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Characteristics of Electron Cyclotron Resonance Heating Plasmas and Experimental Plans for Formation of Radial Electric Field in an Internal Coil Device Mini-RT

OHKUNI Kotaro, OGAWA Yuichi, MORIKAWA Junji, HORI Dan[1], YAMAKOSHI Shigeo[1], GOTO Takuya[1] and YANAGI Nagato[2]

High Temperature Plasma Center, The University of Tokyo, Tokyo 113-8656, Japan

[1]Graduate School of Frontier Science, The University of Tokyo, Tokyo 113-0033, Japan

[2]National Institute for Fusion Science, Toki 509-5292, Japan

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Abstract

The relaxation state under the condition of a strong plasma flow is represented by the double Beltrami field. The generalized Bernoulli condition gives a simple relation between the flow velocity and the static pressure. An internal coil device is suitable for exploring this new relaxation state experimentally, because an appropriate radial electric field induces a strong toroidal flow. An internal coil device, Mini-RT is constructed and the plasma production is started. The magnetic field strength near the floating coil is around 0.1 T, and a microwave of 2.45 GHz is applied for the plasma production. The Mini-RT plasmas were produced with the supported coil. Several parameters have been measured by Langmuir probes. We expect the longer confinement time under the low pressure or the coil levitation and plan the electrode biasing experiment in order to realize a high beta plasma.

Keywords:

high beta plasma, plasma flow, radial electric field, internal coil device, Langmuir probe measurement, biasing electrode

1. Introduction

The relaxed state developed by the new relaxation theory [1], gives the strong coupling of the static pressure over the magnetic pressure β and the plasma flow velocity v, that is, $\beta + (v/v_A)^2 = constant$, where v_A is Alfven velocity. To explore this new relaxation state experimentally, a toroidal device with an internal coil is suitable. By introducing a radial electric field with appropriate methods discussed later, we could drive a toroidal plasma flow given by $v_t = E_r/B_p$, where v_t, E_r and B_p are toroidal plasma flow velocity, radial electric field and poloidal magnetic field, respectively. If the radial electric field is uniform, the poloidal magnetic field decreases and the toroidal plasma flow velocity increases with the radial direction. We expect to confine the high-beta plasma at the core region by utilizing this toroidal flow distribution. In an internal coil device Mini-RT, a high temperature superconductor (HTS) coil is applied. This coil, with a major radius of 150 mm and an averaged minor radius of 40 mm, is made of Bi-2223 tape with 428 turns and can be operated at currents up to 50 kAturns. The magnetic field strength near the coil is around 0.1 T, and a microwave of 2.45 GHz is applied for the electron cyclotron heating (ECH) plasma production. The vacuum chamber is 1 m in diameter and 1 m in height. The Mini-RT first plasma is produced with the supported coil. Several parameters have been measured by Langmuir probes. In order to excite a strong plasma flow in a toroidal direction, we are planning to introduce a radial electric field and to make the $\boldsymbol{E} \times \boldsymbol{B}$ plasma flow. The radial electric field in the plasma would be produced by several techniques. The ECH could produce high energy electrons more than a few tens keV [2]. In a dipole experiment, the high-energy electrons more than 10 keV were produced in the low background pressure such as a few micro Torr [3]. Some part of the extremely high energy electrons might escape from the magnetic surface by orbit loss. This might yield the non-neutralized plasma and the build-up of the radial electric field. Another idea is proposed for injecting electrons through the separatrix. By utilizing the chaotic motion, some part of electrons can travel into the plasma [4]. A direct insertion of the electrode inside the plasma would be a most straightforward method to drive the radial electric field, as demonstrated by the CCT tokamak for achieving H-mode plasmas [5]. Figure 1 shows the schematic drawing of an idea for confining a high beta plasma with an internal coil device.

