30-cm-class Long Plasma Source Using Microwave Slot Antennas on a Rectangular Waveguide for Large Area Plasma Processing

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Abstract

30-cm-class long microwave plasma sources using slot antennas on a rectangular waveguide were developed for large-area processing. Two types of plasma source, the one non-resonant microwave discharge and the other electron cyclotron resonant (ECR) discharge, were examined. In both plasma sources microwaves were radiated efficiently from the slot antennas. Though the non-resonant type plasma source operated above 0.08 Pa for Ar, the ECR plasma source operated under 0.041 Pa. The spatial distributions of plasma parameter for the non-resonant type plasma source were almost flat in the discharge chamber. On the other hand, the ECR plasma source had a rough distribution due to the electric filed and the magnetic field profiles.

I . INTRODUCTION

Long and narrow plasma sources are attractive for material processing in manufacturing industry. They efficiently process large area materials on the conveyor system. Especially, microwave discharge type long plasma source is useful to produce high-density and non-contamination plasmas. However, it is difficult for microwave discharge to produce long plasmas. Then, we developed a new plasma source using microwave slot antennas on a rectangular waveguide to produce long microwave plasma. In this study, 30-cm-class rectangular plasma sources using 2.45-GHz-microwave slot antennas were developed. The plasma source has a simple structure and a compact system for economically assisting large-area material processing.

In the present paper, two types of microwave plasma source were examined. The one is non-resonant microwave discharge type with no magnetic field, and the other is electron cyclotron resonance (ECR) discharge type with magnetic field. Operational characteristics and spatial distributions of plasma parameter along the long direction were investigated for each plasma source.

Ⅱ. EXPERIMENTAL APPARATUS

Figure 1 shows the configuration of the non-resonant microwave discharge type plasma source using microwave slot antennas on a rectangular waveguide [1-3]. Microwaves of 2.45 GHz are transmitted in TE_{10} mode into the rectangular waveguide (WRJ-2(JIS): 109.2×54.6 mm). Slot arrays are cut on the E-side of the rectangular waveguide for microwave radiation as shown in Fig. 1. Each slot length (l) is 61 mm, which corresponds to half wavelength of 2.45-GHz microwave in vacuum. However, the width (w), pitch (d) and total number (n) of slot were parametrically investigated. The minimum plasma maintenance pressure was achieved at w=4 mm, d=12 mm, and n=23. Microwaves are radiated from the slot antennas into a downstream discharge chamber (70×280×28 mm) across a quartz glass plate 10 mm in thickness. The radiated electric field pattern and its intensity are changed by using a T-shaped ridge and a sliding short on the rectangular waveguide for efficient microwave coupling. A conductance grid is settled on the exit plane of the discharge chamber.

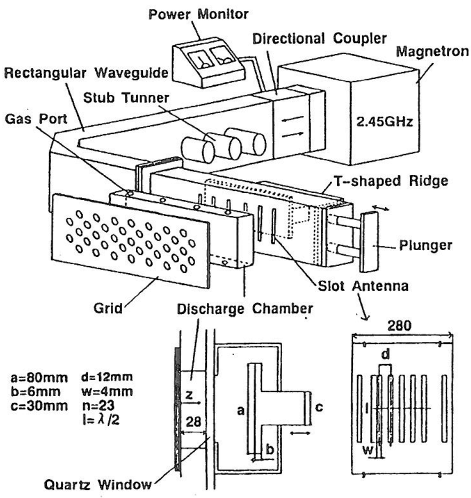

Fig. 1 Configuration of non-resonant microwave discharge type plasma source.

Figure 2 shows the cross section of the ECR discharge type plasma source. The configuration of the plasma source is roughly the same as that of the non-resonant microwave discharge type plasma source as shown in Fig.1. Slot antennas are located within a discharge chamber. SmCo magnets are set on the slot antennas to produce planar ECR magnetic field of 875 Gauss for 2.45 GHz [4]. Each magnet is covered with a stainless steel plate 0.1 mm thick and cooled by water. Figure 3 shows the arrangement of slots and magnets. The slot arrangement for fitting this magnetic field is l=61 mm, w=4 mm and n=10. The ECR layer existed about 5 mm above the magnets. The radiated microwaves is introduced into the ECR layer from the higher magnetic field side and produce overdense plasma within a discharge chamber (70×280×32 mm).

