Topic number: 5

Theoretical study of the influence of nitrogen admixture on plasma decay rate in argon dc afterglow

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In the present work the decay of plasma in a dc afterglow in pure Ar and Ar:N_2 mixtures was studied theoretically under the following conditions: discharge tube radius R = 1.5 cm, N_2 admixture α = 0.1%-1%, gas pressure P = 1 – 5 Torr, discharge current I = 20 – 50 mA. It was shown that the addition of nitrogen to argon led to a dramatic change in plasma decay scenario. One of the reasons is that the effective electron temperature in Ar+N_2 afterglow is rather high due to the second kind collisions of electrons with vibrationally excited molecules. As a result, the rate of plasma decay due to ambipolar diffusion is high, too. Another reason is that at the early stage of the afterglow (≤ 15 ms at P = 5 Torr) the loss of electrons and ions is noticeably compensated due to ionization processes with the participation of excited nitrogen atoms $N(^2P,^2D) + N(^2P) = N_2^+ + e$.

In the present paper, plasma parameters in a dc glow discharge and afterglow in Ar and Ar:N_2 mixtures were studied theoretically using the self-consistent 0-dimentional kinetic model [1]. The model included balance equations for charged species, a system of kinetic equations for populations of electronic states of Ar atoms, N_2 molecules and N atoms, a system of equations for the vibrational kinetics of N_2 molecules in the ground electronic state and an equation for the electric circuit. Rate coefficients for electron-induced processes were calculated from solution to the electron Boltzmann equation (with taking into account electron-electron and second kind collisions). The preliminarily estimated gas temperature was taken as a parameter.

The procedure of simulation was as follows. First, time-evolution of plasma parameters was calculated to come to steady-state discharge conditions (further it is characterized by the discharge current value I). Then, the applied voltage was set to zero and the time-variation of plasma parameters in the afterglow was calculated.

Electron concentrations calculated in the steady state discharge plasma (I = 20 mA, P = 1 Torr, 5 Torr) and in the afterglow are shown in fig. 1. According to the performed analysis, in pure Ar afterglow the electron temperature quickly (< 1 μs) relaxes to the gas temperature. The plasma decay is governed by recombination of electrons with molecular ions and ambipolar diffusion process, the contribution of the former process decreases with the decrease in the ion concentration.

In the discharge in Ar:N_2 mixtures the high degree of vibrational excitation of nitrogen molecules is achieved [1]. As a consequence, the effective electron temperature in the afterglow is also high [2] due to second kind collisions of electrons with vibrationally excited molecules. And high electron temperature in the afterglow results in the high rate of plasma decay due to ambipolar diffusion process. On the other hand, at early stage of the afterglow (≤ 15 ms, at P = 5 Torr) the loss of electrons and ions is noticeably compensated due to ionization processes with the participation of excited nitrogen atoms $N(^2P,^2D) + N(^2P) = N_2^+ + e$.

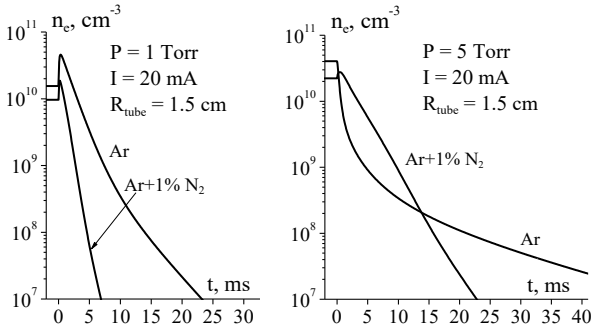

Fig. 1. Calculations. Electron concentration in the discharge plasma (t<0) and in the afterglow (t>0).

Naturally, the contribution of different processes to plasma decay rate depends on the gas pressure. It is seen in fig. 1 that at P = 1 Torr, the addition of N_2 to Ar leads to the significant increase in the decay rate. At P = 5 Torr the situation is more complex. In the beginning, the plasma in Ar afterglow decays faster and then slower than in Ar+1%N_2 afterglow.

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References

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