Corresponding author's e-mail: ohkuni@plasma.q.t.u-tokyo.ac.jp

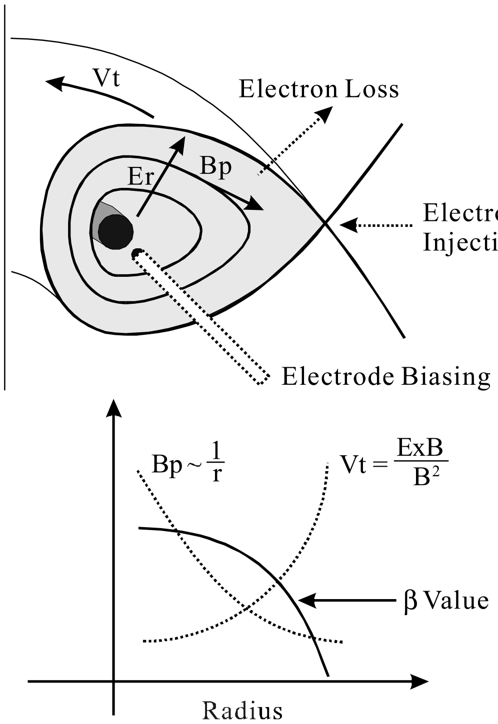

Fig. 1 Schematic drawing of an idea for confining a high beta plasma with several methods to produce the radial electric field.

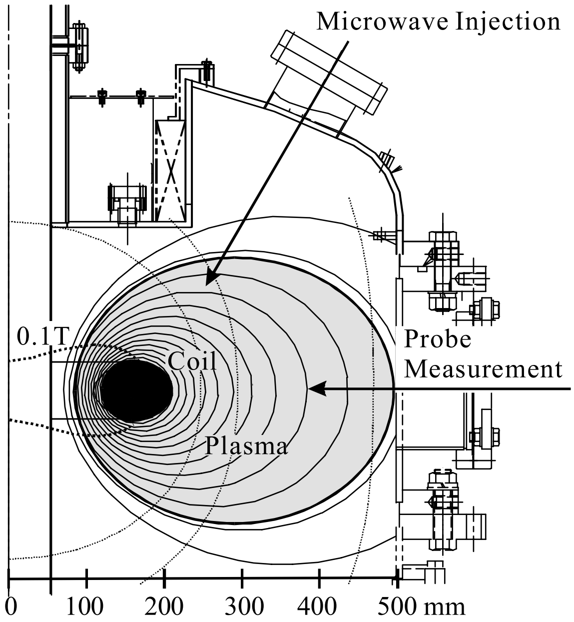

Fig. 2 A cross section of Mini-RT and a magnetic field configuration with internal coil current 25 kAturns.

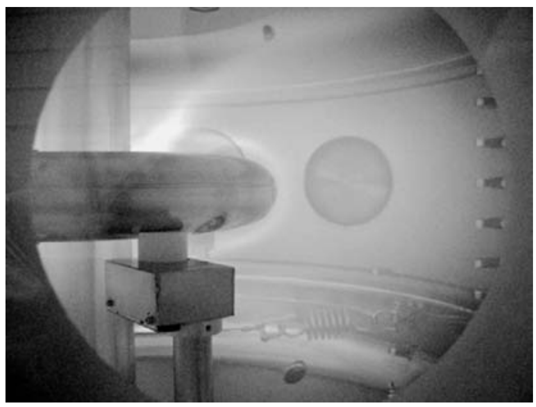

Fig. 3 A photograph of Mini-RT plasma with the supported internal coil.

