§9. Production of a High Density ECR Plasma and Microwave Propagation

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Electron cyclotron resonance (ECR) discharges have been used as processing plasma and an ion beam source. A significant advantage of ECR plasma sources is the high electron density which can be achieved at low gas pressures. Recently, a great interest has been directed toward the uniformity and the area of the plasmas, because the uniformity of an ECR plasma usually depends on such experimental conditions as incident microwave power, gas pressure and magnetic field configuration. The physical mechanism of it has been requested in order to control the uniformity of the ECR plasma. We report the experiments on the observation of the several modes of electromagnetic waves in the uniform plasma, which indicate the possibility that not only the whistler wave but the extraordinary wave (X wave) affect to the plasma uniformity.

The ECR plasma source consists of a vacuum chamber, magnetic coils and a magnetron. The vacuum chamber was made of stainless steel with an inner diameter of 29 cm and a length of 120 cm. Microwaves of 2.45 GHz were used at the principal mode, TE_{11}. The used gas was N_2 or He, and the pressure was changed in the range 0.5 $\sim$ 5×10^{-3} Torr. The magnetic field strength of 0.16T at the window was gradually decreased to a constant 0.05 T, up to the position of the substrate holder. Using a movable loop antenna, the strength of the electric fields was measured with a crystal diode (HP 423B). The wave patterns were obtained by the interferometer method.

The radial profile of the ion saturation current density, I_{is}, was examined as a function of input microwave power. The radial profiles of I_{is} change from hollow, to uniform, to parabolic, depending on the input microwave power. By moving a loop antenna perpendicular to the magnetic field, it was experimentally found that the electromagnetic waves with half-wavelength were excited in a very uniform ECR plasma whose electron density was $1 \sim 2 \times 10^{11}$ cm^{-3}.1) Furthermore, the electrical field was very strong near the chamber wall on the condition. In order to identify the mode of the observed waves, the dispersion relations were investigated. The wave numbers were estimated from the half-wavelength of the wave patterns. These waves were confirmed to be the X wave that propagates perpendicularly to the magnetic field. Therefore, it is concluded that a uniform ECR plasma can be obtained when the electron density is nearly equal to the cutoff density of the X wave. Furthermore, the wave pattern illustrated that the wavelength of the X wave changed according to the local electron density at different radial positions. As is well known, when the wavelength of the X wave becomes short, an upper hybrid resonance (UHR) occurs at a region where $\omega^2 = \omega_h^2 = \omega_{pe}^2 + \omega_{ce}^2$. ($\omega_{pe}$ and ω_{ce} are the plasma frequency and the electron cyclotron frequency, respectively). This resonance can contribute to plasma production at the radial edges of the plasma. The plasma potential, which was estimated by electron temperature and floating potential, increased around the radial edges of the plasma. The result supports the possibility that the UHR produced the uniform ECR plasma. From the above mentioned results, the behavior of electromagnetic waves in a chamber with large diameter is considered in the following way; In a vacuum, many standing electromagnetic waves, that is, higher order modes, are excited radially, which was experimentally confirmed. As soon as a plasma discharge is ignited, the waves propagate as normal modes, such as the X wave. With increasing input microwave power, the wavelength of the X wave becomes long in the plasma. On the other hand, the wavelength of the X wave becomes shorter according to the local plasma density near the chamber wall. The waves with short wavelength sustain the uniformity of the ECR plasma.

In a high electron density plasma about 10^{12} cm^{-3}, on the other hand, the only whistler wave propagates along the magnetic field lines to the ECR point The wavelength of the whistler wave is short compared to the chamber scale. Therefore, focusing or defocusing of the waves may have a great influence on the parabolic plasma density profile, as previously shown by a numerical simulation. The experimental results mentioned above will be useful not only for the design of ECR plasma sources with a diameter larger than 20 cm, but also for predicting the optimal operating conditions of reactive ECR plasmas for CVD and plasma etching.

Reference

1) Ueda, Y., Kawai, Y., J. Vac. Sci. Technol. **A16(3)**, 1998