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Development of Steady State Microwave Ion Source for High Flux Ion Beam Irradiation to First Wall Materials

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Abstract

A steady – state microwave ion source for high flux ion beam irradiation to first wall materials has been developed. It consists of a plasma source chamber and a plasma diffusion chamber with multi-cusp permanent magnets. In this study, the characteristics of ion saturation current and the beam power density were studied. It was found that gas pressure and gas inlet position affected plasma characteristics. The beam power density of 48 W/cm^2 was obtained for acceleration voltage of 3.0 kV. In this case, hydrogen flux is 10^{21} H/m^{2}s, if all of ions are H$^+$. This flux is an order of magnitude higher than conventional mass-separated ion beam devices (< 10^{20} H/m^{2}s).

Keywords:

ECR discharge, steady state operation, high flux beam irradiation, spherical electrode

1. Introduction

Studies of interaction between edge plasmas and diverter plates and limiters are very important for development of fusion devices. It is known that in practical fusion devices plasma ions into first walls have low energy (typically less than 500 eV) with high flux of 10^{22} – 10^{23} m^{-2}s^{-1}. And future fusion devices will be operated in long pulsed modes or a steady state. We have been studying erosion and hydrogen retention of graphite materials by using pulsed ion beams (pulse duration 4 s) with the flux up to 10^{22} H/m^{2}s with a bucket-type ion source [1-3]. However in order to make the database of beam material interaction for future fusion devices, steady-state ion beam must be needed. For this purpose, we have developed electron cyclotron resonance (ECR) ion source [4-5]. In this paper, discharge characteristics of the ion source with hydrogen gas, and characteristics of ion beam extracted with spherical electrodes to obtain a high flux of an order of 10^{21} m^{-2}s^{-1} at a focal point, are described.

2. Experiment

Figure 1 shows a cross sectional view of the ECR ion source for this study to refer to Previous works [6-9]. The ECR ion source consists of two cylindrical stainless steal chambers (a plasma production chamber and a plasma confinement chamber). The plasma produced in the plasma production chamber by ECR discharges diffuses into the plasma confinement chamber uniformly. Microwaves (2.45 GHz) are introduced to the plasma through a rectangular tapered waveguide and a quartz window. The maximum output power of the microwave generator is 5.0 kW. We compared two type of plasma production chambers [ϕ70 mm × L200 mm, ϕ70 mm × L300 mm]. A cutoff

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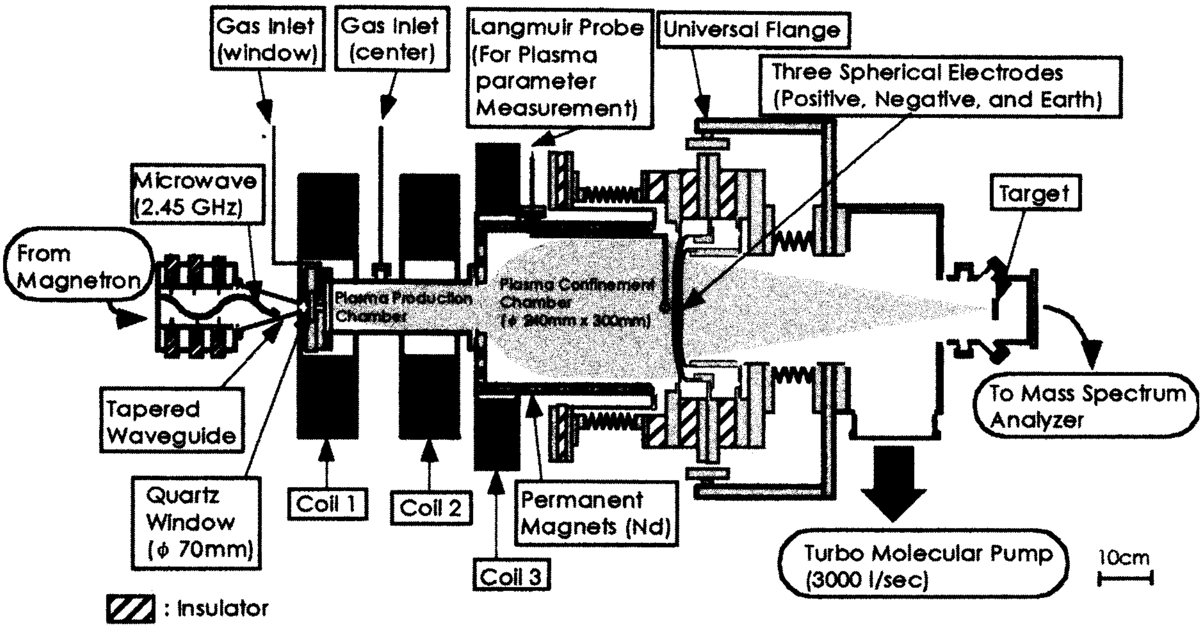

