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Development of large diameter ECR plasma source

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ABSTRACT

To develop ECR plasma source for industrial applications, we produced a large diameter ECR plasma and examined radial profiles of the ion saturation current as a function of pressure and power. It was found that ECR plasma uniform over 300 mm is produced for pressures higher than 1 mTorr and the electron temperature decreases with increasing pressures.

1. Introduction

A large area plasma source with the diameter larger than 300 mm has been required for various plasma technologies [1–4]. Electron cyclotron resonance (ECR) plasma source [5,6] has great advantages such as high electron density, low gas pressure operation and low contaminations compared with other plasma sources. Generally it is hard to produce an ECR plasma uniform over 300 mm. Therefore we studied to clarify the physical mechanism of ECR plasma uniformity using a vacuum chamber of 200 mm in diameter and found out that the upper hybrid resonance plays an important role in plasma uniformity by measuring the dispersion relation of electromagnetic fields in the plasma [5]. Based on this result, we succeeded in producing an ECR plasma uniform over 300 mm using magnetic mirror fields [6]. On the other hand, industries in the fields of plasma CVD, especially thin film silicon solar cells require large diameter plasma sources operated at higher pressures because the electron temperature is relatively low at high pressures, leading to low ion bombardment energy and a result high quality films are fabricated by plasma CVD. Here, in order to develop the ECR plasma source, we examined the dependence of the radial profiles of the ion saturation current on pressures and powers. It is shown that the ECR plasma source provides a large diameter plasma for pressures higher than 1 mTorr.

2. Experimental

Fig. 1(a) is a schematic of the experimental apparatus. The cylindrical vacuum chamber was made of stainless steel with an inner diameter 400 mm and a length 1200 mm. We used many types of magnetic fields distributions; mirror, flat and diverging [7]. As shown in Fig. 1(b), a flat distribution around the substrate was mainly used as the magnetic field distribution because the operation of the flat magnetic field is easier than that of magnetic mirror fields and the electron temperature is lower. The frequency of microwaves was 2.45 GHz and the power could be increased up to 1.3 kW. Microwaves were launched into a vacuum chamber as a circular TE_{11} mode thorough the waveguide uptaper and the quartz window. The matching between the microwave circuit and the plasma was adjusted with the three-stub tuner in such a way that the reflected microwave power monitored by a power monitor is as low as possible. Ar gas was introduced into the chamber through mass flow controller. The gas pressure was ranged from 0.1 mTorr to 5.0 mTorr. The plasma parameters such as the density and the temperature of electrons were measured with a two dimensionally movable cylindrical Langmuir probe whose diameter and length were 1 mm, respectively. The electron density n_e was estimated from the ion saturation current because the electron saturation current does not provide a correct electron density in the presence of magnetic fields.

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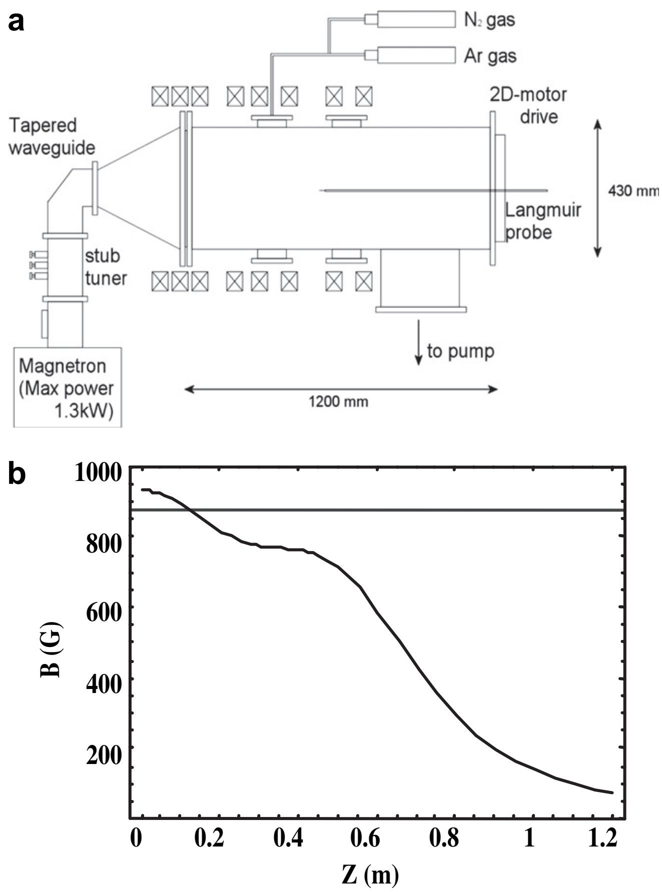

Fig. 1. A schematic of the apparatus: (a) ECR device and (b) magnetic field distribution.

