Topic number: 7

THE ROLE OF METASTABLE ARGON ATOMS AND DUST PARTICLES ON GAS DISCHARGE PLASMA PARAMETERS

Alexander Fedoseev[(1,*)], Gennady Sukhinin[(1,2)]

[(1)] Institute of Thermophysics SB RAS, Novosibirsk, Russia

[(2)] Novosibirsk State University, Novosibirsk, Russia

[(*)] **fedoseev@itp.nsc.ru**

In papers [1-3] the results of experimental investigations of metastable argon atoms and dust particles in gas discharges are reported. It is shown that the metastable argon atoms and dusty particles strongly influence the discharge plasma. Depending on discharge parameters, the presence of dust particles has both positive and negative effects on metastable density [1]. The increase of metastable density up to ten times was detected in the discharge with dusty particles in comparison with pristine argon plasma [3].

We present the model that describes the influence of metastable argon atoms and dust particles on gas discharge parameters. The numerical model is based on a previously developed kinetic model of a low pressure DC glow discharge with dust particles based on Boltzmann equation for the electron energy distribution function (EEDF) [4] and the balance equation for metastable argon atoms. The model takes into account ionization balance, the formation of EEDF, a dust particle charging and balance for metastable argon atoms. The homogeneous stationary Boltzmann equation for the isotropic part of EEDF f_0 for the case of the presence of dusty particles and metastable argon atoms can be written in the form:

$$-\frac{(e_0E)^2}{3}\frac{\partial}{\partial U}\left(\frac{U}{H'(U)}\frac{\partial f_0}{\partial U}\right)=S^{el}(f_0)+\sum_k S_k^{in}(f_0)+ \\ +S_{ion}(f_0)+S_{stpw}(f_0)+S_p(f_0)+S_w(f_0)+S_d(f_0), \qquad (1)$$

where $H'(U)$ is the momentum cross section, E is the electric field strength, U is the electron kinetic energy, S^{el} and S_k^{in} are the integrals of elastic and k-th inelastic collisions. The ionization balance was determined by the processes of direct electron impact ionization S_{ion}, stepwise ionization from metastable argon states S_{stpw}, ionization in metastable-metastable collisions S_p, recombination of electrons and ions on the dust particle surface S_d and on the discharge tube wall S_w. The following balance equation for metastable density N_m was used:

$$\frac{\partial N_m}{\partial t}=-D_m\frac{N_m}{R^2}-k_{mm}N_m^2-\nu_{stpw}(f_0)N_m-\pi r_0^2 N_m N_d<\upsilon_m>+\nu_{exc,m}(f_0)N_g+k_{rec}N_eN_i, \qquad (2)$$

where D_m is the metastable diffusion coefficient, R is the characteristic scale of plasma volume, k_{mm} is the rate constant of metastable-metastable collisions, r_0 is the dust particle radius, N_d, N_g, N_e, N_i are the densities of dust particles, neutral argon, electrons and ions, $<\upsilon_m>$ is the mean velocity of metastable, k_{rec} is the rate constant of electron-ion radiative recombination. For determining ion density, the condition of quasi neutrality in the dusty cloud is used, $N_i = N_e + N_d Z_d$. The dust particle charge Z_d was determined from the Orbital Motion Limited model. The quasi neutrality condition, the Boltzmann equation (1) for EEDF, and the metastable balance equation (2) were calculated numerically in a self-consistent way for different dust particles concentration N_d. For convergence of iterative procedure, the condition of ionization balance was used. The rates of argon metastable states production in electron impact excitation processes, $\nu_{exc,m}(f_0)$, and losses in the processes of stepwise ionization, $\nu_{stpw}(f_0)$, were calculated with the help of Boltzmann equation. In the Boltzmann equation (1), the additional sinks of electrons produced in the metastable-metastable collision and in the stepwise ionization were taken from the calculations of equation (2). The possible emission of electrons from the surface of dust particles after the absorption of metastables was also considered.

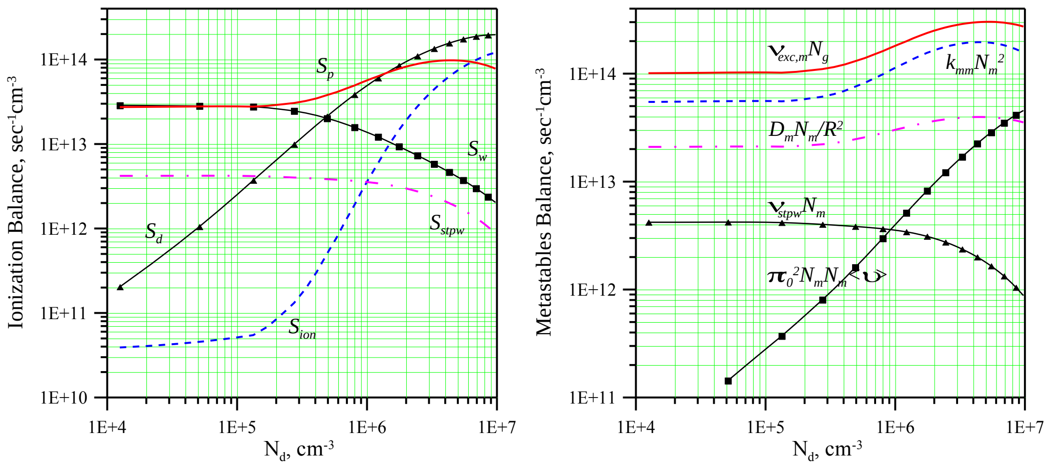

Fig. 1: a) The ionization balance terms: S_p solid line, S_{ion} dashed line, S_{stpw} dashed dotted line, S_d triangles and S_w squares. b) The metastable balance terms: $\nu_{exc,m}N_g$ solid line, $k_{mm}N_m^2$ dashed line, D_mN_m/R^2 dashed dotted line, $\nu_{stpw}N_m$ triangles and $\pi r_0^2 N_m N_d <\upsilon_m>$ squares.

In Fig. 1, the terms of the Boltzmann equation (1) and metastable balance equation (2) are presented for the following parameters of gas discharge: the electron current density j_e = 0.1 mA/cm^2, initial electric field E_0 = 2 V/cm, argon pressure p = 0.5 Torr, r_0 = 10^{-4} cm. For the present conditions and for small dust particle density, the ionization rate in metastable-metastable collisions exceeds the direct electron impact ionization rate. With the increase of dust particle density, the great role is played by the electron recombination on the dust particle surface, and direct electron ionization becomes more important. Metastable argon states are produced mainly in the course of excitation by an electron impact from argon ground states including cascading from upper levels. The metastable-metastable collisions, the diffusion of metastables to the wall, and the diffusion of metastables on the dust particles surface at large dust particles densities are the main processes of metastables losses. Finally, the results show that metastable argon atoms strongly influence the ionization balance. The density of metastable argon atoms sufficiently depends on gas discharge and dust particles parameters. Depending on conditions, the addition of dust particles into the discharge can lead to either an increase or decrease of metastable argon atoms density. As it is a multi-parametric problem, it is necessary to carefully consider and specify all the rates and coefficients more precisely.

Reference

[1] H.T. Do, V. Sushkov and R. Hippler, 2009 *New Journal of Physics* **11** 033020
[2] S. Mitic, M.Y. Pustylnik, G.E. Morfill, 2009 *New Journal of Physics* **11** 083020
[3] I. Stefanovic, N. Sadeghi, J. Winter, 2009 *International Symposium on Plasma Chemistry 19*
[4] G.I. Sukhinin, A.V. Fedoseev, 2010 *Physical Review E* **81** 016402