torr [1].

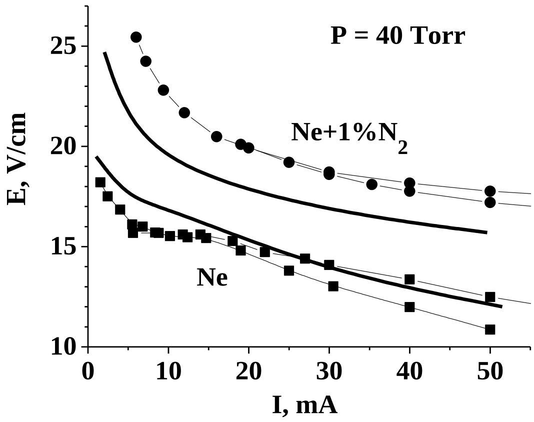

Fig. 2: Measured (symbols) and calculated (thick lines) dependences of the electric field in the positive columns of discharges in pure neon and the Ne + 1% N_2 mixture on the discharge current for P = 40 Torr.

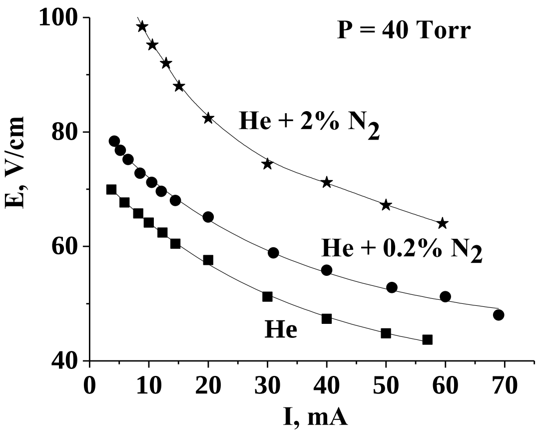

Fig. 3: Measured dependences of the electric field in the positive columns of discharges in pure helium and the He : N_2 mixtures on the discharge current for P = 40 Torr .

References

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