Producing electron cyclotron resonance plasma by using multi-frequencies microwaves and controlling board ion beam profile on a large bore ECRIS with a pair of comb-shaped permanent magnets

Y. Kato, R. Kiriyama, T. Takenaka, Y. Kurisu, D. Nozaki, K. Yano, F. Sato and T. Iida

Institute, Division of Electrical, Electronic and Information Engineering, Graduate School of Engineering, Osaka Univ., 2-1 Yamada-oka, Suita-shi, Osaka 565-0871, JAPAN.

Abstract

In order to contribute to various applications of plasma and beams based on an electron cyclotron resonance (ECR), a new concept on magnetic field with all magnets on plasma production and confinement has been proposed with enhanced efficiency for broad and dense ion beam. Resonance zones corresponding for 2.45GHz and 11-13GHz frequencies are positioned at spatially different positions. We launch simultaneously multiplex frequencies microwaves operated individually, try to control profiles of the plasma parameters and the extracted ion beams, and to measure them in detail.

Introduction

In order to establish a variety of new applications by using plasmas and beams based on an electron cyclotron resonance (ECR) plasma, a new concept on magnetic field for plasma production and confinement by using all magnets has been proposed to enhance efficiency of an ECR plasma for broad and dense ion beam source under the low pressure and also the low microwave power.[1,2] The magnetic field configuration is constructed by a pair of comb-shaped magnet which has opposite polarity each other, and which cylindrically surrounds the plasma chamber. In the comb-shaped magnetic field configuration, we succeeded in obtaining $10^{18}m^{-3}$ order dense plasma at low microwave power about 300W.[1] The resonance zones for 2.45GHz microwaves and those for 11-13GHz are constructed at different positions, *i.e.* around the center and the peripheral regions for each frequency microwave, respectively. We conduct experiments on this ECR ion source (ECRIS) by using each single frequency and multi-frequencies microwaves. While two frequencies heating experiments for enhancing performance of highly charged ion productions were tested in previous works,[3] we try to controlling large bore ion beam profile extracted from the ECRIS with all permanent magnets by using multi-frequencies microwaves.[4]

Experimental Apparatus

The top view and magnetic field configuration of the large bore ECRIS as the first stage of the tandem ECRIS are shown in Fig.1 (a) and (b), respectively. Multi-frequencies microwaves are supplied to the plasma chamber (200mm in diameter and 320mm in length) with the cylindrically comb-shaped magnetic fields. 2.45GHz microwaves (max. power: 1.3kW) are transformed from the waveguide mode to the coaxial mode by using the vacuum-tight coaxial-transformer window, and launched to the chamber along z-axis from the mirror end by tapered aluminium coaxial waveguide and copper semi-dipole (L-shaped) antenna. 11-13GHz microwaves amplified by travelling-wave transformer amplifier (TWTA, max. power: 350W) from the synthesizer are directly fed to the chamber beyond vacuum-tight quartz/polyimide window along the geometrical axis (z-axis) by bent rectangular waveguide (WR-75). Incident and reflected microwaves are tuned by the stainless steel plate tuner for the 11 to 13GHz microwaves. Operating Ar gas pressures are about $10^{-2\sim-3}$Pa.

Ion beam is extracted by the large bore extractor consisted of three electrode plates CE1-3 with multi-holes (8mmϕ×200, 154mm in diameter), and the ion beam currents are measured by two faraday cups, *i.e.* 20mm in diameter and 37mm in length horizontally I_{FCx} (x-direction) and 10mm in diameter and 37 mm in length vertically I_{FCy} (y-direction) located at z=360mm. The extraction voltage V_{CE1} and the mid-electrode CE2 voltage V_{CE2} mean voltages of electrodes CE1 and CE2 against electrode CE3, respectively.

Figure 1(b) shows schematic drawing of the cylindrically comb-shaped magnets and the contour plot at each resonance points for multi-frequencies and line forces. The positions of resonance zones for 11GHz microwaves (0.398T) are formed around peripheral region nearby the chamber wall. Those for 2.45GHz (0.0875T) are formed around the center of the chamber.

Plasma parameters are measured by Langmuir probe at the center of the chamber. The tip of this single probe sensor is consists of molybdenum rod (0.5mm in diameter and 3mm in length) covered by the alumina tube (2mm in diameter). The measurement position ranges vertically from the chamber wall (y=100mm) to the center of the chamber (y=0mm).

Experimental Results and Discussion

A. Ion beam current profiles extracted from the ECRIS at each single and multi-frequenceies

Figure 2 shows the ion beam current I_{FCy} profiles extracted from the ECRIS at each single microwave frequency 2.45GHz and 11GHz (a), and multi-frequencies (b). These data depict averaged values and the standard deviations of the several data. The V_{CE1} and the V_{CE2} voltages are 1kV and -1.0V, respectively. Ar operating pressures ranges within 0.026-0.045Pa.

Microwaves powers are 15-50W for 2.45GHz and 75-120W for 11GHz, respectively. The I_{FCy}'s in 2.45GHz cases have the peaking profiles around the center axis and those in 11GHz has almost flat or local hill around off axis. Each relative profiles dose not change largely at various experimental conditions in microwave powers and operating pressures except for the absolute values.[5] It is considered that profile controlling by single microwave frequency in fixed magnetic field by all permanent magnets are limited within operating pressure and microwave powers. Figure 2(b) shows the ion beam profiles at multi-frequencies microwaves. The each power of 2.45GHz and 11GHz frequency is the same of Fig.2 (a). The current values of the multi-frequencies increase by about 1.4 times larger than each single frequency. The I_{FCy} profile is broaden by multi-frequencies effects. The full width half maximum is larger than that of single 2.45GHz case because of effects superimposed by 11GHz microwaves and then enhanced current around the peripheral regions. We succeeded in controlling the profiles of the ion beam by multiplex frequencies microwaves.

