EFFECT OF THE ARGON METASTABLE QUENCHING BY IONIZATION REACTIONS IN AN RF ARGON DISCHARGE

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ABSTRACT

A planar one-dimensional particle-in-cell simulation with Monte Carlo Collisions (PIC/MCC) package has been used to study 13.56 MHz argon discharge including metastables species. Reactions such as metastable creation, ionization from the metastable state, metastable quenching to resonant level and collisions between two metastables were taken into account. The effect of pressure and applied voltage on the metastable density was examined. At high pressure and high voltage the metastable profile is slightly peaked at the sheath edges. At low pressure and low voltage the metastable profile are rather flat and the plasma density profile has a peak in the center of the discharge. The shape of the profile is determined by mean free path for electrons and metastables in the discharge. For high voltage and high-pressure cases an essential part of the ionization comes from multiple step ionization and metastable-metastable collisions.

INTRODUCTION

Discharge with inactive gases such as argon has been widely studied since argon can be used in mixtures with others reactive gases. This kind of mixture have wide application in materials processing plasmas [1,2]. The metastable species has been considered since once formed, the metastable densities are often significant compared to those ground-state atoms, due to their long lifetimes [3]. Furthermore, the cross sections for interactions with the metastable states are comparable or higher than to that ones. This work consideres reactions between two metastable argon atoms and ionization from metastable state. Metastable particles are created by electron collisions and diffuse themselves through the discharge interacting with the neutral species. They can be destroyed by further collisions with electrons or other metastables or by hitting to the walls.

In the present work, the planar one-dimensional particle in cell simulations with Monte Carlo Collision package [4] is used to study a 13.56 MHz rf argon discharge including metastable species. The effect of pressure and applied voltage is also verified.

MODEL

In the simulation it is assumed that the ground state argon gas density remains constant and uniform in space, and so the neutral particles are not represented as particles. In this model, the metastable excited atoms are followed as particles, allowing them to make collisions. The algorithm for determining collisions between charged and neutral species uses the method described by Birdsall [4] and Vahedi and Surendra [5]. The algorithm was modified in order to include the reactions (3), (5) and (6) [6]. The reactions used in the argon MCC model are:

(1) e + Ar -> e + Ar elastic scattering

(2) e + Ar -> e + Ar* excitation, E=11.83eV

(3) e + Ar -> e + Arm metastable excitation, E=11.55eV

(4) e + Ar -> 2e + Ar+ ionization, E=15.76 eV

(5) e + Arm -> 2e + Ar+ multistep ionization, E=4.21eV

(6) Arm + Arm -> Ar+ + Ar + e metastable pooling

(7) Ar+ + Ar -> Ar + Ar+ charge exchange

(8) Ar+ + Ar -> Ar+ + Ar elastic scattering

The reaction including collisions between two metastables has a large cross section [6] and the new electron created carry out a energy of 7.34 eV. So, this process can be important to maintain high electrons energy in glow discharges.

RESULTS AND DISCUSSION

The simulation modeled an rf capacitive discharge with external circuit elements R=L=0 and C=1 F (i.e., the external matching network is a short circuit). An electrode spacing of L = 0.05 m and an electrode area of 0.002 m^2 is used. The initial conditions for electron, ion and metastable densities were $n_e = n_i = 10^{16} m^{-3}$ and

$n_m = 10^{14}m^{-3}$. The simulations were run for until the particle densities and energies remained constant, averaged over the rf cycle, at which time the plasma was presumed to have reached equilibrium. In order to verify the pressure and voltage effects were considered two cases: 1 - low pressure/voltage, p= 50 mTorr and V= 50 V and 2 - high pressure/voltage, p= 1 Torr and V= 500 V.

Figure 1 shows the density profiles for cases 1 and 2. For case 1 the plasma density profile has the form of a typical diffusion profile, with a peak at the center.

For the case 2, the densities have a peak near the plasma sheath interface. This happens due to enhance metastable production in this region and because the electron mean free path is small at this pressure. So, electrons with high energy are produced at this region.

