Effect of Substrate Bias on Production and Transport of Etchant Ions in a Magnetic Neutral Loop Discharge Plasma [1]

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Abstract

Production and transport of etchant ions in an rf (13.56 MHz) magnetic neutral loop discharge plasma in the presence and the absence of an ac (1.695 MHz) substrate bias were simulated using a Monte Carlo method. Under the bias, electrons accelerated near the neutral loop were attracted to the substrate and produced more etchant ions near the substrate than in the absence of the bias. Effect of bias leading to enhancement of the ion inflow to the substrate was discussed.

Etchant species in neutral loop (NL) discharge (NLD) plasma, a type of inductively coupled magnetized plasma [1, 2]. are produced mainly around the NL of zero magnetic field and the separatrices of the quadrupole magnetic field applied to the NLD plasmas [3, 4]. The transport of the etchant species is a key feature in control of the NLD plasma via magnetic field for uniform large-area processing [4, 5]. This paper reports an effect of ac substrate bias preferable for enhancement of etchant ion inflow to the substrate at the bottom of the chamber. Production of CF_3^+ in a CF_4 NLD plasma and their inflow to the substrate are depicted.

The model NLD chamber was a cylinder with a 40-cm height and a 20-cm inner radius surrounded by three coaxial dc coils and a one-turn rf antenna (13.56 MHz, 25 A amplitude). A quadrupole magnetic field induced by the currents of the top, middle, and bottom coils (60-turn), +95.6, −115.5, and +95.6 A, respectively, had the NL at $r = 11$ cm and $z = 0$, where $r = \sqrt{x^2 + y^2}$. Electrons obtained energy near the NL and thus the NLD plasma became ring-shaped.

The simulation was performed in two steps. In step 1, 5×10^4 electrons were traced using a Monte Carlo method to obtain time-averaged spatial distribution $P(r, z)$ of the ionization collisions producing CF_3^+. The CF_4 pressure was set at 5 mTorr. The electron collision cross sections [6] used in the simulation included dissociative processes to produce CF_3^+, CF_2^+, CF^+, F^+, F^-, CF_3^{2+}, CF_2^{2+}, CF_3, CF_2, CF, and F. The electrons were released from the NL with a weight of 10^5 and their trajectories in real space (x, y, z) under electric and magnetic fields were calculated using a Runge-Kutta method with a time step $\Delta t = 37$ ps. The magnetic field had B_r and B_z components ($B_\theta = 0$), and the electric field had E_θ by the rf antenna and E_r and E_z due to the bias and space charge.

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The plasma density was about 10^7–10^8 cm^{-3} around the NL. The electron reflectivity at the chamber wall was assumed to be 60%. The charge on the wall was also taken into account in the calculation of the space charge field. The ac bias (100-V amplitude, 1.695 MHz, sinusoidal) was applied to the substrate. The positions of CF_3^+ production were sampled and mapped to the r-z plane assuming azimuthal homogeneity in θ, where $x = r\cos\theta$ and $y = r\sin\theta$.

In step 2, flight of CF_3^+ was traced to obtain the CF_3^+ inflow distribution $I(r)$ at the substrate in the same space charge fields as in step 1. The number of CF_3^+ was 2.5×10^5 commonly in the absence and the presence of the substrate bias. The initial positions of CF_3^+ were chosen at random from $P(r, z)$, and they were traced for 2×10^4 rf periods or until they reached the substrate, sidewall, or chamber ceiling. Only elastic collision with CF_4 was considered as the in flight process of CF_3^+ for simplicity.

Fig. 1 shows $P(r, z)$ normalized in the r-z plane (the region of $P > 20$ m^{-2} is shown) and $I(r)$. $P(r, z)$ expanded toward the substrate along the downward separatrix under the bias. The bias attracted not only CF_3^+ during its negative phase, but also energetic electrons during the positive phase. The CF_3^+ production increased, and this was in part due to electron heating by the bias. Repulsion of electrons during the negative phase did not appear significantly because of the geometrical asymmetry between the biased substrate and chamber wall. Because the flight of ions was governed partly by the space charge field, the CF_3^+ production near the substrate contributed to the increase of the CF_3^+ inflow to the substrate. In addition, $I(r)$ was also expanded from the foot of separatrix to a wider range on the substrate. Even in the presence of in-flight loss of CF_3^+, for example by recombination and charge exchange not considered in the simulation, the CF_3^+ production near the substrate under bias would still be advantageous because the in-flight loss would be more significant for longer flight from the CF_3^+ source around the NL to the substrate in the absence of the bias.

