# Effect of Magnetic Field Configuration on the Plasma Parameters of Cylindrical Inductively Coupled Plasma

Jiseong Nam [a], Jimo Lee [b], Geunwoo Go [a], Kyoung-Jae Chung [a*]
[a]*Dept. of Nuclear Engineering, The Seoul National Univ., 1, Gwanak-ro, Gwanak-gu, Seoul 08826, Republic of Korea*
[b]*Mechatronics Research, Samsung Electronics Co., Ltd, 10, Samsung 1-ro 6-gil, Hwaseong-si, Gyeonggi-do 18381, Republic of Korea*
[*]*Corresponding author: jkjlsh1@snu.ac.kr*

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## 1. Introduction

Inductively coupled plasma (ICP) sources are used in semiconductor manufacturing processes because they provide better discharge power efficiency and high plasma density even at low gas pressure [1]. A magnetic field is one of the uprising factors in controlling the ICPs, yet research in this area remains limited. In this paper, we obtained the plasma parameters under the converging, parallel, and diverging magnetic field profiles. 2D scanned parameters will be provided to discuss the effect of the magnetic field in ICP.

## 2. Experimental setup

In this section, an introduction to the cylindrical ICP chamber and magnetic field system will be provided. 2D diagnostics method based on the Langmuir probe will also be discussed.

### *2.1 Cylindrical ICP with magnetic field*

ICP sustains the plasma discharge with a current induced by the inductive coil. Discharge occurs inside the quartz chamber with an inner diameter of 140 mm and a height of 100 mm. We used argon gas for discharging with a pressure of 50 mTorr. 200W of radiofrequency (RF) power is applied to the coil with a frequency of 60 MHz to make a time-varying magnetic field, which induces the inductive current inside the quartz chamber.

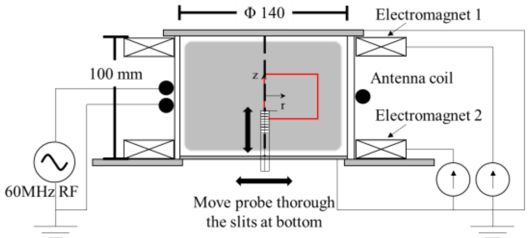


Fig. 1. Schematic of cylindrical ICP chamber with two parallel electromagnets. The red box at the center represents the scanning area.

The magnetic field is generated by a pair of Helmholtz-like coils. The coil has an inner diameter of 156 mm and an outer diameter of 250 mm. The thickness of the coil is 20 mm. The distance between the center of the coil is 80 mm. The number of turns in a coil is 80.

In this paper, we first studied the effect of magnetic fields on plasma depending on the magnetic field strength. Currents of 5 A (400 A·t) and 10 A (800 A·t) are applied both to the coil equally to makes the axially parallel magnetic field (corresponds to the magnetic flux intensity of 38 G and 75 G). The direction of the magnetic field is toward the +z direction. We also investigated the effect of the diverging or converging magnetic fields on plasma. To generate these fields, currents of 5 A and 10 A are applied to each of the coils (magnetic flux intensity changes from 49 G to 63 G). The direction of the magnetic field is toward the +z direction.

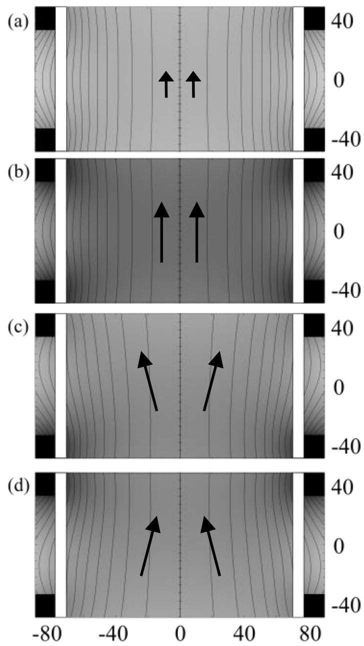


Fig. 2. Magnetic field profile of weak (a) and strong (b), diverging (c) and converging (d) magnetic field.

*2.2 2D Langmuir probe scan*

To diagnose the local plasma parameters, we used Langmuir probe diagnostics. The tip is cylindrical shape tungsten wire with a diameter of 0.3mm and a length of 3.6mm. A compensation circuit is applied to the probe [2,3]. Assuming azimuthal symmetry, we scanned plasma 2 dimensionally to check both the radial and axial effect of the magnetic field. The scanning range is r = 0 mm ~ 50 mm and z = -18 mm ~ 18 mm. A total of 6 by 9 points is obtained for each condition. (See Fig. 1.)