2. Experimental setup

The confining magnetic field is produced by a HTS coil supported by three poles. This experiment is carried out using ECH plasmas produced by 2.45 GHz microwaves. The electron density and its temperature are determined by the use of a double probe and a triple probe. A poloidal cross sectional view of Mini-RT is shown in Fig. 2. The microwaves were injected from upper inclined port and the probes were inserted from horizontal ports. The triple probe and the double probe are 135 and 90 degrees apart from the microwaves in the toroidal direction, respectively. The density and temperature measured by the triple probe were indicated in this paper, however, there are the difference between those measured by the double probe and those measured by the triple probe, that is, the former are almost 3/4 and 2/3 of the latter, respectively. The coil current and the microwave input power are ~30 kAturns and ~2.6 kW, respectively. The operating pressure is kept between 0.02 and 0.05 Pa, which is measured by ionization gauge put next to the gas-supplying port. The plasma density is about 10^{16} m^{-3} with a typical electron temperature range of 10 to 20 eV.

3. Experimental results

A photograph of Mini-RT plasma with the supported coil is shown in Fig. 3. We examined the characteristics of the plasmas about the pressure dependence, the power dependence and the radial profiles of electron temperature and density. Figure 4 shows the pressure dependence of electron temperature and its density. The coil current and the microwave input power were 28 kAturns and 550 W, respectively. The triple probe was fixed at 240 mm, that is, 30 mm apart from the internal coil. In this condition, the electron density peaking around 0.03 Pa is about 2×10^{16} m^{-3} and its temperature is almost constant at 18 eV. The density decreases toward the lower pressure region under 0.01 Pa, where we challenged the plasma production with a preliminary ionization. The ionization ratio at the maximum density is 0.1% in this condition. Figure 5 shows the microwave input power dependence of electron temperature and its density. The coil current, the operating pressure and the probe position were 25 kAturns, 0.02 Pa and 240 mm. The density increases with the input power and about 5×10^{16} m^{-3} at 2.6 kW, which is the highest density in this present experimental series. The temperature is mostly constant or gradually decreases form 18 to 12 eV. Figure 6 shows the radial profiles of electron temperature and its density. The coil

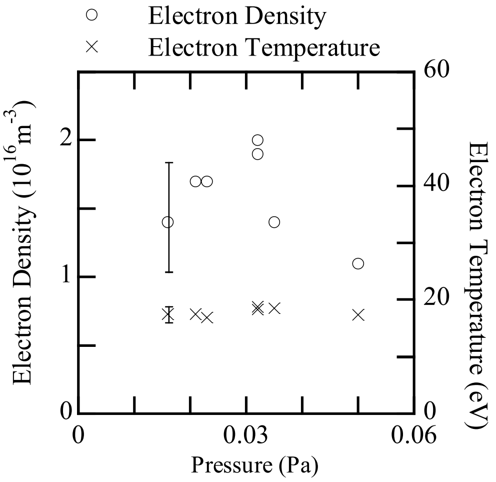

Fig. 4 Pressure dependence of electron density and electron temperature.

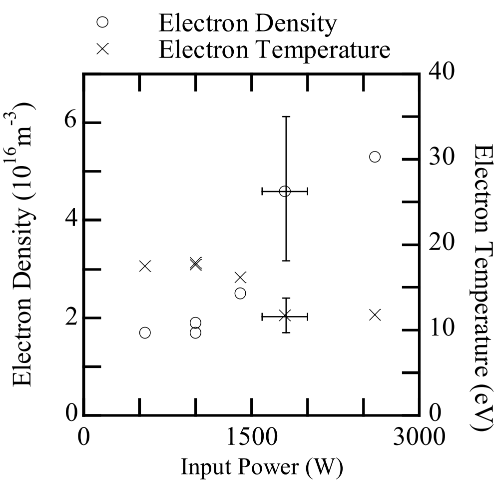

Fig. 5 Input power dependence of electron density and electron temperature.

