EFFECT OF VOLTAGE BIASED PLATE ON MAGNETIZED PLASMA DISTRIBUTION AND FLOW

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ABSTRACT

Applying a voltage on the rectangular metal plate in RF produced plasma, two-dimensional profiles of ion saturation current, transverse plasma flow and floating potential were measured, changing a filling pressure, magnetic field and applied voltage. It was found that near the plate surface, plasma density was lower and the spatial inhomogeneity of shifted profile was enhanced, which was consistent with the Mach probe measurement and $\boldsymbol{E} \times \boldsymbol{B}$ direction ($\boldsymbol{E}$: electrostatic field, $\boldsymbol{B}$: magnetic field).

I. INTRODUCTION

In mirror machines, control of the electric field in the end sections by the voltage biasing to the plates is very important for the profile control and the plasma stability[1-5] such as flute and drift modes, and enhanced confinement was found by this biasing,[6] similar to the tokamak experiment inducing the H mode by the $\boldsymbol{E} \times \boldsymbol{B}$ velocity shear.[7] On the other hand, recent high power neutral beam injection (NBI) system utilizes negative hydrogen/deuterium ions for their good neutralization efficiency.[8] However, the production of negative ions is less efficient than that of positive ions, which makes the ion source very large. One of the problems of the large plasma source is spatial inhomogeneity of the plasma production that is supposed to be partly due to the magnetic field and electric field induced by the plasma-potential variation. Nevertheless, the effect and role of the electric field on the plasma performance have not been investigated in detail from such a basic viewpoint of the ion-source development.

In this paper, we studied how the plasma density, bulk plasma flow and floating potential in two-dimensional space changed in a magnetized plasma by applying a voltage on the metal plate. Furthermore, the effect of the magnetic field and filling pressure on the plasma performance was investigated.

II. EXPERIMENTAL SETUP

The experimental system[5, 9] is shown in Fig. 1. Argon plasma was produced by a spiral antenna at a pressure of P = 0.3 ~ 30 mTorr with uniform magnetic field (B = 100 ~ 1000 G). The RF power and frequency of 100 W and 7 MHz, respectively, were applied to a linear device, 45 cm in diameter and 170 cm in axial length. A voltage biased (V_b = -50 ~ 50 V) metal plate was located at z = 30 cm from the quartz window, and this plate was made of stainless steel (20 cm × 20 cm with 0.1 cm thickness) with or without an insulator plate on the back side (the same size as the metal plate).

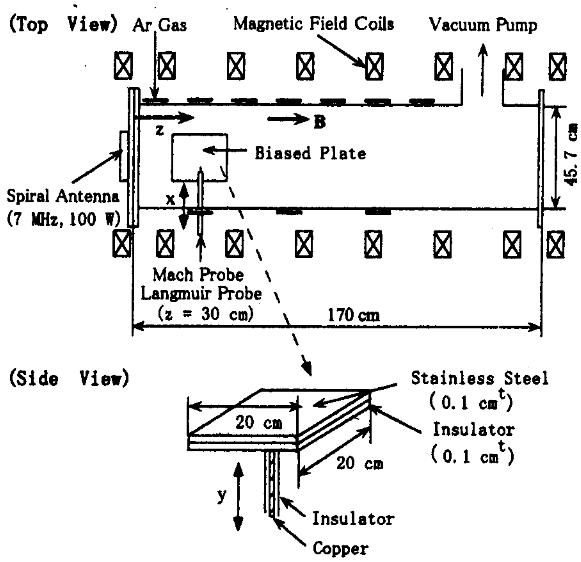

Fig. 1 Schematic view of experimental setup.

Plasma parameters were measured by the Langmuir probes (0.1cm in diameter and 0.3cm in length), including the Mach probe (two metal plates with a size of 0.2 cm × 0.2 cm facing opposite sides each other) for the plasma flow measurements. Here, the plate was moved vertically (measurement was performed at y = 1, 1.5, 2.5, 5.5, 10.5 cm) and the probes were scanned radially (x direction) with y = 0 cm. Typical central plasma density n_e without biasing was in the range of $(1 \sim 5) \times 10^9$ cm^{-3} with the electron temperature T_e = 3 - 8 eV and estimated ion temperature 1 eV (ion Larmor radius ρ_i was less than 1 cm for the magnetic field B = 500 G).

III. EXPERIMENTAL RESULTS

The dependences of the plasma density, bulk plasma flow (x direction: parallel to a plate surface and perpendicular to $\boldsymbol{B}$) and floating potential was studied, changing V_b, P and B.

