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Research on Spatial Distribution Control of Radiation Electric Field from Antenna in Microwave-Excited Plasma
マイクロ波励起プラズマにおけるアンテナ放射電界制御分布に関する研究

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In the manufacturing process of semiconductors, plasma processing is an essential technology, and the plasma used in the process is required to be of high density, high uniformity, and large diameter. This research focuses on the microwave-excited plasma as a plasma source that meets these needs, and the research target is a spatial distribution control. The authors have investigated to control the radial distribution of the plasmas in the experimental device with the multi-slot planar (MSP) antenna with a double coaxial feeder. In the paper, results of the plasma distribution control experiment are presented.

1.Introduction

In the manufacturing process of semi-conductors, plasma processing is an essential technology, and the plasma used in the process is required to be of high density, high uniformity, and large diameter. We are developing a plasma production device which can adjust plasma distribution freely from the outside as one of the techniques of solving the requirement.

In this research, to control freely the radial distribution of the microwave plasmas, a novel antenna system using a double coaxial feeder has been developed. It has a function that the microwave can be separately radiated from the radial inside and outside of the antenna by using two microwave sources. In addition, this device is designed so that microwave can be extensively radiated using the MSP antenna[1,2]. The device has the advantages that the mode spectra of the electric fields radiated from the MSP antenna exist in the limited region due to the effect of the multi-slots, and the mode depends not on eignmodes deternimed by the plasma but on the standing waves formed in the antenna cavity.

The purpose of this research is to clarify control performance of the radial distribution of the microwave plasma by a double coaxial feeder, using plasma production experiments, numerical calculation and simulations.

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2.Experimental Setup

Figure 1 shows the experimental setup for the plasma production by a double coaxial feeder. It consists of two microwave sources, two directional couplers, two power monitors, two three-stub tuners, a double coaxial waveguide, an unique antenna cavity, the MSP antenna[1,2], a quartz window, and a plasma chamber. The microwave driven at 2.45 GHz excited from the microwave source 1 propagates in the rectangular waveguide via the TE_{10} mode and is supplied to the inner coaxial waveguide. In the same way, the microwave excited from the microwave source 2 is radiated from the outside of the MSP antenna. In the coaxial waveguides, the microwave propagates via the TEM mode. Then, it is transferred to the TM mode in the antenna cavity and is radiated from the MSP antenna. The aim of the double coaxial feeder is to adjust the radial distribution of the plasmas by controlling the power ratio of the microwave sources 1 and 2.

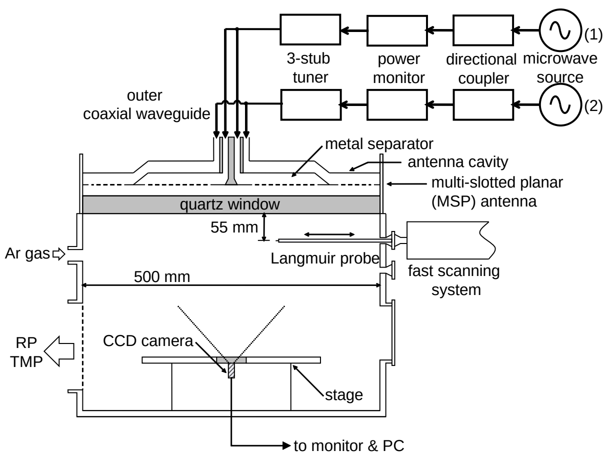

Fig.1. Experimental setup for plasma production.

Ar gas is used to produce the plasmas, and the pressure p_{Ar} in the chamber is kept constant. The radial distribution of the plasmas is measured by a Langmuir probe set at a fast scanning system.

3.Results

Figure 2 shows the dependence of the radial distribution of the ion saturation current density J_{is} on the incident microwave power from the source 1 $P_{in,1}$. Here, $P_{out,2}$ is fixed to 180 W. The other plasma production conditions are Ar gas pressure p_{Ar} = 31.0 mTorr, and flow rate Q_{Ar} = 66 sccm. Also, in the graph, parenthetic values for $P_{in,1}$ and $P_{out,2}$ represent the reflected power.

