Topic number: 1

Effect of gas discharge conditions on argon surface-wave-sustained plasma kinetics

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A self-consistent numerical model of surface-wave sustained argon plasma column is applied to investigate the elementary processes in the discharge and levels population dynamics at gas pressure in the range 0.2 – 5 Torr and plasma radii 0.15, 0.25 and 0.45 cm. The model describes both the gas discharge kinetics and the wave propagation along the axially inhomogeneous plasma. It is based on steady-state Boltzmann equation coupled with collisional-radiative model for argon discharge solved together with Maxwell's equations.

Surface-wave-sustained discharges (SWDs) offer an efficient way of creating pure (electrodeless) plasmas in a wide range of operating conditions. The plasma properties strongly depend on geometric factors and the discharge conditions which allows easy control and optimisation of plasma parameters for various technological applications.

The plasma is sustained by a travelling electromagnetic wave excited by wave launcher [1] situated at one end of a dielectric tube. The wave propagates along the plasma–dielectric interface and heats the electrons. By absorbing the wave energy the electrons are able to create and sustain plasma by collisions. The wave power decreases along the plasma column, therefore the plasma density decreases, too (see Fig. 1), and the plasma becomes axially inhomogeneous. All plasma characteristics change along the column and it is necessary to obtain their axial distribution. The plasma length varies with the wave power supplied by the launcher and it is usually much larger than the size of wave exciter. The plasma is non-equilibrium in the whole range from low to atmospheric pressure: the electron energy distribution function (EEDF) is non-Maxwellian – and changes along the plasma column – (Fig. 2). The neutral gas temperature T_g (~ 300–4000 K) is lower than the electron temperature T_e (~ 1–2 eV; $T_e = 2/3 <u>$, where $<u>$ is the mean electron energy calculated from the EEDF).

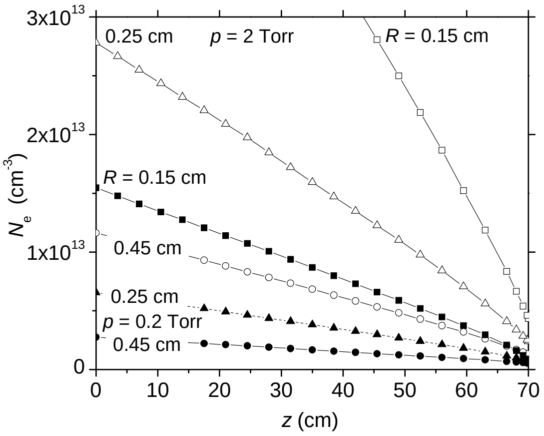

Fig. 1: Plasma density axial profiles at gas pressure 0.2 Torr and 2 Torr and three plasma radii

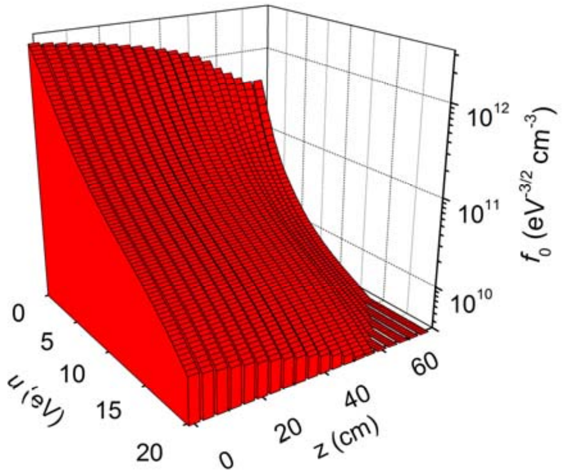

Fig. 2: EEDF at R = 0.15 cm and p = 0.2 Torr

The plasma is sustained by the electromagnetic wave as well as is a part of the waveguide structire for wave propagation. This makes modelling a rather complex problem which requires a self-consistent description of both the wave propagation and the plasma properties. We have studied SWDs using a 1D self-consistent model which couples plasma kinetics and electrodynamics of wave propagation [2, 3]. It is based on simultaneous solution of the complete set of the wave and plasma equations: the Maxwell's equations, the electron Boltzmann equation, a set of particle balance equations for electrons and heavy particles, the wave and electrons energy balance equations, as well as the gas thermal balance equation. The model allows to obtain the axial distribution of all wave and plasma characteristics: the electron density, wave power, maintaining electric field, gas temperature, mean electron energy, mean power for electron–ion pair creating in the discharge, electron–neutral collision frequency for momentum transfer [4], atomic and molecular ions densities, population of all excited states and the partial contribution of elementary processes in the particle and energy balances.

The model is applied to argon plasma columns of three different radii R = 0.15, 0.25, 0.45 cm at gas pressures p = 0.2, 0.5, 1, 2, 5 Torr sustained by surface wave of frequency f = 2.45 GHz. One can see from Fig. 1 that with pressure increasing the plasma density increases while it decreases with the plasma radius increasing. So in the cases under investigation presented in Fig. 1 the highest plasma density is obtained in tube with radius of 0.15 cm at pressure 2 Torr. The axial distributions of excited atoms (four 4s levels – two metastable $^3P_2$ and $^3P_0$ and two resonant $^3P_1$ and $^1P_1$ and the 4p block of levels) are presented in Fig. 3 (a) at radius 0.15 cm and (b) at radius 0.45 cm and gas pressure 0.2 Torr and 2 Torr. With gas pressure increasing the population of all excited atoms decreases but not monotonous – the axial profiles of 4s levels pass through a maximum and decrease at the column end at low pressure while at higher pressure their population is increasing up to the column end. At smaler tube radius the excited atoms population is higher (Fig. 3a) than in the wider tube (Fig. 3b). This behaviour is due to the strong dependence of the EEDF and elementary processes rates on the gas pressure and tube radius [5, 6].

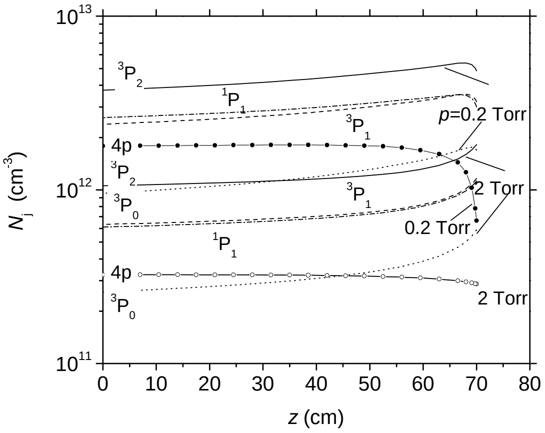

Fig. 3a: Axial distributions of excited atoms population at R = 0.15 cm

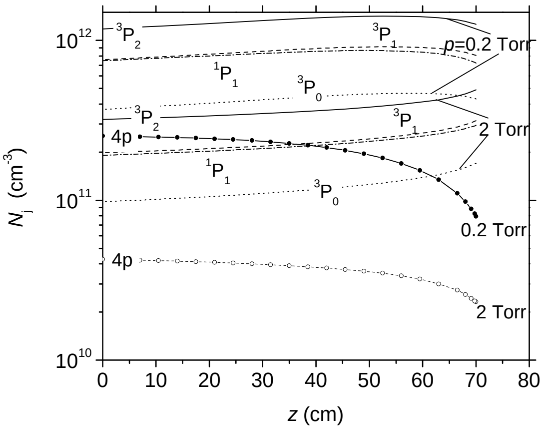

Fig. 3b: Axial distributions of excited atoms population at R = 0.45 cm

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