27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** (2000) 1465 -1468

Characterization of a Large Area ICP Using a Long Range Fast Scanning Probe

Yong-Sup Choi and Kyu-Sun Chung
Department of Nuclear Engineering, Hanyang University, Seoul, Korea
Jun-kyo Bak and Myeun Kwon
Korea Basic Sience Institute, Dae-Jeon, Korea

Spatial variation of plasma parameters were measured in a large Inductive Coupled Plasma(ICP) chamber(diameter 610mm) using a Fast Scanning Probe(FSP), which can scan 100 cm long with speed of 0.8m/sec. Spatial variations of plasma parameters were measured by using single, triple and emissive probes which are implemented at the tip of the FSP. A new modified diffusion model is introduced to analyze the spatial variations of the normalized density, since the variable mobility model cannot explain measured data. In our new model, effects of ion thermal motion and temperature of neutral particle are included.

Ⅰ. INTRODUCTION

With the demand of a lager plasma sources in plasma aided manufacturing industry, Inductive Coupled Plasma (ICP) sources has several advantages to meet the need. To Characterize a larger plasma source with electric probe, smaller and faster device becomes preferable to avoid unnecessary disturbance to the plasma..

A long-range Fast Scanning Probe(FSP) was developed to measure large area plasma such as the plug of "Hanbit", which is a large Tandum mirror device in Korea Basic Science Institute. The FSP was tested in RFTC[1](RF Test Chamber) before attaching at "Hanbit" device. To measure the plasma parameters, triple, single and emissive probes are used and measured plasma density profiles are analyzed using simple diffusion theory. At first time, variable mobility model, which neglect thermal motion of ion in low pressure because drift velocity of ion is much better than thermal velocity, was applied but there were big discrepancy with experimental result. To explain experimental result, effect of thermal motion of ion and temperature of neutral were included in simple diffusion model, Combined Mobility Model, and it explain well the experimental results.

Ⅱ. EXPERIMENTAL SETUP

RF Test Chamber has a double half turn antenna which has a diameter of 380mm with a pair of circular limiters(350mm in diameter). Plasmas are generated by 4MHz RF with power of 100～600W and helium gas was used. The schematic of experimental apparatus is shown in figure 1. Plasma parameters were measured along radial direction using Fast Scanning Probe that is installed 280mm apart from the antenna along axial direction. Technical properties of FSP could be find in previous paper[2] .

Single[3], triple[4], and emissive[5] probes were used in this experiment. Single and triple probes were made using diameter of 1mm molybdenum wire, which has a length of 4.3mm. Triple probe was insulated using 4-hole ceramic tube, which has a diameter of 6 mm. 1% thoriated tungsten of 10mil was used as tip of emissive probe. Although 1mil tungsten is usually used as emissive probe tip, 10 mil tungsten was used in this experiment because 1mil tip would be broken due to the fast motion of FSP. Due to the thick tungsten tip, we worried about the possibility of severe perturbation of plasma, but comparison between measurement result of 1mil tip and 10 mil tip showed nearly same value as like fig 2. In this experiment, strong emission method was applied to get V_f and Vp. When temperature of probe surface is sufficiently high, floating potential of emissive probe become close to plasma potential[5]. To reduce RF-noise, low pass RF-filter was used during all experiment.

