Helicon wave experiments with steep magnetic field gradient devices Mini-RT and Mini-RT/L

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1. Introduction

To explore high beta plasmas on the internal coil device Mini-RT (B ~ 0.01T) with the dipole magnetic configuration, the Electron Cyclotron Wave (f =2.45GHz) has been applied and the plasma density of 10^{17} m^{-3} (about two times higher than the cut-off density) has been achieved. In addition, the mode conversion to the Electron Bernstein Wave has been observed by direct measurement of wave propagation in plasmas [1]. Now we have conducted helicon wave experiments in the Mini-RT device, since helicon wave might be an attractive candidate to produce higher density plasmas in the low magnetic field devices.

In linear and torus devices, the high density plasmas up to ~$10^{18\sim19}$ m^{-3} have been achieved [2-4]. Compared with these devices, the Mini-RT has slightly unique characteristics; i.e., the magnetic field produced by the dipole configuration has a steeper gradient, i.e., B ~ $1/R^2$. In our experiments the radio frequency (RF) wave with 13.56 MHz has been applied for the Mini-RT plasmas. In addition to the torus device Mini-RT, a linear device Mini-RT/L with a diverging magnetic field configuration has been constructed, in order to study helicon wave characteristics in a steep magnetic field gradient.

2. Experimental results in the Mini-RT device

The magnetic configuration of the Mini-RT device is shown in Fig. 1, where the High Temperature Superconductor REBCO is employed for the internal coil [5]. The major radius and the coil current of the internal ring coil are 0.15m and 50 kAt, respectively. As shown in Fig. 2, we have considered two types of antenna to excite helicon wave as shown, where a loop antenna in toroidal direction and a saddle one. Here we have installed a saddle type antenna at the outer surface of the plasma column. At first, we have calculated the wave characteristics with FDTD code for the Mini-RT dipole magnetic field configuration. Figure 3 shows the calculation results for (a) high ($\omega < \omega_{pe}$) and (b) low ($\omega > \omega_{pe}$) density cases. When the plasma density is high (i.e., $\omega < \omega_{pe}$), the wave with the short wave length appears at the plasma outer region, as shown in Fig. 3(a). This might suggest the mode conversion to Trivelpiece-Gould wave from helicon one.

The radio frequency wave with 13.56 MHz has been superimposed to plasmas produced by the Electron Cyclotron Wave (ECW : f=2.45GHz). As shown in Fig. 4, unfortunately, the plasma density is suppressed during the RF pulse. Although Argon is employed and the RF power is increased up to ~ 1kW, we could not observe an improvement of the plasma density. Compared with other helicon plasma experiments, the Mini-RT device has the following characteristics; i.e., a plasma radius is relatively large (a = 15 ~ 20 cm), a filling pressure is limited at low level (0.01 ~ 0.05 Pa), and only a saddle type antenna can be installed at the outer surface of the plasma column. In addition, we have observed a glow discharge at unexpected regions such as a feeder of the antenna and an area between antenna and vacuum chamber. These might be reasons why the high density plasma has not been achieved in the Mini-RT device.

3. Helicon wave experiments with the linear device Mini-RT/L

Since the steep gradient configuration of the magnetic field in the Mini-RT device is quite different from other linear and torus devices, a new linear device Mini-RT/L with a divergent magnetic field has been fabricated, in order to study excitation, propagation and absorption of the helicon wave in the steep magnetic field gradient configuration. Figure 5 shows the schematic drawing of the Mini-RT/L device, where the magnetic field strength is given in Fig. 5. A loop antenna has been installed at two sections; A and B shown in Fig. 5.

At first, a loop antenna is located at the position A. As the helicon wave power is increased up to 3 kW, the plasma density of $4x10^{17}$ m^{-3} has been achieved, shown in Fig. 6. In the helicon wave experiments a stepwise increase of the plasma density have been observed as the RF power is increased; i.e., CCP(Capacitor Coupled Plasma), ICP(Inductively Coupled Plasma) and HWP(Helicon Wave Plasma) [6]. While the density jump seems not to appear in Fig. 6, we could expect the production of Inductively Coupled or Helicon Wave Plasmas for 1kW RF power cases, because the high density plasmas up to $(3\sim4)x10^{17}$ m^{-3} have been produced. It has been observed the monotonic increase of the plasma density according to the increase of the magnetic field strength (B < 15 G).

Next we have conducted helicon plasma experiments in the case that the loop antenna is located at the position B. As the magnetic field has been raised, shown in Fig. 7, the plasma density has become the maximum value around 40 G. This characteristics seems to be similar to that observed by F.F. Chen[7]. Since the wave index parallel to the magnetic field is estimated to be $k_{//} = 10 \sim 30$ m^{-1}, the corresponding phase velocity is roughly equal to the thermal velocity of electron with the temperature of a few tens eV. This would suggest the possibility of Landau damping of the helicon wave.

References

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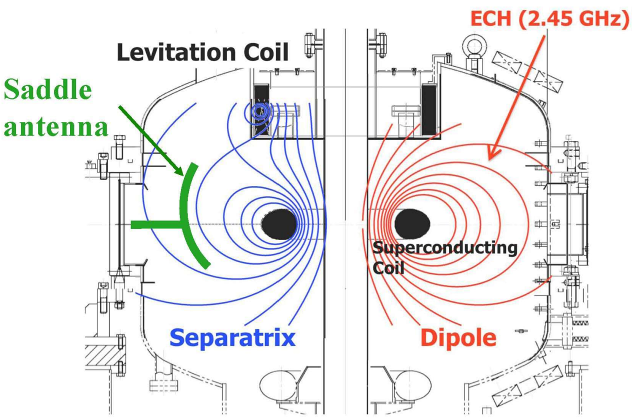

Fig. 1 Schematic drawing of the internal coil device Mini-RT (left; a separatrix configuration and right: dipole one). A saddle antenna is installed at the outer surface of the plasma column.