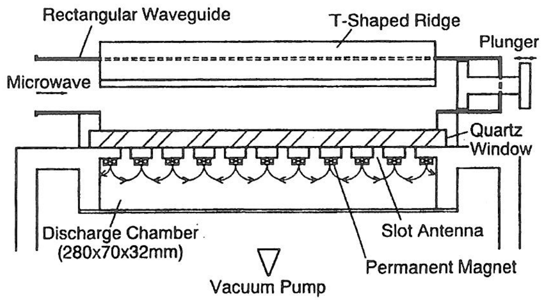

Fig. 2 Cross section of ECR discharge type plasma source.

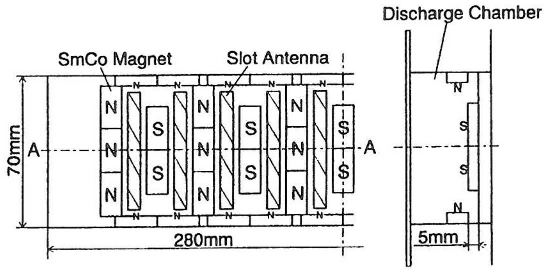

Fig. 3 Magnet and slot arrangement for ECR discharge type plasma source.

Argon, nitrogen and oxygen are used as working gases. The working gases are injected into the discharge chamber from eight gas ports. The discharge chamber pressures vary from 0.01 to 0.2 Pa. The maximum microwave power of 580 W is available.

Electric fields profiles, which are radiated from slot antennas, are measured with a microcoax probe antenna at the discharge chamber exit for no discharge plasma. This profile are measured with the positions of the ridge and the plunger giving minimum maintenance pressure for Ar.

Plasma density, electron temperature and ion saturation current density are measured with a Langmuir probe at 6 mm upstream from the conductance grid. The spatial plasma uniformities of these plasma sources are evaluated with ion saturation current density. The discharge chamber wall and the conductance grid are connected to ground.

III. RESULTS AND DISCUSSION

NON-RESONANT MICROWAVE DISCHARGE TYPE PLASMA SOURCE

For the non-resonant microwave discharge type plasma source, plasma is produced for its high electric field strength. Figure 4 shows the spatial profile of electric field at the discharge chamber exit. The symmetric profile of electric field intensity has two dull peaks. The peak intensity increases with microwave power.

Under 0.08 Pa, plasma could not be produced. Figure 5 shows the spatial profile of ion current density for Ar. Above 0.13 Pa, plasma is produced within 250 mm long. The ion current density increases with pressure and microwave power. The maximum ion current density of 8 mA/cm^2 is achieved at 580 W for 0.19 Pa. Spatial profile of plasma is almost flat at the discharge chamber exit (22 mm downstream from the window). The plasma uniformity is 4.4 % within 200 mm long at 368 W for 0.19 Pa. However, the plasma profile becomes rough with increasing pressure.

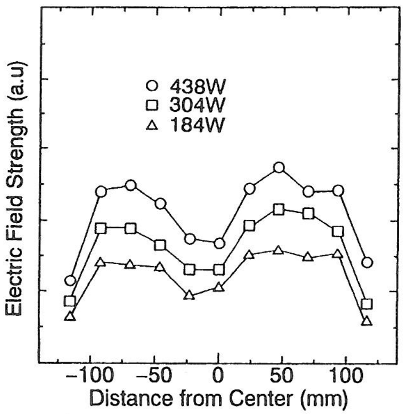

Fig. 4 Spatial profile of electric field intensity for non-resonant microwave discharge type plasma source.