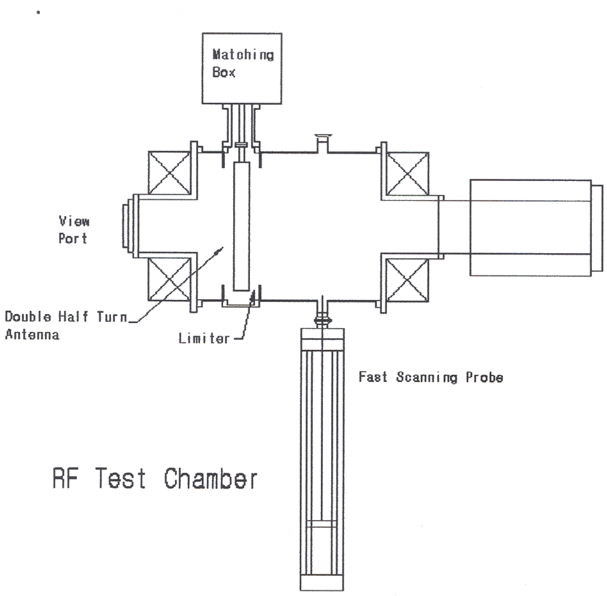

Fig.1 Experimental Setup

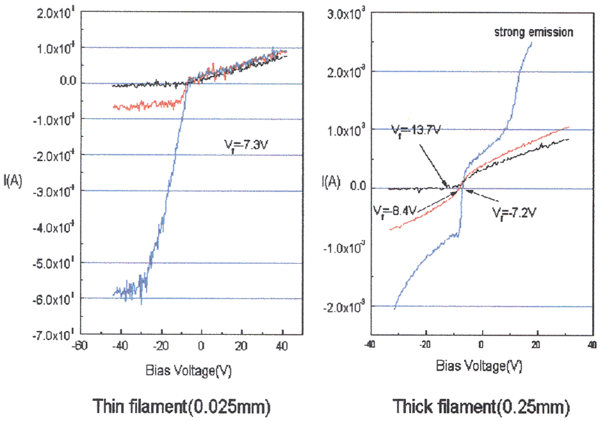

Fig. 2 Comparison of 10mil emissive probe with 1mil emissive probe

III. MEASUREMENT AND ANALYSIS

Figure 3 shows the results measured by a triple probe. Radial variations of electron temperature (T_e) and density(n_e) are directly deduced as Te=3.5eV-4.5eV and $n_e = 5 \times 10^9$ - 3 ××10^{10} cm^{-3} with pressure of 5~23mTorr. With the increase of pressure, density becomes large while the temperature become small. Except near the wall, electron temperature is uniform regardless of the pressure. Plasma(V_p) and floating potential(V_f) measured by an emissive probe are shown in Fig. 4. Electron temperature is also deduced by the following relation:

$$Te=e(V_p-V_f)/(3.34+0.5\ln(\mu)). \quad (1)$$

where, isothermal electron and As=Ap are assumed. (As=sheath area, Ap= probe area)[6]

There is big difference in Te between those measured by EP and TP, while electron temperature measured by EP and TP seem to be similar in the central region. This may be due to the following reasons: i) Neglect the ratio of sheath and probe area (As/Ap) ii) Strong electron emission in low density area. iii) violation of isothermal properties due to atomic processes.

As for the first case, if we add area effect, then the Eq. (1) should be written as

$$Te=e(V_p-V_f)/(3.34+0.5\ln(\mu)+\ln(As/Ap)).$$

Depending upon the sheath thickness(χ_s) ln(As/Ap) can be varied 0.3-1.5 for $n_e=10^{10}$ cm^{-3} (χ_s = 1-10 λ_D), so that Te can have difference by 10-40%. As for the last case, When the strong emitting probe was inserted, emitted electron density may be similar or greater than that of plasma density. Emitted electrons would make relatively dense plasma nearby emissive probe. And due to the density gradient, potential of plasma would increase in near emissive probe tip. So emissive probe would measure higher plasma potential than real value. As probe was moved into the central region, perturbation effect of emissive probe would decrease due to the increase of plasma density. Anyway emissive probe results show higher value than that of triple or single probe through all radial direction. And Figure 5 is the comparison results of single probe measurement with other probes.

From the results, normalized density profile of cylindrical chamber was investigated. At first time variable mobility model[7] was applied to analyze normalized density profile. Although analytical solution for this model was given by Godyak and Maximov[7], their solution is just for parallel plan geometry. That model is redefined here for cylindrical geometry.

Although all experiment was done in low pressure range(5-23mTorr), there are big difference between experimental results and Variable Mobility Model. That can be explained by neglecting of thermal velocity of ion. Drifty velocity of ion is not much faster than thermal velocity as assumed by variable mobility model. To combine the diffusion due to thermal velocity with drift velocity, Ion distribution function was assumed as drift-Maxwellian and average collision frequency of ion with neutrals is calculated. To include thermal velocity effect, ion temperature was not neglected and assumption on electron was used as previous model. i.e. electron thermal velocity is much large than drift velocity. With that assumption Eq. (6) is given as following:

$$\nabla \cdot \Gamma = \nabla \cdot \left(-\frac{kT_e(1+\gamma)}{M\nu_m} \nabla n \right) = \nu_{iz} n \qquad (6)$$

where, ɣ is a ratio of Ti/Te. To solve this equation, collision frequency of ion-neutral must be calculated respect to drift and thermal velocity of ion. Using dimensionless variables ($y=n/n_0$, $x=r/a$) and integration over x, Eq. (6) can be written as following:

$$\frac{dy}{dx} = -\frac{m\nu_m}{k(T_e+T_i)} \frac{1}{x} \int_0^x a^2 \nu_{iz} y x' dx' \qquad (7)$$