## 3. Result and discussion

*3.1 Effect of magnetic field intensity on plasma*

The measured plasma parameters with different intensities of plasma are shown in Fig. 3.

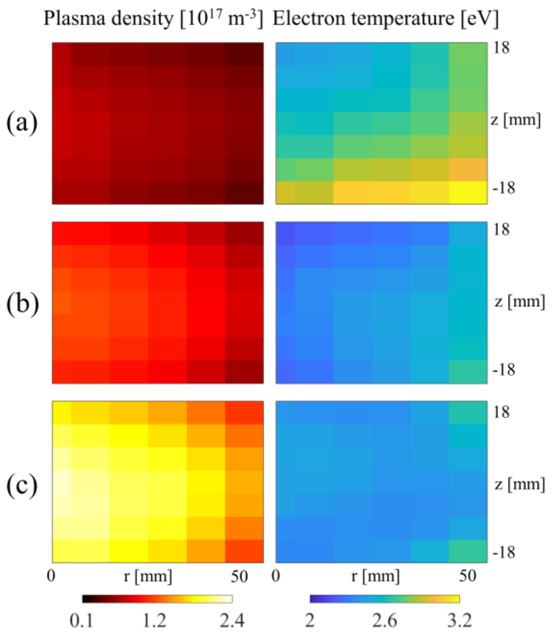


Fig. 3. Experimental results of plasma density (left) and electron temperature (right). No magnetic field is exerted on case (a), 38 G is exerted on case (b), and 75 G is exerted on case (c).

In the plasma density results the density at position r = 0 mm is higher than at position r = 50 mm. As the intensity of the magnetic field increases, an increase in plasma density is observed. This is because the magnetic field traps the electrons with gyro motion which inhibits the electrons escaping from the plasma.

The density distribution of the plasma under the magnetic field is shown in Fig. 4 and Fig. 5. From the density distribution result, the relative density in the radial direction gets higher at the center and lower at the edge. This density distribution can be explained by the electron trapping by the axial magnetic field. Electrons are generated by the ionization at the center of the plasma. Hence, the magnetic field focuses the discharge at the center, making the plasma radial uniformity worse. The axial distribution of the plasma changes as the magnetic field strengthens. When there is no magnetic field, the axial plasma density is almost symmetric to the z = 0 plane. However, when the magnetic field is exerted, the plasma at z < 0 gets denser. The explanation for this phenomenon is related to the power dissipation change by magnetic field changing the electron motion. From the chamber geometry, the change of the electron motion could change the power dissipation by the antenna, and move the discharge center of the gas from the center of the antenna to the axially shifted position.

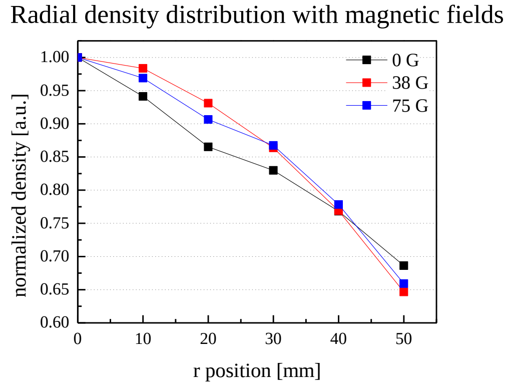


Fig. 4. Radial density distribution of plasma. Density values are normalized by dividing the density value at position r = 0.

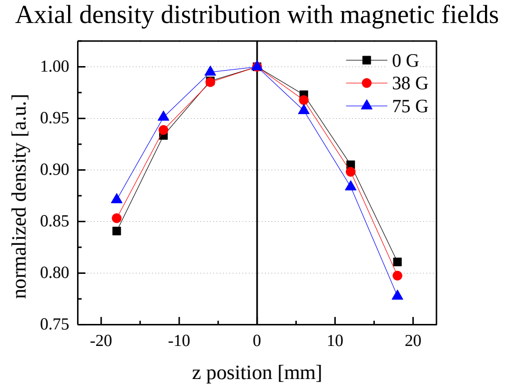


Fig. 5. Axial density distribution of plasma. Density values are normalized by dividing the density value at position z = 0.

*3.2 Diverging or converging magnetic field effect on plasma*

The measured plasma parameters with different intensities of plasma are shown in Fig. 6.