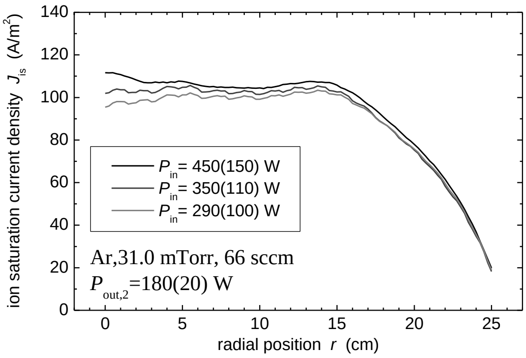

Fig.2. The dependence of radial distribution of J_{is} on $P_{in,1}$.

It shows that J_{is} near the center increase by increasing $P_{in,1}$, and J_{is} on 15≤ r ≤20 cm hardly changes by increasing $P_{in,1}$.

Figures 3(a) and 3(b) show the dependence of the plasma uniformity and the gradient in the radial distribution on the power ratio ($P_{in,1}/P_{out,2}$), respectively, where the value is for J_{is} in r ≤ 15 cm. Here, p_{Ar} = 31.0, 47.1, and 80.5 mTorr. The plasma uniformity of J_{is} is calculated by $\sigma(J_{is})/(2\times\mathrm{ave}(J_{is}))\times 100$ %, where $\sigma(J_{is})$ and $\mathrm{ave}(J_{is})$ represent the standard deviation, and average values, respectively. The gradient is calculated by $(J_{is}(15)–J_{is}(0))/(J_{is}(15)+J_{is}(0))\times 100$ %. In Fig. 3(a), the radial distribution uniformity is improved by increasing the power ratio, and the plasmas with the best uniformity are produced near $P_{in,1}/P_{out,2} \approx 1.0 – 1.5$ for various p_{Ar}. The uniformity becomes worse when the power ratio is increased further. It shows that the plasmas with good uniformity in the radial distribution can be produced for a wide range of p_{Ar} by using the double coaxial feeder. In Fig. 3(b), the radial distribution of the plasmas changes from upward slant to the right to downward slant to the right by increasing the power ratio. It shows that the radial distribution of plasmas can be adjusted in various p_{Ar} by adjusting the power ratio.

Therefore, it is concluded that the microwave-excited plasma device with the double coaxial feeder has a function that the radial distribution of the plasma parameters can be controlled by the power ratio from the microwave source 1 and 2.

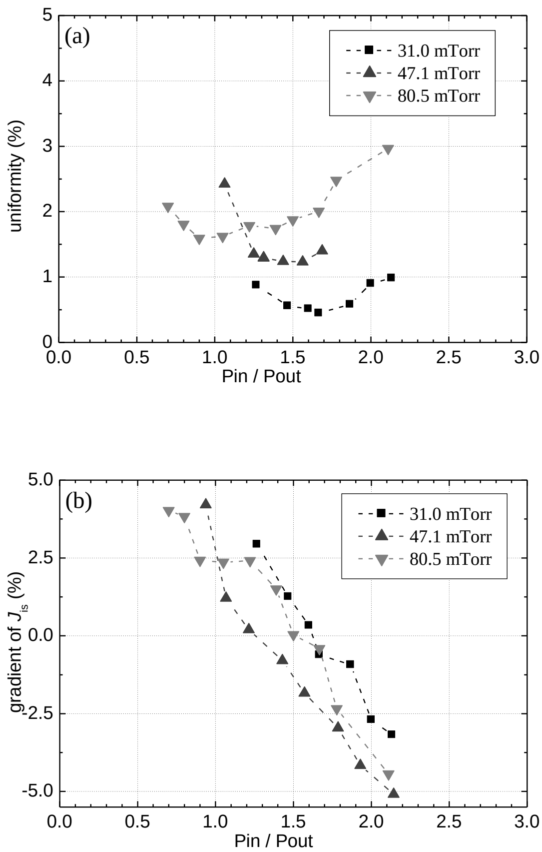

Fig.3. The dependence of the plasma parameters on the power ratio: (a) uniformity and (b) gradient.

In addition to plasma distribution control experimental result, the results of an investigation by the numerical calculation and simulation, will be presented.

References

[1] Y. Yasaka, K. Koga, N. Ishii, T. Yamamoto, M. Ando, and M. Takahashi: IEEE Trans. Plasma Sci. **32** (2002) 1029.

[2] Y. Yasaka, N. Ishii, T. Yamamoto, M. Ando, and M. Takahashi: IEEE Trans. Plasma Sci. **32** (2004) 101.