From the flux equation, drift velocity is given as Eq. (8)

$$u = -\frac{k(T_e+T_i)}{m\nu_m} \frac{1}{ay} \frac{dy}{dx} = \frac{a\nu_{iz}}{yx} \int_0^x y x' dx' \qquad (8)$$

Figure 6 shows comparison of experimental result with variable mobility and combined diffusion model

Ⅳ. CONCLUSIONS

Normalized density profile of large Inductively Coupled Plasma was analyzed by using a Combined Mobility Model, which includes the effect of thermal ion motion. In the analysis, we come to know that thermal velocity of ion and neutral temperature do important role in determining of spatial density profile. Although Combine Mobility Model cannot fit density profile of surface region, it shows more reasonable results than Variable Mobility Model, which neglect the thermal motion of ion. Discrepancy between the theory and experiment near the wal would be explained by including spatia temperature variation and surface recombination More exact model of density profile determinatioı will be shown in next time.

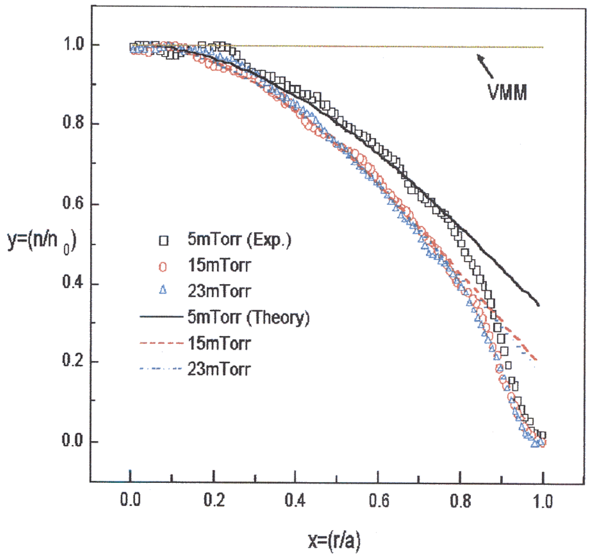

Fig. 6 Comparison of experiment with theory

ACKNOWLEDGMENTS

This work is supported by the Korea Basi Science Institute.

[1] J. G. Yang, *et al.*, Asian-European Plasma International Conference on Plasma Surface Enginnering (1997)
[2] J. G. Bak, S. G. Lee, S. M. Hwang, Y. S. Choi K.-S. Chung, Rev. Sci. Instrum. **71**, 2071 (2000)
[3] F. F. Chen, in *Plasma Diagnostic Techniques* edited by R.H. Huddlestone (Academic Press Inc, 1965)
[4] S.-L. Chen and T. Sekiguchi, J. Appl. Phys. **36** 2363 (1965)
[5] M.A. Makowski and G. A. Emmert Rev. Sci Instrum. **54,** 830 (1983)
[6] N. Herskowitz, in *Plasma Diagnostics*, edited by O. Auciello and D. L. Flamm(Academic Press, New York, 1989)
[7] M.A. Lieberman and A.J. Lichtenberg *Principles of Plasma Discharges and Materials Processing* (John Wiley & Sons, Inc 1994)