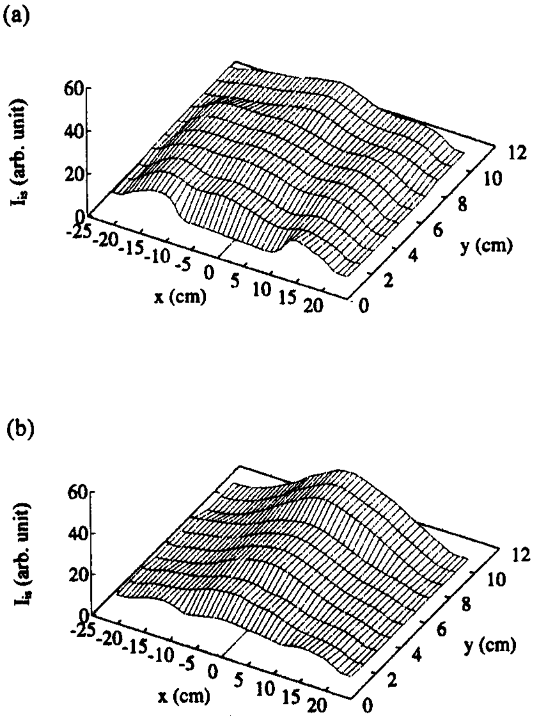

Fig. 2 Radial profiles of I_{is} with (a) V_b = -50 V and (b) 50 V (P =10 mTorr and B = 100 G with the insulator).

First, we present the comparison of the plasma distributions between the negatively and positively voltage biasing to a metal plate. Figure 2 shows two-dimensional profiles of ion saturation current I_{is} (P = 10 mTorr, B = 100 G), applying (a) V_b = -50 V and (b) 50 V to the plate with an insulator plate on the back side (smoothing was done from the data taken at five discrete y values with continuous x position mentioned above). Here, n_e corresponded to $\sim 8 \times 10^8$ cm^{-3} for I_{is} = 10 taking T_e=5 eV.

For both cases, the plasma density n_e, which is proportional to I_{is}, near the plate was lower than that far from the plate, but the profiles obtained were different between negative and positive biasing cases. The reason that the shifted profile was not clear compared with the high magnetic field case mentioned below is considered as a non-neglecting value of ρ_i / L (L : typical plasma size). Generally, near the plate, the average I_{is} value over the radius (-10 cm < x < 10 cm) was higher for the positive biasing than that for the negative one, and the biased current on the order of 10 mA was lager with the higher P, the higher V_b, the decrease in y and the lower B conditions. Here, the arcing was not observed in our biased conditions.

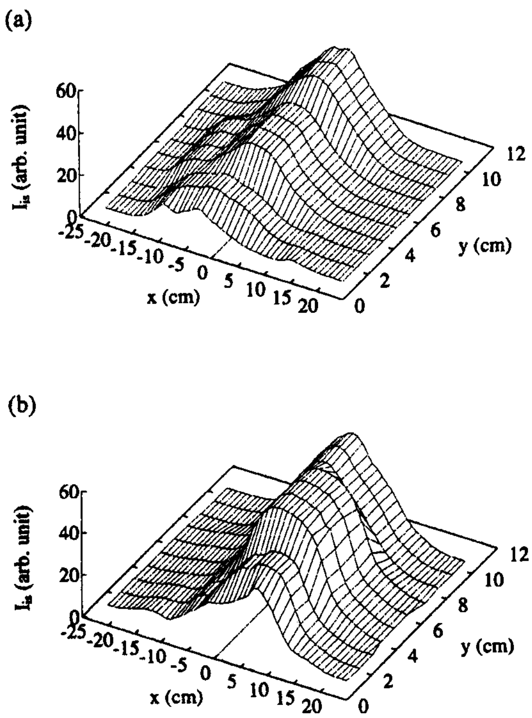

Fig. 3 Radial profiles of I_{is} with (a) V_b = -50 V and (b) 50 V (P =10 mTorr and B = 500 G with the insulator).