Fig. 1 Cross sectionnal view of the ECR ion source

diameter of the cylinder in vacuum for the microwave of 2.45 GHz is ϕ72 mm. So the diameter of both of plasma production chambers is almost cutoff. It was found that the short chamber (L = 200 mm) is suitable for high density plasma production [10] and all of the data shown in this paper were obtained with this short chamber. The plasma confinement chamber, whose diameter and length are 23 cm and 30 cm, makes uniform plasmas on the multi-aperture extraction electrodes (effective diameter is 15 cm). Multi-cusp magnetic field for the plasma confinement is made by the configuration of neodymium permanent magnets.

Plasma ions are extracted by spherical electrodes (Positive electrode of molybdenum, negative and earth electrodes of copper) with the radius of curvature of 600 mm and a thickness of 2.0 mm each. These electrodes have the 638 circular apertures of 4.2 mm in diameter, and a gap distance between the positive and negative electrode is 2.0 mm and that between the negative and earth electrode is 1.3 mm. The beam optics of similar aperture geometry was already studied [11], and it was found that the brightness of the beam increases rapidly when the ratio of deceleration voltage to acceleration voltage (accel – decel ratio) exceeds about 8. This characteristic is advantageous for low energy and high flux beam. Maximum applicable acceleration and deceleration voltage are 6.0 kV.

In the experiment, ion saturation current J_{is} of the source plasma near the electrodes was measured by the Langmuir probe with a diameter of 0.5 mm located 1cm from the electrode. Ion beam power density was measured by a calorimeter.

3. Experimental Results

Figure 2 shows dependence of J_{is} on hydrogen gas pressure for different gas inlet positions in the case of 2 kW microwave input power. In general, ion saturation current increases linearly against microwave power. We compared the discharges with gas inlet positions near the quartz window and the center of plasma production chamber. It was found that J_{is} is higher and plasma discharge occurs in lower gas region with the gas inlet position near the window. It is noted that the dependence of J_{is} on the magnetic field was different between the case of high gas pressure (> 5 mtorr) and low (< 5 mtorr) pressure. In the high pressure case (typically 16 mtorr), J_{is} increased as the increase of the magnetic field, while in the low gas pressure case (typically 4 mtorr), ion saturation current became lower as the increase of the magnetic field.

Figure 3 shows dependence of beam power density P_{axis} near the focal point of the spherical electrodes on beam acceleration current I_{acc}. In this experiment, microwave power changed from 0.6 kW to 3.2 kW. The accel – decel ratio was kept 0.2. For the acceleration voltage V_{acc} of 1.5 kV and 2.0 kV, P_{axis} increases almost