A bias applied to the substrate in a CF_4 NLD plasma attracted energetic electrons from the NL. As a result, the region of CF_3^+ etchant production approached the substrate. This tendency was considered to be preferable for the increase of the CF_3^+ inflow to the substrate.

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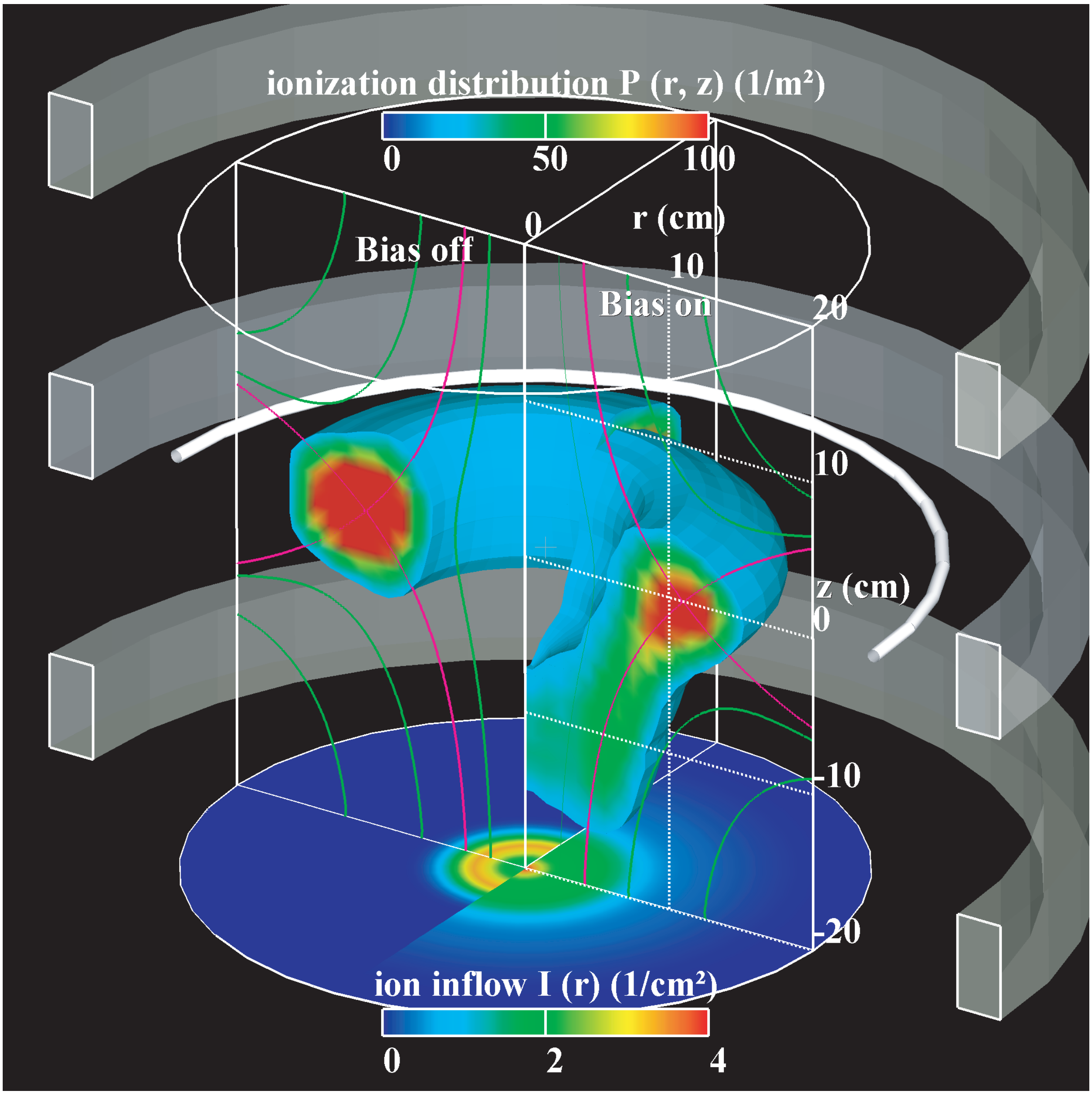

Figure 1: Spatial distribution of dissociative ionization collisions, $P(r, z)$, producing CF_3^+ and ion inflow distribution, $I(r)$, on substrate in the absence (left) and the presence (right) of substrate bias of 100 V. The green curves represent the magnetic field lines, the pink ones are separatrices of the quadrupole magnetic field, and the NL is at the cross point of the separatrices. The bias attracted the ion production region from the NL toward the substrate along the downward separatrix. The ion inflow to the substrate spread and increased under the bias.

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