In contrast to the above low magnetic field case, this trend was much clearer and a polarity of V_b changed the direction of a shifted distribution (x direction) for the high magnetic field case (P =10 mTorr, B = 500G), as shown in Fig. 3. For the positive (negative) biased case, the plasma density shifted to the positive (negative) x direction. This inhomogeneity of plasma density faded when y was more than several cm. With the higher magnetic field (B = 1000G), this tendency was pronounced (not shown). Here, the typical Debye length was $\sim$ 0.02 cm, and the vertical length (y direction) to affect the plasma was longer than this Debye length by more than two orders of magnitude and was comparable to a magnetic sheath length of C_s / ω_{ci} (C_s : ion sound velocity, ω_{ci}: ion gyration angular frequency).[10]

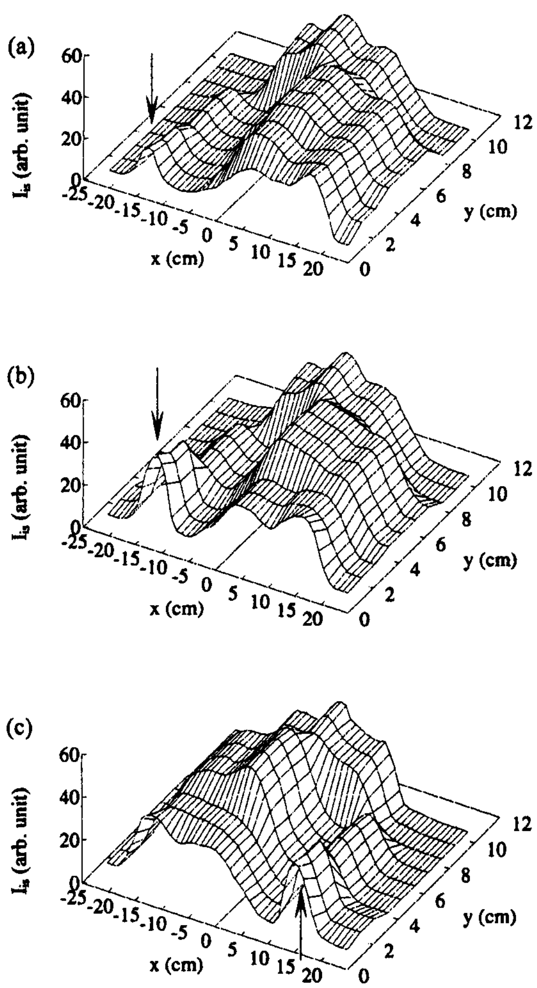

Fig. 4 Radial profiles of I_{is} applying (a) B = 500 G with the insulator, (b) B = 500 G without the insulator and (c) B = -500 G without the insulator (P = 1 mTorr and V_b = 50 V).

The I_{is} profiles under these conditions were measured, in order to see the dependences of the filling pressure, a polarity of V_b and the influence of the insulator plate, as shown Fig. 4. From this, the plasma distribution at low pressure was more distorted than that at higher pressure (see Fig. 3 (b) and Fig. 4 (a)) by voltage biasing. This was much clearer for the lowest pressure case of P = 0.3 mTorr (not shown).

The inhomogeneity also faded as y was larger than several cm. Figure 4 (a) shows that there was a local maximum density region around x = -15 cm near the plate (see an arrow). Comparing Figs. 4 (a) and 4 (b) (with and without the insulator), this hump, which was larger without the insulator, was reflected by the $\boldsymbol{E} \times \boldsymbol{B}$ flow due to the change of the potential distribution at the back side: This may be similar phenomena with the voltage biasing without the magnetic field.[10] Changing a polarity of B, the reversed radial distribution of I_{is} was obtained (see Figs. 4 (b) and 4 (c) for comparison).

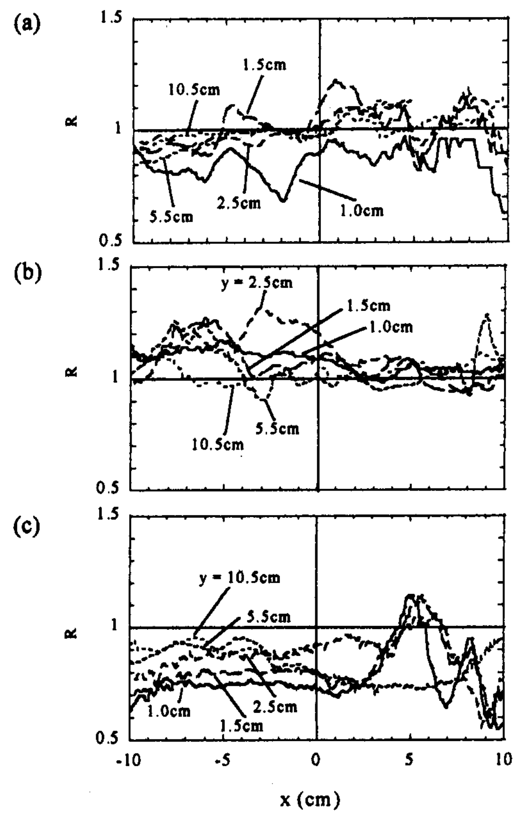

Fig. 5 Radial profiles of plasma flow at (a) P = 10 mTorr, B = 500 G and V_b = -50 V with the insulator, (b) P = 10 mTorr, B = 500G and V_b = 50 V with the insulator, (c) P = 1 mTorr, B = -500 G and V_b = 50 V without the insulator.