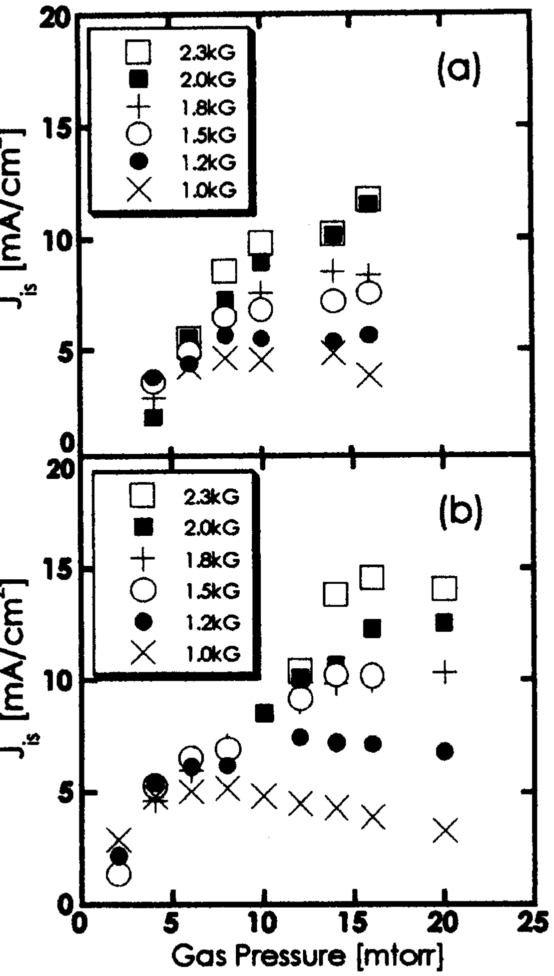

Fig. 2 Dependence of ion saturation current J_{is} for different gas inlet positions, (a) the center of the plasma production chamber, (b) near the window. Microwave power is 2.0 kW.

linearly with I_{acc} until it shows saturation over some critical value of I_{acc}. This critical I_{acc} is about 450 mA for V_{acc} of 1.5 kV and about 700 mA for V_{acc} of 2.0 kV. These critical I_{acc} are roughly proportional to $V_{acc}^{3/2}$. Since I_{acc} is limited to about 1000 mA due to insufficient optimization of plasma production, P_{axis} for V_{acc} of 3.0 kV does not show saturation. According to the scaling of the critical $I_{acc} \propto V_{acc}^{3/2}$, the critical I_{acc} for V_{acc} of 3.0 kV could be around 1300 mA. So far maximum power density for V_{acc} of 3.0 kV is about 48 W/cm^2, which corresponds to the equivalent current density of about 16 mA/cm^2. In this case, hydrogen flux is about ~ 1.0 × 10^{21} H/m^{2}s, if all of ions are H^+. This flux is an order of magnitude higher than conventional mass-separated ion beam device (< 10^{20} H/m^{2}s) [12].

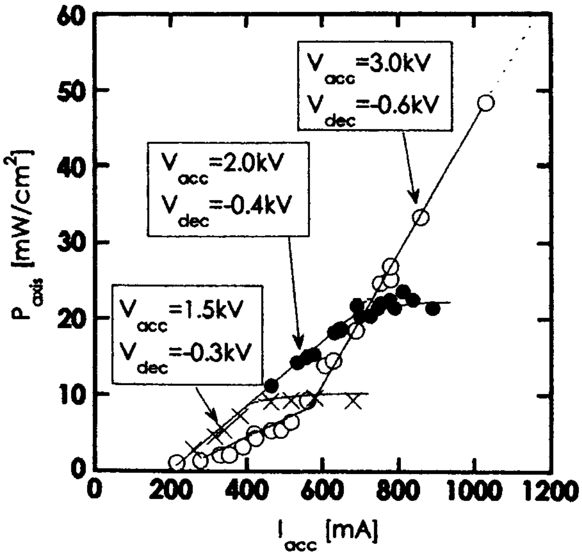

Fig. 3 Dependence of the beam power density P_{axis} on the acceleration current I_{acc}. Solid line are only for eye-guided.

4. Conclusion

We have developed the ECR ion source to first wall material studies with spherical electrodes for irradiating the steady state ion beam with high flux and low energy, and made experiments on the characteristics of ECR plasma production and ion beam extraction. Hydrogen flux of 10^{21}/m^{2}s was obtained for V_{acc} of 3.0 kV. In the future, low energy (≤ 500 eV) and high beam flux could be obtained by optimizing plasma condition and to apply high deceleration voltage.

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