B. Electron density and temperature profiles in ECRIS at each single and multi-frequencies

Figure 3 (a) and (b) shows the typical profiles of the n_e and the T_e obtained in both each single and multi-frequencies microwaves. The experimental conditions are the same to Fig.2 corresponding to each single and multi-frequencies. The peak positions of the n_e and the T_e are around the center in single 2.45GHz and the periphery in single 11GHz microwaves; the n_e peaks of single 2.45GHz and 11GHz are recognized around y=30 and 70mm; those of the T_e corresponds to y=10 and 70mm, respectively. The position of y=70-80mm is corresponding to nearby the second harmonic ECR for 11GHz, as we had already reported.[2] On the contrary, the n_e and the T_e profiles in the multi-frequencies microwaves are roughly the sum of the values obtained at each microwave frequencies. It is found that controlling beam profiles is available by feeding multi-frequencies microwaves and adjusting their powers to the ECRIS in which profiles of plasma parameters can be controlled due to different positioning ECR zones in the comb-shaped magnets.

C. Dependence of ion saturation currents against lower frequencies below 11GHz

We start investigating the preliminary effect of launching lower frequencies microwaves to ECRIS plasma than 11-13GHz microwaves. The TWTA is tuneable for the frequencies continuously. Figure 4 shows the typical ion saturation currents I_{is} at y=40mm in the ECRIS as the frequency changes continuously within 11.5-10.0GHz. The incident microwave powers are about 100W and Ar operating pressures are about 0.03Pa. The I_{is} shows grossly-changes periodically associated local-steep peaks. The maximum profiles are obtained around 10.65GHz within this frequencies range, while the optimized tunings for each frequency are not conducted, but there does not exist coincidence to changes of the net absorption of microwave. We will investigate the frequency dependence on production of ECR plasma and will survey the optimum coupling of multi-frequencies in near future.

The cylindrically comb-shaped magnetic field configurations are easy to scale up to more large size by selecting the number of multipole and the strength of the ring like magnets. The disadvantages of fixed magnetic configuration of ECR zone, operation and controllability of the profiles are redeemed by frequency-controllable TWTA, and moreover multiplex frequencies feeding large different frequency microwaves as like our experiments

References

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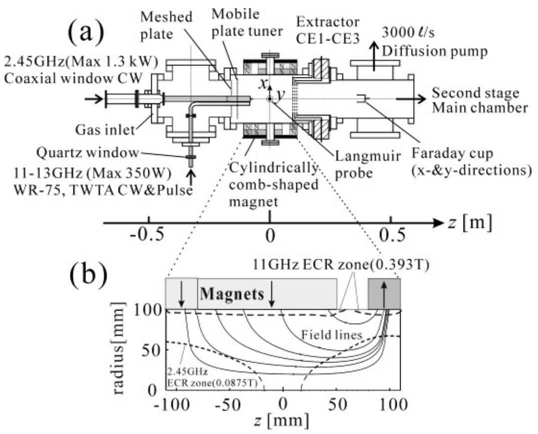

FIG. 1. Schematic drawing of the top view (a) and the magnetic field configuration (b) in the comb-shaped magnetic configuration ECRIS.

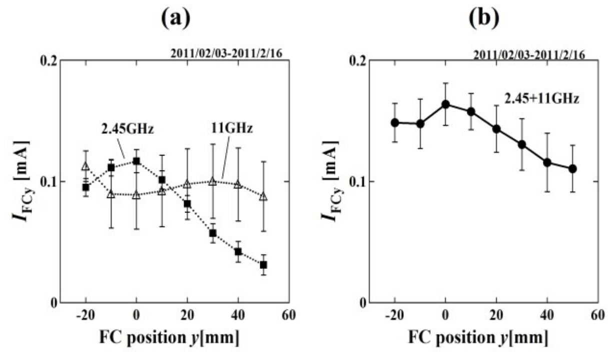

FIG. 2. Ion beam current I_{FCy} profiles extracted from the ECRIS at each single microwave frequency 2.45GHz and 11GHz (a), and multi-frequenceies (b).

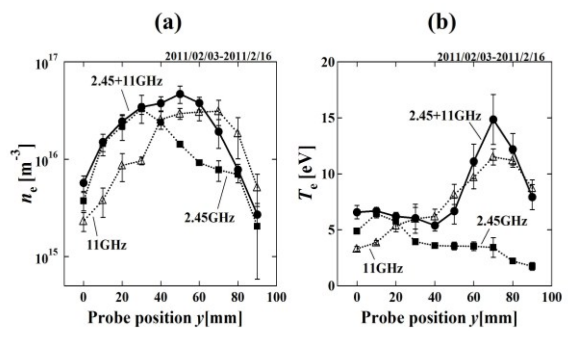

FIG. 3. Spatial profiles of the n_e (a) and the T_e (b) at each single and multi-frequencies microwaves.

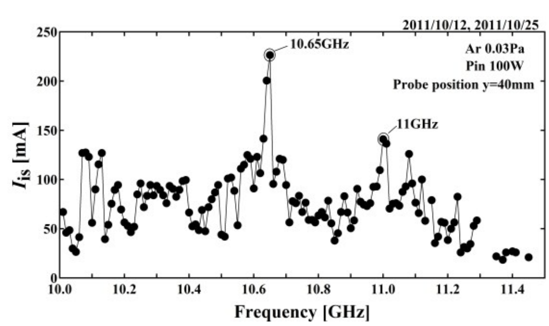

FIG. 4. Typical dependence of the I_{is} against microwave frequencies below 11-13GHz.