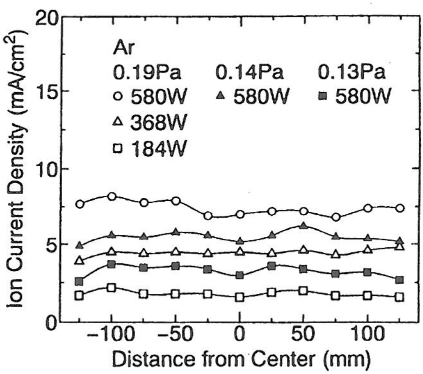

Fig. 5 Spatial profile of ion current density for non-resonant microwave discharge type plasma source.

The ion current densities at the position, where the electric field intensities have peaks as shown in Fig. 4, slightly increase with pressure and microwave power. The plasma profiles depend on the electric field profile within the discharge chamber.

The plasma density increases with microwave power. Above 300 W, the plasma density for Ar is in order of 10^{11} cm^{-3}, i.e., beyond the plasma cutoff density. The electron temperature ranges from 3 to 4 V. The plasma density for N_2 and O_2 is beyond the cutoff density above 400 W.

ECR DISCHARGE TYPE PLASMA SOURCE

Figure 6 shows the spatial profile of electric field at the discharge chamber exit. The profiles of electric field intensity have three peaks and large variation. The strong electric field is produced around the central region. The total number of slot for the ECR discharge type is less than that for the non-resonant microwave discharge type, and microwave radiation becomes non uniform.

The minimum plasma maintenance pressure was 0.014 Pa for Ar. Figure 7 shows the spatial profile of ion current density at the discharge chamber exit (22 mm downstream from the window) for the ECR discharge type plasma source. Above 0.041 Pa, plasma was produced within 200 mm long. The ion current density

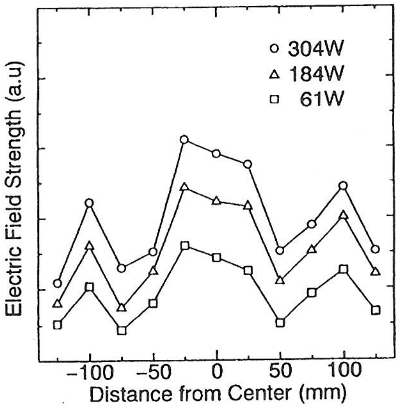

Fig. 6 Spatial profile of electric field intensity for ECR discharge type plasma source.

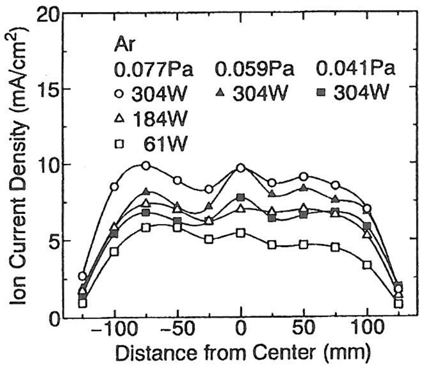

Fig. 7 Spatial profile of ion current density for ECR discharge type plasma source.

increases with pressure and microwave power. The maximum ion current density of 10 mA/cm^2 is achieved at 304 W for 0.077 Pa. The spatial profile of plasma has a rough distribution and three peaks. The electric field profile has a serious effect on the plasma profile as shown in Fig. 6. Though the spatial profile of plasma is similar to the electric field profile, the peak position shifts inward. The plasma uniformity is 10 % within 200 mm long at 304 W for 0.077 Pa.

The plasma density for Ar is beyond the cutoff density above 100 W for 0.094 Pa. The maximum plasma density for Ar was 1.19×10^{11} cm^{-3} at 437 W. The electron temperature ranges from 4 to 6 eV.

Ⅳ. CONCLUSION

Two types of 30-cm-class long microwave plasma sources were investigated. The non-resonant microwave discharge type plasma source achieved the production of uniform plasma within the range of pressure 0.13 to 0.19 Pa. The plasma uniformity was 4.4 % within 200 mm long at 368 W for 0.19 Pa. The plasma density for Ar was beyond the plasma cutoff density above 300 W. The ECR discharge type plasma source achieved the production of uniform plasma above 0.041 Pa. The plasma uniformity was 10 % within 200 mm long at 304 W for 0.077 Pa. The plasma density for Ar was beyond the cutoff density above 100 W.

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