Figure 5 shows the ratio R of the ion saturation currents collected from the negative x direction to the positive one, measured by the Mach probe (see also Figs. 3(a), 3(b) and 4(c) for the cases of Figs. 5(a), 5(b) and 5(c), respectively). If the R is larger (smaller) than 1, the plasma flows towards the positive (negative) x direction. Mach number M (flow velocity v is normalized by C_s) can be represented as $M = (1 / K) \ln R$, and $M = 0.32$ for $R = 1.5$ if we use $K \sim 1.26$ for unmagnetized or kinetic models with viscosity.

Applying positive (negative) biased voltage, the plasma flow near the plate was towards the positive (negative) direction. The $|R\text{-}1|$ term, in other words, the absolute flow velocity was larger for the lower P and/or the higher B conditions, and the plasma flow far from the plate was nearly zero. The measured direction was consistent with the $\boldsymbol{E}\times\boldsymbol{B}$ direction and the shifted I_{is} profiles in the x direction. Note that the $\boldsymbol{E}\times\boldsymbol{B}$ drift can be expected under the conditions that ρ_i is well smaller than L (more than a few hundreds of G is necessary in our experiment) and the multiplying factor $f = 1 / [1 + 1 / (\omega_{ci}\ \tau_{in})^2]$ is ~ 1 ($v = f E / B$, τ_{in} : ion-neutral collision time).

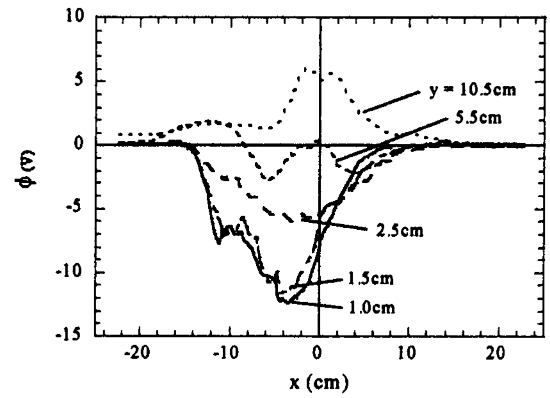

Fig. 6 Radial profiles of floating potential ϕ with P =10 mTorr, B = 500 G and V_b = -50 V in the presence of the insulator.

Although the effect of the biasing was small, this trend of shifted I_{is} profile was found even at the high pressure of 30 mTorr ($\omega_{ci}\ \tau_{in} \sim 0.2$), where the $\boldsymbol{E}\times\boldsymbol{B}$ flow was estimated to be smaller by a factor of $\sim$ 25 ($= 1 / f$) compared with a collisionless case.

In order to check the $\boldsymbol{E}\times\boldsymbol{B}$ drift, we measured the two-dimensional profiles of floating potential ϕ, although this is not plasma potential, as shown in Fig. 6. Near the plate, the potential increased with y and saturated at y was more than several cm.

Rough estimates on the $\boldsymbol{E}\times\boldsymbol{B}$ velocity showed consistencies with the shifted profile and the direction of the plasma flow velocity, considering the collision factor and Mach probe theories mentioned above.

IV. CONCLUSION

Two-dimensional profiles of ion saturation current I_{is}, plasma flow v and floating potential ϕ were measured in magnetized RF produced plasma, in the presence of a voltage biased plate. The clear spatial inhomogeneity was observed under the conditions of the lower P, the higher B, the higher V_b and near the plate. Changing a polarity of B or V_b reversed the radial distribution of I_{is}. Without the insulator on the metal plate, the obtained results were nearly the same as the ones with the insulator, but the I_{is} (hump) was larger near the edge of the plate. These results obtained could be understood by the $\boldsymbol{E}\times\boldsymbol{B}$ drift, based on the estimation of ρ_i / L and $\omega_{ci}\ \tau_{in}$.

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