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Two-dimensional Simulation of RF CF_4 Discharge Using the Particle-in-Cell/Monte Carlo Method

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Two-dimensional structure of rf CF_4 plasma is investigated using the Particle-in-Cell/Monte Carlo method. The discharge structure is characterized by both an asymmetric electric field in the axial direction due to the self-bias at the powered electrode and an enhanced electric field around the edge of the powered electrode. We found, for example, that a double-layer appears in the radial component of the electric field near the edge of the sheath along the cylindrical reactor wall.

1. Introduction

Fluorocarbon gases are widely used in plasma-assisted processes, especially selective etching of SiO_2 on Si.

In the previous papers[1-3], we were successful in self-consistent one-dimensional (1-D) simulation of rf CF_4 plasma between parallel electrodes using the Particle-in-Cell/Monte Carlo (PIC/MC) technique[4]. The simulation revealed the detailed discharge structure and its dependence on secondary electron emission by ion impact and on electrode spacing. It was also found that reactive collisions between positive ions and CF_4 molecules are remarkable in the sheath region.

In this paper our 1-D PIC/MC code is extended to axisymmetric discharge in order to clarify two-dimensional (2-D) structures of rf CF_4 plasma such as the potential distribution, electric field, density and temperature distributions of charged species, and reaction rates. Furthermore, we investigate the flux, energy distribution, and angular distribution of charged species coming onto a powered electrode.

2. Outline of Numerical Simulation

The region simulated is the inside of a cylindrical reactor with radius R_c over the powered electrode($z = 0$) with radius $R = R_d$ as shown in Fig. 1. The upper wall($z = D$) and side wall($r = R_c$) of the reactor are grounded. The rf voltage $V = V_a \sin 2\pi ft$ is applied to the electric circuit from an rf generator, where f is the frequency. On the powered electrode the voltage

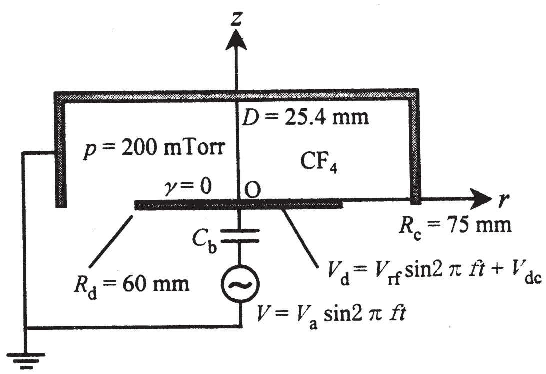

Fig. 1 Plasma reactor model.

$V_d = V_{rf} \sin 2\pi ft + V_{dc}$ appears. In this paper V_a and the blocking capacitance C_b are treated as adjustable parameters while V_{rf} is fixed. A self-bias V_{dc} at the powered electrode is determined by balancing fluxes of positive and negative charges coming to the powered electrode so as to make the dc component of the current null[5].

The charged species considered are electron, five positive ions(CF_3^+, CF_2^+, CF^+, C^+, F^+), and two negative ions(F^-, CF_3^-). The collisions taken into account are the electron-CF_4 collision[6], ion-CF_4 collision[2], positive-negative ion recombination[7], and electron-CF_3^+ recombination[8]. The motion and collision of charged particles are simulated self-consistently using the PIC/MC method.

The potential distribution is obtained from a space charge distribution by solving the Poisson

