Mathematical modeling of THE STREAM OF rarefied RADIO-frequency plasma

V.S. Zheltukhin, \*A.Yu Shemakhin

Kazan National Research Technological University, Kazan, Russia, vzheltukhin@gmail.com
\*Kazan Federal University, Kazan, Russia, e-mail: shemakhin@gmail.com

Plasma of radio-frequency (RF) discharges at low pressure (p = 13.3 - 133 Pa) with the gas flow is effectively used for modifying surfaces of of organic and inorganic materials [1]. The plasma has the following properties: ionization degree is in range 10-4 -10-7, electron density is in range 1015 – 1019 m-3, electron temperature is in range 1 - 4 eV, temperature of the atoms and ions in a plasma jet is in range (3.2 - 10) •102 K.

The RF plasma flow at low pressure is carried out in the transitional regime, for which there is no well-established models such as the Navier-Stokes equations.

The analysis and evaluation of the characteristic scale of elementary processes in plasma is showed that the flow of RF plasma at low pressure has specific features, namely: The Knudsen number Kn for charged gas 5 ·10-4 < Kn < 5 ·10-3, for the neutral gas 8·10-3 < Kn < 7·10-2. This means that for neutral component flow is in a transitional regime between continuum flow and free-molecular flow, while for the charged component can be considered as occurring in the regime of continuous medium.

A mathematical model consists of Boltzman equation for neutral component, continuity and energy conservation equation for electron gas, added by initial and boundary conditions.

The program code for calculating of RF plasma flow at low pressure is developed by using libraries of OpenFoam package (DSMC, FVM). The calculation was performed for the model of the vacuum chambers having the radius in range of R = 0.1 - 0.3 m, the heght in range of L = 0.3 – 0.5 m, and radius of inlet hole in range of r = 0.012 – 0.024 m. Cylindrical specimen has a radius in range of Rb = 0.01 – 0.05 m, a height in range of Lb = 0.02 – 0.05 m and is located in the center of the stream at a distance Ltb = 0.03 - 0.3 m from the inlet. The specimen position is perpendicular to the sample stream.

Through the inlet of the vacuum chamber is flowing stream of the plasma working gas (argon) with the inlet pressure in the range of Pinlet = 35 - 155 Pa, the temperature Tinlet = 400 - 600 K, the flow velocity Vinlet = 700 - 1000 m/s and the electron temperature Te = 1 - 4 eV. The gas consumption is G ∽ 0.12 - 0.24 g/s. The degree of ionization in the chamber δn = 10-4 - 10-7, the initial chamber pressure P0 = 3.5 - 15.5 Pa.

The calculations of unperturbed flow of low pressure RF plasma as well as a flow with specimen circumfluence are presented. The distributions of velocity, pressure, temperature in carrier gas and the distribution of electron density and electron temperature are presented. Calculations showed that the settling time to steady state flow under these conditions amounted to about 10-2 s.

The reported work supported by RFBR, research projects № 14-01-00728а and № 14-01-00755а.

References

1. Abdullin I.Sh., Zheltukhin V.S., Sagbiev I.R., Shaekhov M.F. Modification of nano-layers in radio-frequency plasma in low pressure // Kazan, 2007.- 356 p.