Plasma-Profile Control in an ICP Reactor

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Abstract. ICP is widely used in electromagnetic scattering due to its high electron density and simple structure. The distribution of plasma parameters can affect the electromagnetic scattering, so the control of plasma parameter distribution is very important for aircraft stealth. Firstly, the effect of the number of coil turns on the plasma parameter distribution is analyzed. With the increase of the number of coil turns, the peak value of induced magnetic field decrease, the width of magnetic field increase and the homogeneity of plasma increase. Then, the Boltzmann solver is used to calculate the plasma electron energy distribution function at different positions under the four-turn coil. Finally, the influence of external circuit capacitance on plasma parameter distribution is analyzed. In this cavity structure, the electron density first increases and then decreases with the external circuit capacitance increase, and the peak value is on 75 pF. In this study, we propose a method to further regulate the plasma parameter distribution by using terminal capacitance to control the induced magnetic field.

1. Introduction
RF driven inductively coupled plasma (ICP) has been widely applied in etching system for the advantages of the simple discharge structure and the high ne [1, 2, 3]. In addition, due to its widely response frequency band-width of electromagnetic, it is also used in aircraft stealth. In this report we aim to achieve the control of the band-with of electromagnetic adaptively. The change of particle number density (ion density) and plasma temperature (electron temperature) of plasma can be controlled by designing magnetic field. Plasma is composed of a large number of charged particles, which are affected by the Lorentz force in the magnetic field, causing their own path to change. And the charged particles collide with each other and the electrostatic force between each other, resulting in aggregation or dispersion of the charged particles, which can be reflected by the number density of particles. At the same time, the collision between particles and the electrostatic work will lead to the energy change of particles, which can be reflected by the plasma temperature. Therefore, the particle number density and temperature of plasma can be controlled by designing different magnetic field distribution. In this study, the permanent magnet magnetic field will be used to influence the particle number density and plasma temperature of glow discharge plasma.

2. Model description
In the following numerical simulation, Ar is used as the working gas of ICP. Figure 1 shows the circuit topology containing the matching circuit, the external circuit L or C and the antenna. The C1 and C2 are the impedance matching algorithm to provide the RF power [4].
3. Results and description
In order to understand the influence of external circuit on the structure of ICP plasma, Ar plasma simulation was performed at 13.56MHz. The plasma parameters distribution was discussed as follow. The initial gas temperature of 300K, the initial electron energy of 3eV, and the quasi-neutral hypothesis is applied to the whole chamber.

3.1. Influence of coil distribution on plasma parameters
Firstly, we consider the distribution of plasma parameters under different number of coils. In this case, we keep the first coil position at 4 cm from the central axis. Distance between coils remains constant at 4 cm and the number of turns varies from 1 to 4 turns. The synchronous variation of the ne and magnetic field strength along the chamber symmetrical axis is shown in figure 2. In 1 coil, the ne achieve the highest point in the core region. As the coil number of turns increase, in 4 coils, the ne uniformity increases and turns from ellipsoid-shaped profile to saddle profile, under the common discharge pressure temperature and power supply.

As the increases of coil turns, the plasma region increases, the electric field convert to uniformity that the peak decreases, and the peak ne region moves away from the axis. This can be own to the reverse electric field generated by the electron movement, which cancels out part of the external electric field. Hence, the electron diffusion drift is dominant that the electron constantly diffuses to both sides of the peak as the electric field decreases (Figure 2(b)). In the process of electron diffusion and migration, the ionization rate, far away from the center of the potential well, is gradually increased, due to the influence of the bipolar potential. Meanwhile the ne distribution is more uniform appearing the trailing. Since then, this trend has been continuously strengthened.
As the number of coils turns increases, the peak electric field is far away from the center in the radial direction, leading to the synchronous radial motion of electron collision reaction. Due to the diffusion and recombination of ions and electrons, the peak move from 0cm to 11cm with the increase of coil number of turns. The result shows that plasma uniformity is pretty good in 4 turn coils as shown in Figure 2(a), which is conducive to the industrial plasma processes and electromagnetic wave transmission [5].

Then, the variation law of EEDF (Electron energy distribution function) with magnetic field intensity is studied. In previously mentioned studies, the electron energy is mainly concentrated in the low energy region in the high magnetic field [6, 7]. In addition, the high-energy electrons under strong magnetic field (>27eV) are significantly lower than under the weak, due to the overall ne is low. Meanwhile the collisions between charged particles are insufficient in low magnetic field. In Figure 4, the EEDFs were given a function of the total electron energy along different axial and radial positions.

![Figure 3. The EEDFs at different axial and radial points](image)

(a) The EEDFs along axial points  
(b) The EEDFs along radial points

From the perspective of dispersion of EEDF curves at different positions, low-energy electrons increase with the magnetic field intensity, while high-energy electrons decrease. It should be mentioned that the influence of restricting the low-energy electrons by the magnetic field is not as significant as that by the high-energy electrons. In addition, the energy transfer of high-energy electrons by the collisions is small, and the electrons were accounts for a larger proportion than that in high magnetic field regions. Meanwhile, the coupling electrical energy increase and the collisions between charged particles were enhanced in high magnetic field regions, so the ne is higher in general. As can be seen from Figure 4, from both directions moving to the borders from the center, the low-energy electron group increases slightly, while the high-energy electron tail decreases, and most of the electrons are concentrated in the low energy region that is attributed to the sufficient particle collisions which are conducive to the energy transfer of high-energy electrons.

3.2. The single resonant circuit controls of the ICP plasma parameter distribution

Next the single resonant circuit controls of the ICP plasma parameter distribution is studied. The magnetic field induction generated under the different single resonant circuit and the ne from 75pf to 140pf is shown in the Figure 5. When magnetic field induction is in 5-10G, the ne is highest in this antenna condition.
4. Conclusions
The control of response frequency band-width of electromagnetic is of vital importance in aircraft stealth. In this study we attempt to achieve the distribution control of plasma parameters which can affect the electromagnetic scattering. Firstly, with the increase of the number of coil turns, the peak value of induced magnetic field decrease, the width of magnetic field increase and the homogeneity of plasma increase. Then, the Boltzmann solver is used to calculate the plasma electron energy distribution function at different positions under the four-turn coil. Finally, the influence of external circuit capacitance on plasma parameter distribution is analyzed. In this cavity structure, the electron density first increases and then decreases with the external circuit capacitance increase, and the peak value is on 75 pF. In this study, we propose a method to further regulate the plasma parameter distribution by using terminal capacitance to control the induced magnetic field.
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