Microwave Plasma Source Using Planar Ring-Cusp Magnetic Field and Reentrant Coaxial Cavity for Large Area Processing

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Abstract

An electron cyclotron resonance (ECR) plasma source 16 cm in diameter using a planar ring-cusp magnetic field and a reentrant coaxial cavity was developed. The planar ring-cusp magnetic field produces a large-area ECR surface. The reentrant coaxial cavity efficiently introduces microwaves into the ECR surface. This plasma source generated large-area, uniform and stable plasmas for large-area processing.

I. INTRODUCTION

Electron cyclotron resonance (ECR) discharge efficiently produces high-density and non-contamination plasmas at low pressures (< 0.1 Pa). Moreover, there is an increasing demand for ECR plasma sources with low power consumption and uniformity over large processing areas. The ECR plasma sources using permanent magnets achieve low power consumption and a simple structure [1,2]. Though these plasma sources using various magnet arrangements, it is difficult for them to produce large-area and uniform plasmas. This is because the ECR surface is localized near the discharge chamber side wall, and the magnetic field is not uniform at its plane. Also, microwaves have to be introduced into plasma from the side of magnetic field strength higher than the ECR field for producing high density plasmas.

The key points for the production of a large-area, uniform and overdense plasma are a magnet arrangement and a microwave launching system. Planar ring-cusp magnetic fields permit production of a large-area ECR surface [3-5]. Also, a reentrant coaxial cavity is useful for launching microwaves from the side of great magnetic field strength into this large-area ECR surface [6-11]. By using both two methods, we developed a new ECR plasma source with a 16 cm diameter discharge chamber and examined fundamental characteristics of the plasma source.

Ⅱ. EXPERIMENTAL APPARATUS

The plasma source is composed of a reentrant coaxial cavity, a 16 cm-inner diameter annular quartz microwave window, a conductance grid and a planar ring-cusp magnetic field, as shown in Fig.1. The planar ring-cusp magnetic field, which is composed of SmCo magnets, sets on the surface of the center conductor. A disk-shaped discharge chamber is located in the gap between the center conductor and the bottom of the cavity. Microwaves of 2.45 GHz are launched radial-inward from the outer side of the planar ring-cusp magnetic field and generate plasma. The sliding wall and the center conductor are movable to provide variable axial cavity lengths and the window widths. The cavity length (L), the distance between the sliding wall and the bottom of the cavity, is adjusted to achieve optimal impedance matching. The window width (d), the distance between the bottom plate of the center conductor and the bottom of the cavity, is adjusted for efficient plasma production. In this experiment, window widths of 6, 10, 15 and 20 mm are principally used.

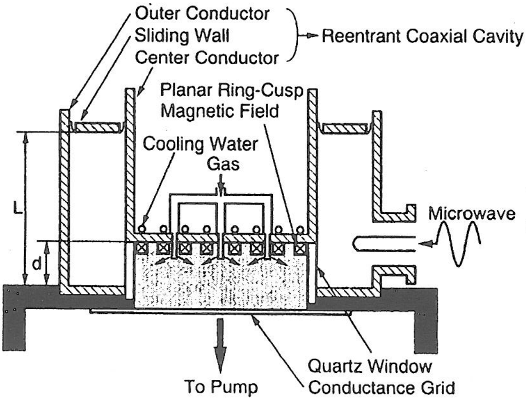
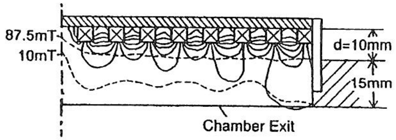
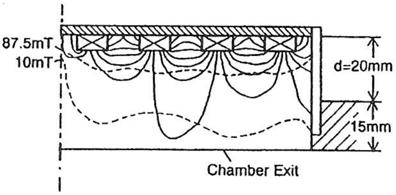


Fig. 1 ECR plasma source using planar ring-cusp magnetic field and reentrant coaxial cavity.



(a)8-ring



(b)4-ring

Fig. 2 Calculated profiles of planar ring-cusp magnetic field.

Figure 2 shows the calculated profiles of the ring-cusp magnetic field in the discharge chamber. Two kinds of magnetic fields are used in this experiment. The one has eight ring magnets as shown in Fig.2 (a). Each ring magnet is composed of 5 mm x 5 mm x 10 mm SmCo blocks. The other has four ring magnets as shown in Fig.2 (b). Each ring magnet is composed of 10 mm x 5 mm x 20 mm SmCo blocks. There exists the ECR surface of 87.5 mT at 2.45 GHz about 5 mm apart from the magnets. The magnetic field using 8-ring produces a slightly nonuniform ECR surface, and the magnetic field lines are confined within a close surface of the magnets. The magnetic field using 4-ring has a rough ECR surface. The magnetic fields spread downstream and have large arch regions between the magnetic cusps.