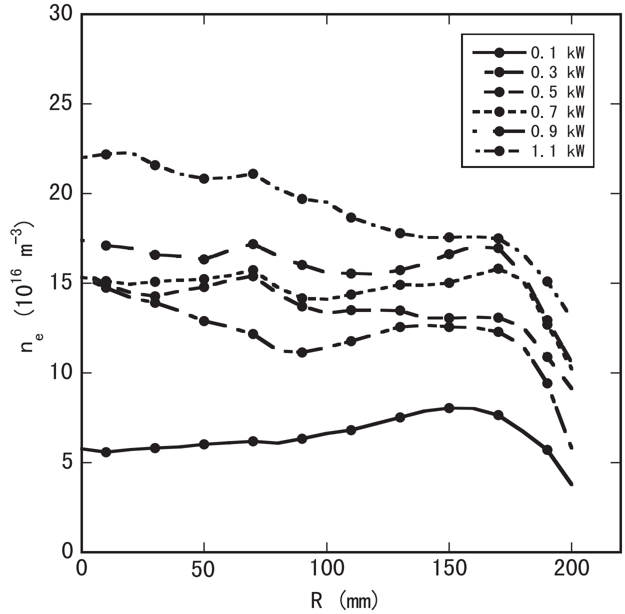

Fig. 2. Radial profiles of the electron density n_e for different microwave powers, where the pressure was 0.5 mTorr.

3. Experimental results and discussion

At first we measured the radial profile of the ion saturation current for different input microwave powers and pressures. To look for optimum conditions of uniform ECR plasma, radial profiles of the electron density were obtained from the radial profiles of the ion saturation current, where the pressure was 0.5 mTorr. Fig. 2 shows that a large diameter plasma uniform over 300 mm is achieved around 700–900 W. Note that as the microwave power is increased, the radial profile of the electron density changes from concave profile to convex profile [8–10]. To examine such a transition in detail, we plotted the dependence of both the electron density n_e and electron temperature T_e on the input powers in Fig. 3. Fig. 3(a) clearly indicates that there is a jump of the electron density around $(1.6–2) \times 10^{17}\ m^{-3}$. This critical density corresponds to the L-cutoff density that is calculated from the left-hand cutoff frequency (L-cutoff frequency) ω_L of the extraordinary wave (X-wave) [11,12] because the electron plasma frequency ω_p is proportional to $(n_e)^{1/2}$. The L-cutoff frequency is defined as follows:

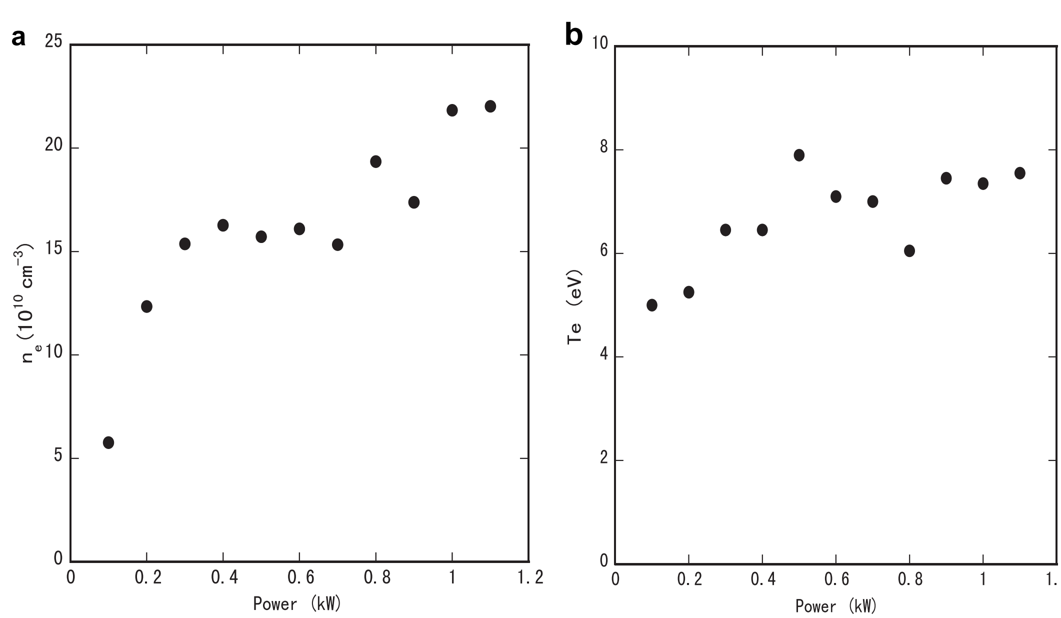

Fig. 3. The dependence of the plasma parameters on the power: (a) electron density n_e and (b) electron temperature T_e, where the pressure was 0.5 mTorr.