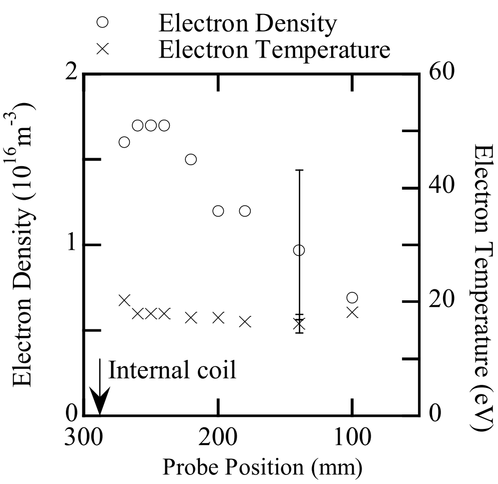

Fig. 6 Radial profiles of electron density and electron temperature.

current, the microwave input power and the operating pressure were 22 kAturns, 1.3 kW and 0.02 Pa, respectively. The triple probe moved from 230 mm to 400 mm. The density decreases with the radial direction, and the temperature is almost constant at 18 eV.

4. Discussions

4.1 Confinement time

Energy confinement time $\tau_E \sim neTV/P$ derived from the microwave input power $P \sim 10^3$ W, the density $n \sim 10^{16}$ m^{-3}, the temperature $T \sim 10$ eV and the plasma volume $V \sim 10^{-1}$ m^{-3} is about 10^{-6} s. We would like to compare it with other specific time. Electron-neutral collision time is 10^{-6} s, because the ionization ratio is 0.1% in this experiment. The grad-B and curvature drift speed is about 10^2 – 10^3 m/s when the temperature T and the magnetic field B are about 10 eV and 10^{-3} – 10^{-2} T, respectively. The averaged time of toroidal drift electrons to conflict with the coil-supporting poles is about 10^{-4} s. At present, the energy confinement time would be governed by the electron-neutral collision time. If the plasma could be produced at the lower pressure, the increase of the energy confinement time would be expected because of the reduction of the electron-neutral collision, and would be followed by the limitation due to the drift conflict time to the coil-supporting poles. We expect the longer confinement time at the lower pressure and the coil levitation. In the past spherator experiment, the confinement time at low pressure is ten times as long as that at high pressure, and more, the confinement time with a levitated condition is two times as long as that at low pressure [6,7].

4.2 Electrode biasing for radial electric field

We plan to have a toroidal flow produced by the radial electric field. A plasma potential (Vs) is estimated by an electrode floating potential (Vf) and an electron temperature (Te), such as $Vs = Vf + 3Te$. In this experiment, the plasma potential has 30 to 40 V and almost same shape with the electron temperature profile shown in Fig. 6. As we need to enhance the radial electric field, the electrode biasing method is prepared. The toroidal velocity is approximated by Er/Bp and the damping is balanced by the toroidal component of the $\boldsymbol{J} \times \boldsymbol{B}$ force [8]. The biasing electrode has a cylinder form with 60 mm diameter and 60 mm height.

The electrode is considered a single probe, and then the electron and the ion saturation current are 85 mA/cm^2 and 3 mA/cm^2 at the electron temperature 10 eV and the electron density 10^{16} m^{-3}, respectively. The electron saturation current is drawn by the 100 V bias voltage. We intend to prepare an electrode with the surface area 100 cm^2 and a power supply with more than 100 V – 10 A specifications.

5. Summary

The internal coil device Mini-RT is constructed to explore the new relaxation state experimentally, and to produce the high-beta plasma. The Mini-RT plasmas have been produced with the supported coil by using 2.45 GHz microwave and several parameters have been measured by Langmuir probes. The electron density is peaking around 0.03 Pa and its temperature is almost constant in the pressure alteration experiment. The ionization ratio is 0.1% in this condition. The density increases with the input power and about 5×10^{16} m^{-3} at 2.6 kW, which is the highest density in Mini-RT at the present. The density decreases and the temperature is almost constant with the radial direction. Energy confinement time derived from the microwave input power is about 10^{-6} s, and we expect the longer confinement time under the low pressure or the coil levitation in the next experimental programs. As the plasma potential is almost uniform with the radial direction, we need to enhance the radial electric field by the electrode biasing or other methods.

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