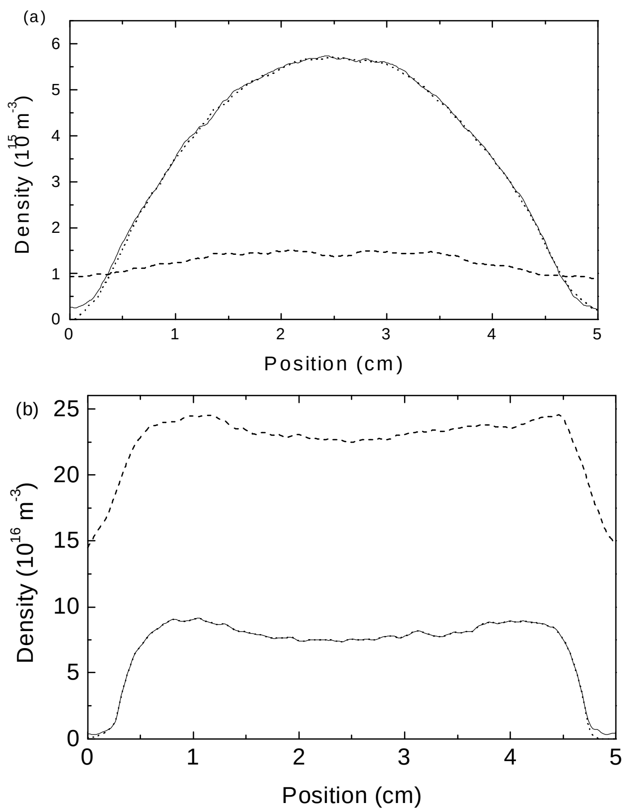

Figure 1: Particle densities for cases 1(a) and 2(b): ions (solid line), electrons (dotted line) and metastables (dashed line).

Figure 2 shows the collision rates for ionization from the ground state, multistep ionization from the metastable state, and metastable-metastable collisions for cases 1 and 2.

For case 1 almost all of the ionization comes from the direct ionization from the ground state, with less than 1% due to other processes. From Fig. 1(a) one can seen that metastable density is too low to allow significant contributions to ionization rate. However, for the case 2, ground state ionization, multistep ionization and metastable collisions contribute with 64%, 11% and 25% of the total ionization, respectively. Note that for this case, ground state ionization is strongly peaked at the sheath edges since it is a function of the higher electron density in this region. Multistep ionization is not peaked since the lower energy bulk electrons carry it out. Metastable-metastable ionization is slightly peaked at the sheath edges (although it is difficult to see in this graph) in accordance with the peak in the metastable density in this region.

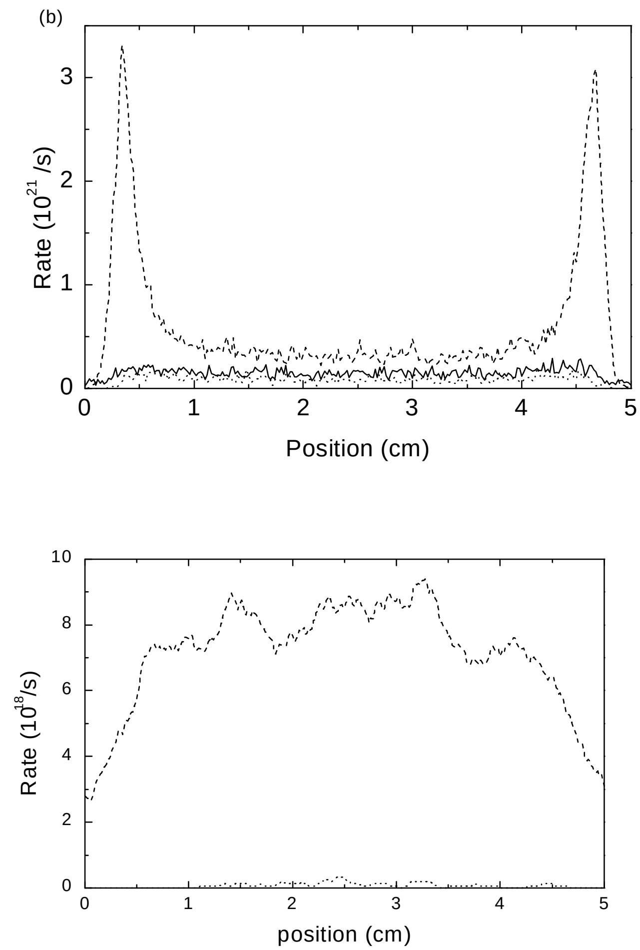

Figure 2: Ionization rate profiles for cases 1 (a) and 2 (b), plotting ionization from the ground state (dashed line), multistep ionization rate (dotted line) and metastable pooling (solid line).

CONCLUSION

A planar one-dimensional particle-in-cell simulation with MCC package has been used to study the effect of metastable atoms in an rf argon discharge. It has been found that multiple step ionization and ionization from collisions between two metastables are relevant for high pressure/voltage case which contribute with 36 \% of the total ionization.

For low pressure case the plasma density has the form of a diffusion profile, with a peak in the center of the discharge. On the other hand for high pressure the profiles have a peak near the sheaths due to enhance metastable production in this region and because the electron mean free path is small at this pressure.

ACKNOWLEGMENTS

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