The radial profiles of ion saturation current density are measured with an electrostatic single probe at 5 mm upstream from the conductance grid, i.e., the chamber exit plane. Also, plasma parameters are measured with a floating double probe at 5 mm upstream from the conductance grid on the center axis. In this experiment, argon, nitrogen and oxygen are used as a working gas. The working gases are injected radially into the discharge chamber from five gas ports on the bottom plate of the center conductor. The discharge chamber pressures are in the range from 0.01 to 0.1 Pa.

III. EXPERIMENTAL RESULTS AND DISCUSSION

RADIAL PROFILES OF ION CURRENT DENSITY

Figure 3 shows the radial profiles of ion current density for the 8-ring and the 4-ring. The microwave window widths were set to 10 mm for the 8-ring and 20 mm for the 4-ring, which achieved the minimum plasma maintenance pressure. As for the 8-ring, plasma is localized between the 1st and 3rd ring magnets outward from the axis on the center axis at 0.054 Pa. Although the plasma is produced over a 120 mm diameter plane at 0.079 Pa, the ion current density is low except the plane within the 3rd ring outward from the axis. On the other hand, the 4-ring produces plasma over a 120 mm diameter plane above 0.03 Pa. Above 0.054 Pa, uniform plasmas are produced across the discharge chamber and the ion current densities exceed 5 mA/cm^2. A small variation of the radial distribution of plasma is caused by the magnetic field. Near the wall region, the ion current density decreases radial-outward.

The shape of the profile at the 4-ring does not vary with pressures above 0.54 Pa and the ion current density increases with the pressure.

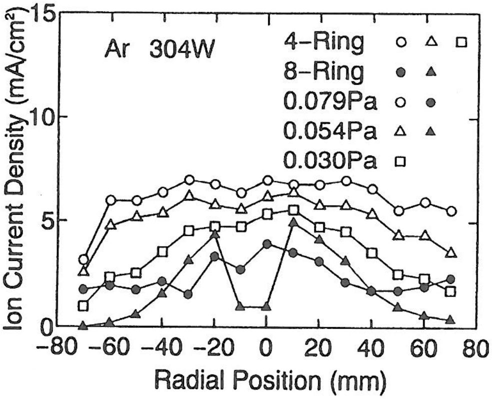


Fig. 3 Radial profiles of ion current density using 8-ring and 4-ring magnetic fields.

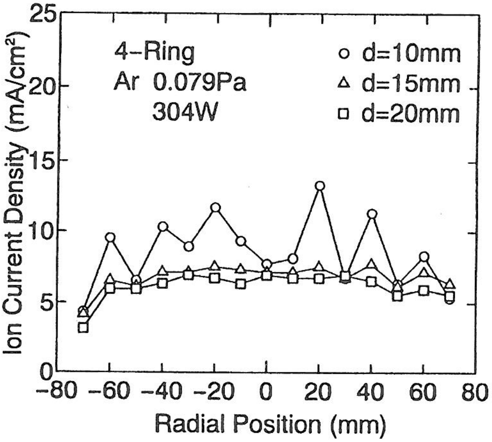


Fig. 4 Radial profiles of ion current density using 4-ring magnetic field for various window widths.

Figure 4 shows the radial profiles of ion current density with various window widths for the 4-ring at 0.079 Pa and 304 W. The roughness of the profile increases with decreasing window width. At a 10 mm window width, measured at 20 mm downstream from the magnet surface, the uniformity is above 30 % within a 120 mm diameter plane. The magnetic field has a large variation in this distance as shown in Fig. 2 (b). The ion current density has great peaks at the arch region between the magnetic poles. The maximum peak current density is above 13 mA/cm^2. At 20 mm window width, which is 30 mm downstream from the magnet surface, the peaks disappear. The uniformity is 11.1 % within a 120 mm diameter plane. Because of increasing distance from the magnet surface, the changes of magnetic field directions between the magnetic cusps are reduced, and the plasmas become uniform by diffusion.