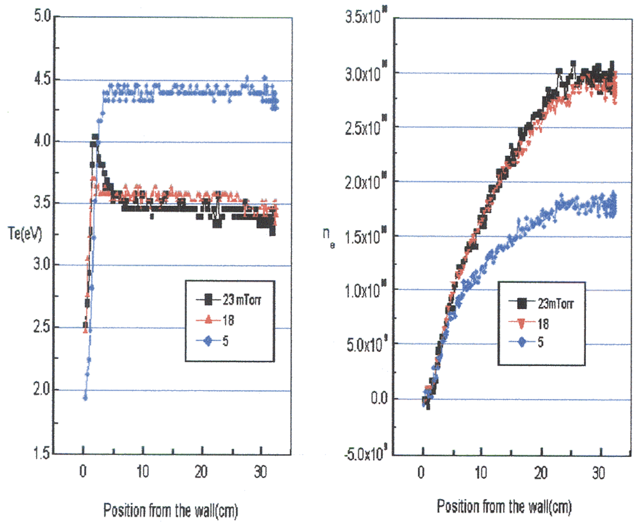

Fig. 3 Measurement results of TP

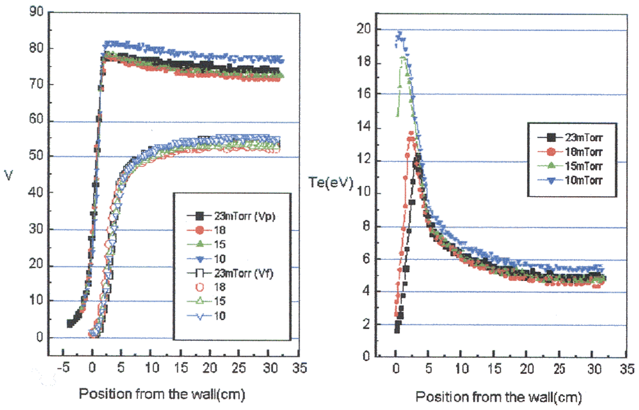

Fig. 4 Measurement results of EP

A. Variable Mobility Model(VMM)

Normalized density profile in cylindrical chamber can be given from continuity equation. Plasma is assumed as steady state and ionization function is assumed as independent of position. The basic assumption of variable mobility model is that when thermal velocity of ion is much less than drift velocity, ion velocity can be given as $u_i = \mu E$. Ion mobility, μ, and electric field, E, are given as following in low pressure[7].

$$\mu_i = \frac{2e\lambda}{\pi M |u_i|}, \quad \overline{E} = -\frac{kT_e}{e}\frac{\nabla n}{n} \quad (2)$$

In cylindrical chamber, these equation can be normalized as equation (3) along radial direction.

$$\frac{1}{x}\frac{d}{dx}\left(x \left(-y\frac{dy}{dx} \right)^{1/2} \right) = \alpha y \quad (3)$$

where, dimensionless variable are given a following:

$$y = n/n_0,\ x = r/a,\ \alpha = \sqrt{\frac{\pi M a^3}{2\lambda_i k T_e}} v_{iz}$$

Equation (3) can be easily solved after integratio over x with boundary condition, y=1 and y'=0 a x=0.

$$-\frac{1}{2}\frac{dy^2}{dx} = \frac{1}{x^2}\left[\int_0^x \alpha x' y dx' \right]^2 \quad (4)$$

Equation (4) can be written as following with th finite different method.

$$y(i+1) = \left[y(i)^2 - 2\frac{\alpha^2 \delta}{x(i)^2} \left\{ \sum_{k=0}^{i} x(k) y(k) \delta \right\}^2 \right]^{1/2}$$

From above relation all y(i) value can b determined if y(0) and y(1) values are given. Th value of y(0) is known and y(1) can be acquire by limit as following.

$$y(1) = \left[y(0)^2 - 2\alpha^2 \delta^3 \right]^{1/2} \quad (5)$$

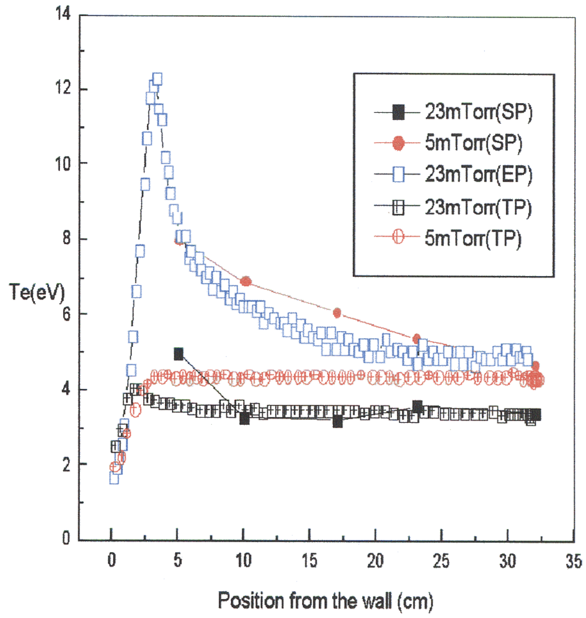

Fig. 5 Comparison of Te with results of TP and EI

B Combined Mobility Model (CMM)