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Spatial Profile Measurement of High Energy Electrons near Inductively Coupled Plasma Antenna by Optical Emission Spectroscopy
発光分光法を用いたICPアンテナ近傍の高エネルギー電子空間分布計測

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To investigate influence of electronegative gas introduction into an inductively-coupled plasma (ICP) on the power deposition to the plasma, two dimensional profiles of Ar and He emissions from Ar/He/HBr plasma was investigated by a CCD camera with interference filters especially focusing on the variation in the vicinity of the ICP antenna. From spatial variation of He/Ar emission intensity ratio, localization of high-energy electron region in the vicinity of the ICP antenna was observed with introduction of HBr gas into He/Ar plasma. This result suggests that introduction of HBr gas strongly changes power deposition to the plasma as well as load impedance of plasma source.

1. Introduction

Inductively-coupled plasmas (ICPs) are commonly used in semiconductor fabrication processes as one of high density processing plasma sources to enhance productivity. Mechanism of power absorption for the ICP is well-known and density-jump of ICP has been well explained from consideration of capacitive and inductive couplings of the RF power [1]. However, the influence of electronegative gas to the ICP is still not well known such as spatial profile of negative ions and influence of electronegative gas on the power deposition to the ICP.

In this study, behavior of ICP with electronegative discharge gas such as HBr is investigated, especially focusing on variation of power absorption with use of electronegative discharge gases.

2. Experimental

Figure 1 shows schematic of experimental apparatus. A vacuum vessel of 33×33×33 cm^3 is evacuated by a turbo molecular pump (TMP) at a base pressure of 4×10^{-7} Torr. Ar, He, and HBr are fed into the vessel through independent mass flow controllers at total flow rates of 30~53 sccm and total pressures (p) of 30~70 mTorr. Pressure is controlled by a conductance valve between the vessel and the TMP. RF power (13.56 MHz, P<700 W) is coupled to the plasma through a one-turn antenna (11.5 cm in diameter). Light emission from the plasma is monitored by a CCD camera installed at the bottom of the vessel. To investigate relative spatial variation of high-energy electrons, spatial profile of He and Ar emissions are monitored using interference filters. To investigate dissociation of HBr, a differentially-pumped quadrupole mass spectrometer (QMS) is also attached to the vessel.

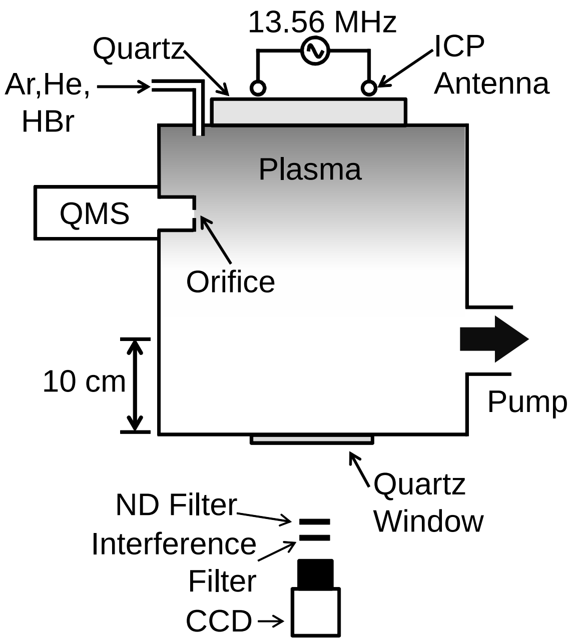

Fig. 1. Schematic of experimental apparatus.

3. Results and Discussions

From mass spectrometric measurement of Ar/He/HBr plasma, mass peaks from 79 to 82 originated from Br isotopes of HBr^{79} and HBr^{81}

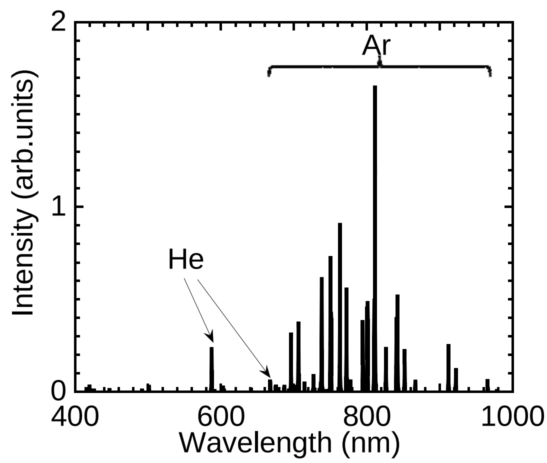

Fig. 2. Typical emission spectrum of Ar/He ICP plasma.