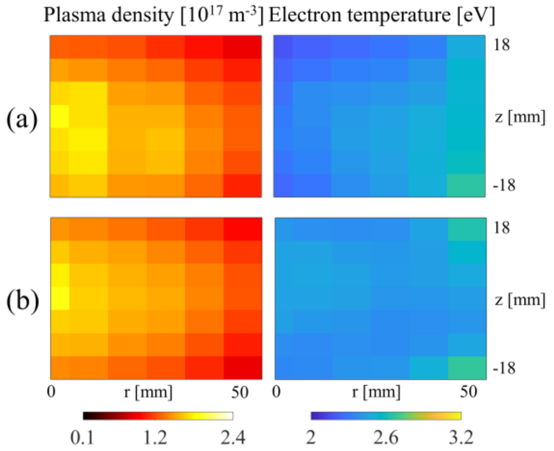


Fig. 6. Experimental results of plasma density (left) and electron temperature (right). Diverging magnetic field is exerted on case (a) and converging magnetic field on case (b).

For diverging magnetic fields and converging magnetic fields, plasma density at the center is higher than the radial edge which is corresponding to the results in section 3.1. The plasma density is higher on the side with a strong magnetic field since higher magnetic field confines the electron better.

On the contrast of the parallel magnetic field, diverging or converging magnetic field makes the significant axial asymmetry as shown in Fig. 8. The density peak point of the plasma is shifted to the z position toward the stronger magnetic field side. Plasma's axial asymmetry also affects the radial density distribution since the center of the plasma is moved. Fig. 7 shows the radial plasma density distribution. The diverging magnetic field has different distribution to the converging magnetic field. When the plasma is skewed to one side, it experiences significant asymmetric effects from structures such as slits designed for probe movement. Therefore, by controlling the convergence of the magnetic field, we can control not only the axial plasma density but also the radial density distribution.

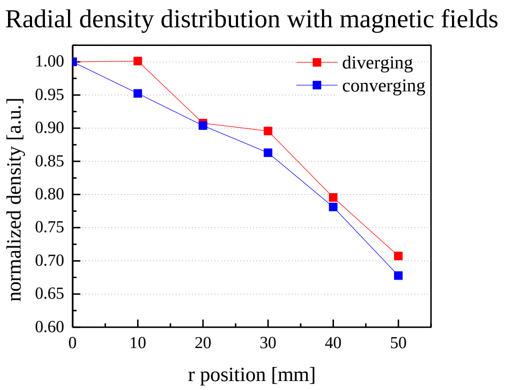


Fig. 7. Radial density distribution of plasma with diverging magnetic fields and converging magnetic fields. Density values are normalized by dividing the density value at position r = 0.

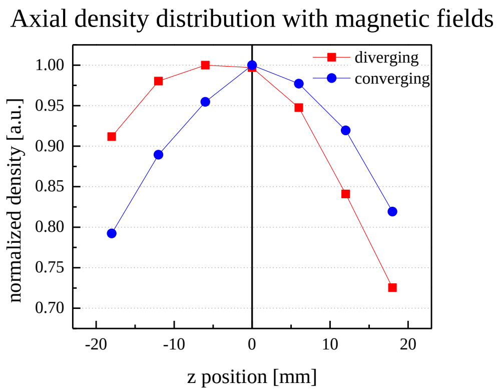


Fig. 8. Axial density distribution of plasma with diverging magnetic field and converging magnetic fields. Density values are normalized by dividing the density value at position z = 0.

## 4. Conclusions

Axial magnetic field in the ICP source influences the plasma by trapping the electrons. From the experiment result, the magnetic field increased the plasma density by confining the electrons from the loss in all cases.

When the parallel magnetic field is applied, plasma density is higher with stronger magnetic field. Also, the plasma is observed to be shifted toward the -z direction. This is believed to be a consequence of changes in electron motion induced by the magnetic field, altering the manner in which power is transferred in association with the chamber structure.

In regions of diverging or converging magnetic fields, higher plasma density was observed in the direction of the stronger magnetic field. This phenomenon is attributed to a further reduction in electron loss near intense magnetic fields. Diverging and converging magnetic fields resulted in a skewed axial alignment of the plasma center, influencing the interaction with chamber walls and potentially affecting the radial distribution of plasma density. Therefore, magnetic field divergence can be employed to control the density distribution of plasmas by adjusting the axial alignment of the plasma center.

## ACKNOWLEDGEMENT

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