PLASMA PARAMETER CHARACTERISTICS

From the above results, the plasma source was operated with the 4-ring-cusp magnetic field and 20 mm window width. Figure 6 shows the plasma parameter

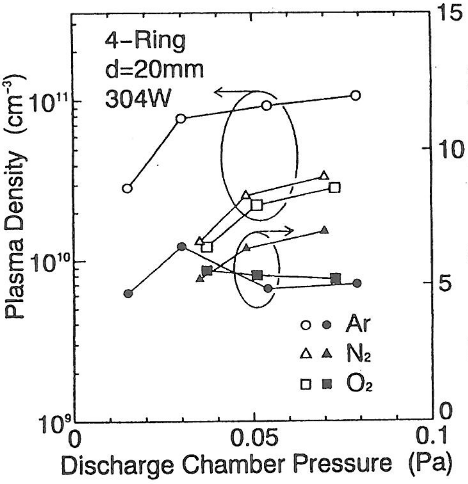


Fig.5 Dependence of plasma parameters on discharge chamber pressures.

characteristics for various discharge chamber pressures at 304 W. The plasma density for Ar rapidly increases with the pressure from 0.015 to 0.03 Pa. Above 0.03 Pa, the plasma density for Ar is beyond the cutoff density and gradually increases with pressure. This is because the plasma production area becomes large above 0.03 Pa as shown in Fig. 3. The electron temperatures around 5 eV have little variation. The maximum Ar plasma density is in the order of 10^{11} cm^{-3}. For N_2 and O_2, it is difficult to sustain plasmas under 0.03 Pa. The minimum plasma sustaining pressure is 0.027 and 0.037 Pa for N_2 and O_2, respectively. The maximum plasma densities for N_2 and O_2 are under 4×10^{10} cm^{-3}. As for probe measurements of N_2 and O_2 plasmas, only atomic ions are assumed to exist. If the molecular ions are the principal species, then plasma densities are little higher than this value. However, they are not beyond the cutoff density.

Ⅳ. CONCLUSIONS

The fundamental characteristics of the ECR plasma source using the planar ring-cusp magnetic field and the reentrant coaxial cavity were studied. The 4-ring-cusp magnetic field achieved the minimum plasma maintenance pressure of 0.015 Pa for Ar. Above 0.03 Pa, the plasma production area became large and the plasma density for Ar gradually increased with pressure. The electron temperatures around 5 eV have little variation. At 0.079 Pa for Ar, plasmas were produced over a 120 mm diameter plane with 11.1 % uniformity and beyond the cutoff density on the center axis at 304 W. The maximum Ar plasma density is in the order of 10^{11} cm^{-3}. However, the plasma densities were lower for N_2 and O_2. The maximum plasma densities were 3.21×10^{10} cm^{-3} for N_2 and 3.14×10^{10} cm^{-3} for O_2.

REFERENCES

[1] L.Mahoney, M.Dahimene and J.Asmussen: Rev. Sci. Instrum. **59** (1988) 448.

[2] M.Pichot, A.Durandet, J.Pelletier, Y.Arnal and L.Vallier: Rev. Sci. Instrum. **59** (1988) 1072.

[3] M.Geisler, J.Kieser, E.Räuchle and R.Wilhelm: J. Vac. Sci. & Technol. **A8** (1990) 908.

[4] Y.Yoshida: Rev. Sci. Instrum. **63** (1992) 2565.

[5] N.Sato, S.Iizuka, Y.Nakagawa and T.Tsukada: Appl. Phys. Lett. **62** (1993) 1469.

[6] T.Yasui, H.Tahara, K.Onoe and T.Yoshikawa: *AIDAA/AIAA/DGLR/JSASS* 22nd Int. Electric Propulsion Conf. Italy, 1991.

[7] T.Yasui, J.Kitayama, H.Tahara, K.Onoe and T.Yoshikawa: Proc. 18th Int. Symp. Space Technology and Science, Kagoshima, 1992, p.359.

[8] H.Tahara, T.Yasui, M.Hiramatsu, K.Onoe and T.Yoshikawa: Proc. 10th Symp. Plasma Processing, Osaka, 1993, p.21.

[9] T.Yasui, M.Hiramatsu, H.Tahara, K.Onoe, T.Tsubakishita and T.Yoshikawa: Trans. Mat. Res. Soc. Jpn. **17** (1994) 89.

[10] M. Hiramatsu, T. Yasui, H. Tahara, K. Onoe and T. Yoshikawa: Pro. 2nd Int. Conf. Reactive Plasma and 11th Symp. Plasma Processing, 1994, Yokohama, p.335.

[11] T. Yasui, H. Tahara and T. Yoshikawa: Jpn. J. Appl. Phys. **33** (1994) 4787.