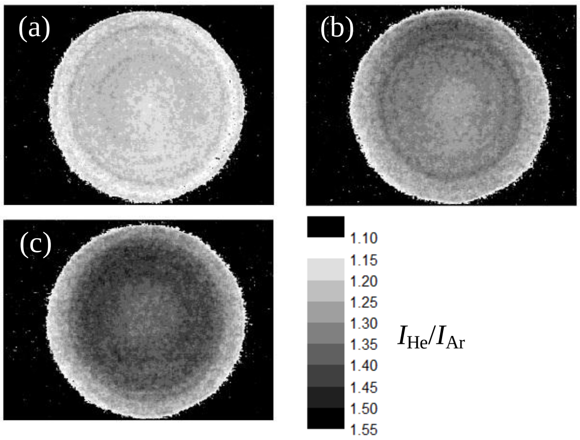

Fig. 3. Spatial profile of I_{He}/I_{Ar} in He/Ar/HBr plasma at HBr flow rates of (a) 6 sccm, (b) 12 sccm, and (c) 18 sccm.

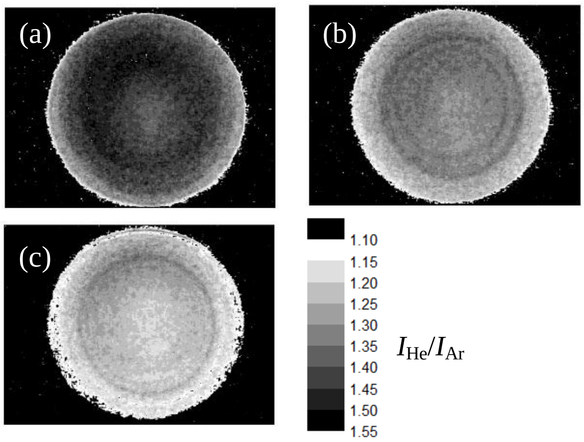

Fig. 4. Spatial profile of I_{He}/I_{Ar} in He/Ar/HBr plasma at total pressures of (a) 30 mTorr, (b) 50 mTorr, and (c) 70 mTorr.

were clearly observed. During the discharge, and dissociation of HBr in the plasma was confirmed. Figure 2 shows typical emission spectra of He/Ar ICP. From these emission lines, we focus on a He emission line of 587.6 nm (1s2p-1s4d) and a Ar emission line of 750.4 nm ($3p^5 4s$-$3p^5 4p$). Upper state energy levels of these emissions are 23.1 eV and 13.5 eV, respectively. Emission intensities of these emissions (I_{He} and I_{Ar}) are expressed by following formulae,

$$I_{He} \propto k_{He}(T_e)[\mathrm{He}]n_e \quad (1)$$

$$I_{Ar} \propto k_{Ar}(T_e)[\mathrm{Ar}]n_e. \quad (2)$$

Here k_{He}, k_{Ar} are rate coefficients of electron-impact excitations to upper levels, [He], [Ar] are densities of He and Ar, n_e is electron density. From the above formulae, emission intensity ratio I_{He}/I_{Ar} is expressed as

$$\frac{I_{He}}{I_{Ar}} \propto \frac{k_{He}(T_e)[\mathrm{He}]}{k_{Ar}(T_e)[\mathrm{Ar}]}, \quad (3)$$

and this value becomes higher when high energy electron component becomes larger in electron energy distribution function (EEDF).

Figure 3 shows I_{He}/I_{Ar} spatial profile of He/Ar/HBr plasma (p=50 mTorr, P=500 W, Q_{Ar}=10 sccm, Q_{He}=25 sccm) observed by the CCD camera with interference filters. With increasing the HBr flow rate from 6 to 18 sccm, spatial variation becomes enhanced with high I_{He}/I_{Ar} ratio in the vicinity of ICP antenna region. This result suggests that, by the HBr introduction, the mean free path of high energy electron becomes drastically shorter and the power deposition region becomes smaller in the vicinity of the ICP antenna. Figure 4 shows pressure dependence of I_{He}/I_{Ar} spatial profile of He/Ar/HBr plasma (P=500 W, Q_{HBr}=12 sccm, Q_{Ar}=10 sccm, Q_{He}=25 sccm). The result indicates that the spatial profile of I_{He}/I_{Ar} is not drastically changed by the increase of the total pressure by a factor of two, suggesting stronger influence of the HBr addition than the pressure increase.

4. Conclusions

An inductively-coupled plasma with using electronegative HBr gas was studied focusing on spatial variation of high-energy electrons. 2-D profiles of emission intensity ratio of He and Ar were observed with a CCD and an interference filter as a measure of the high-energy electrons. Strong influence of the HBr on the spatial variation of the high energy electron was observed.

Reference

[1] K. Suzuki, K. Nakamura, H. Ohkubo, H. Sugai: Plasma Sources Sci. & Technol. **7** (1998) 13.