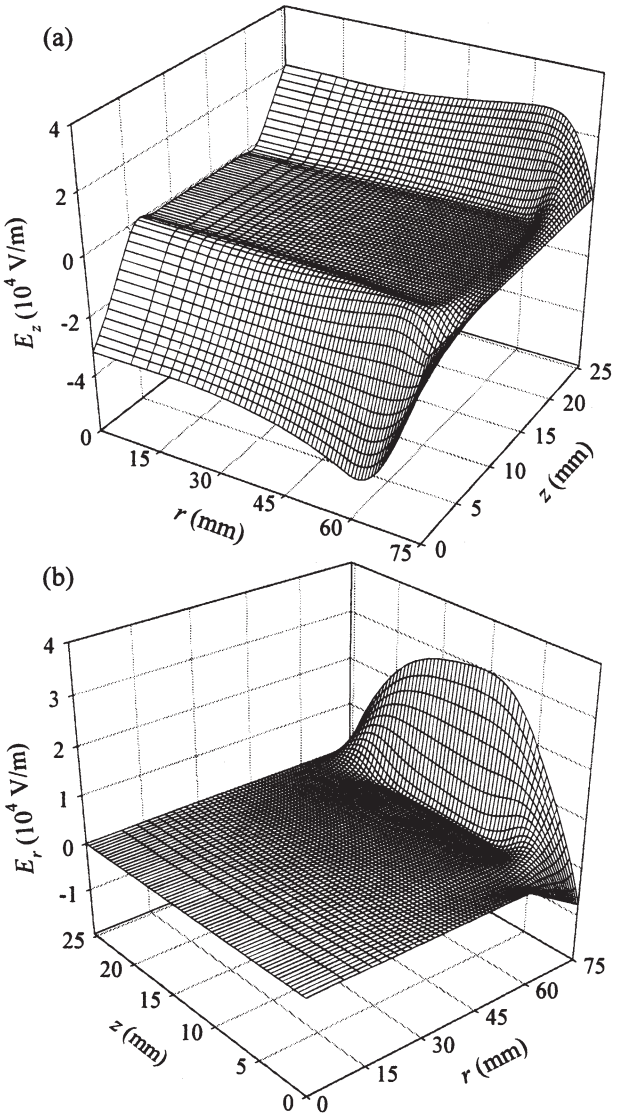

Fig. 2 Electric field at $2\pi ft = \pi$: (a)axial component, (b)radial component.

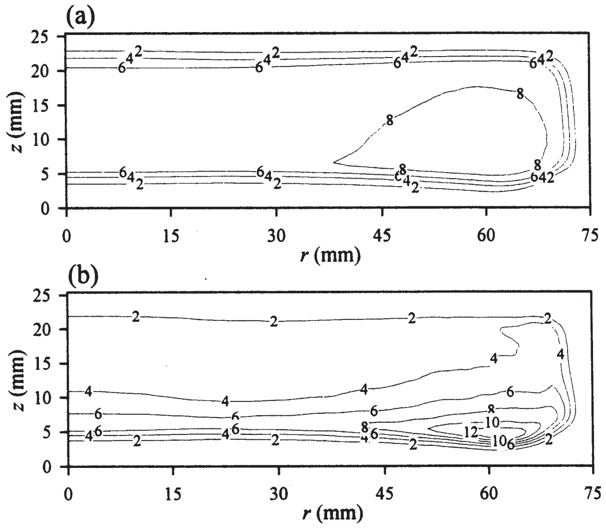

Fig. 3 Spatial distributions: (a)electron density ($\times 10^{14}$ m^{-3}), (b)ionization rate ($\times 10^{20}$ m^{-3} s^{-1}).

equation at each time step. As a fast solver of the equation, we employ the ADI method accelerated by the multi-grid method with the FAS algorithm. Then, the electric field is obtained from the potential distribution.

3. Results and Discussion

The simulation is performed for D=25.4 mm, R_c=75 mm, R_d=60 mm, V_{rf}=200 V, f=13.56 MHz, gas pressure p=200 mTorr, and secondary electron emission coefficient γ=0.

Figures 2(a) and (b) show the z-component E_z and r-component E_r of the electric field at the phase of $2\pi ft = \pi$. It is found that a double-layer appears in E_r near the sheath edge along the cylindrical reactor wall. Of course, the double-layer in E_z can be seen as observed in 1-D simulations[1-3]. The asymmetry of the potential distribution in z-direction due to the self-bias at the powered electrode results in E_z being strengthened in the sheath over the powered electrode. Additionally, both E_z and E_r are enhanced between the electrode edge and the reactor wall.

Figures 3(a) and (b) represent the time-averaged spatial distributions of electron density and the ionization rate, respectively. These distributions reflect the electric field mentioned above and have maxima around the edge of the powered electrode.

Other results will be presented at the conference.

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