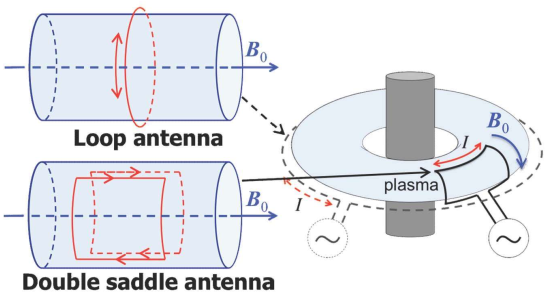

Fig. 2 Schematic drawing of (a) a loop antenna and (b) a saddle one, compared with linear devices.

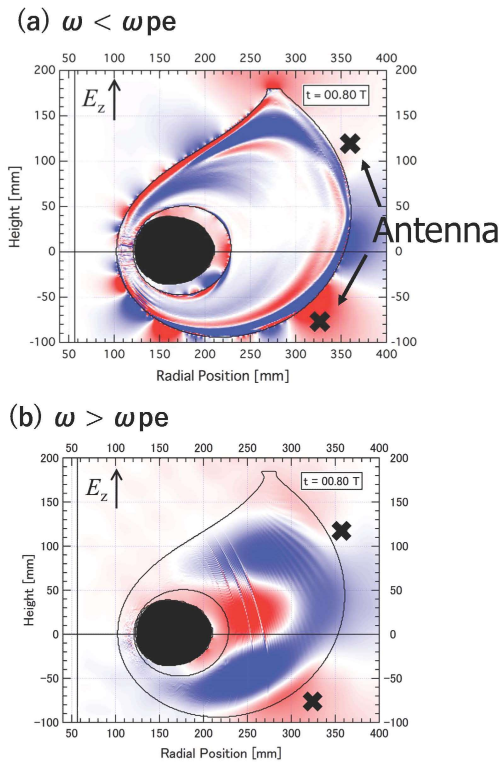

Fig. 3 FDTD calculation results for (a) high and (b) low density cases, where f = 13.56 MHz. In the case (a) the wave with the short wave length is seen at the outer region of the plasma column.

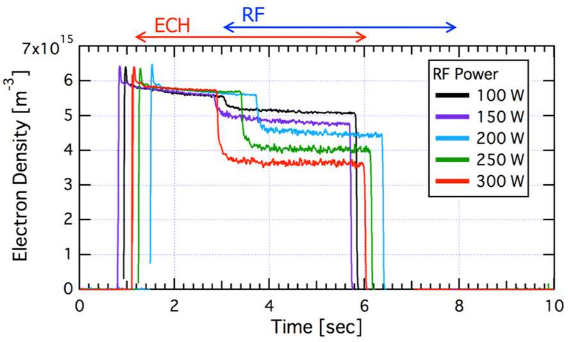

Fig. 4 Superimposed experimental results; the RF wave (f=13.56MHz) has been superimposed with the ECW (f=2.45GHz). The suppression of the plasma density has been observed when the RF wave is applied.

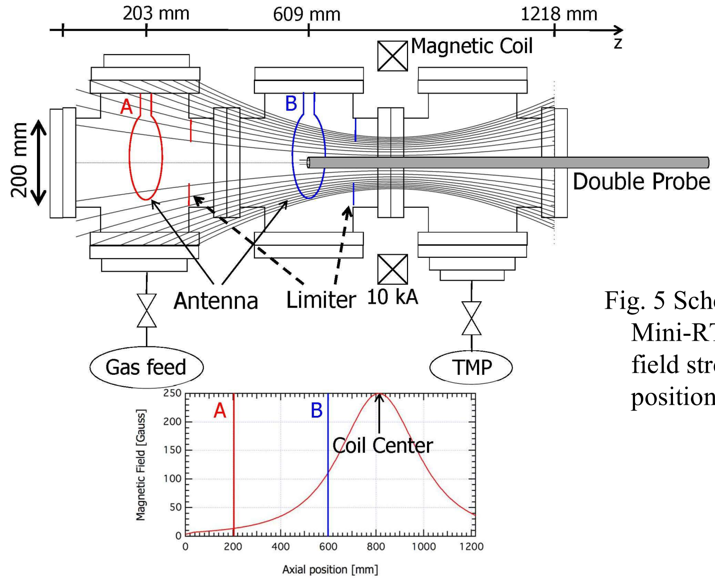

Fig. 5 Schematic drawing of the linear device Mini-RT/L and the spatial profile of the magnetic field strength. The loop antenna is installed at the positions A and B.

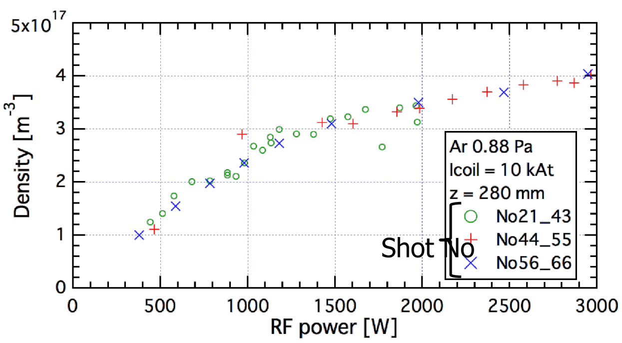

Fig. 6 Plasma density as a function of the RF power in the Mini-RT/L experiments. The plasma density increased up to $4\text{x}10^{17}$ m^{-3} as the RF power was increased to 3 kW.

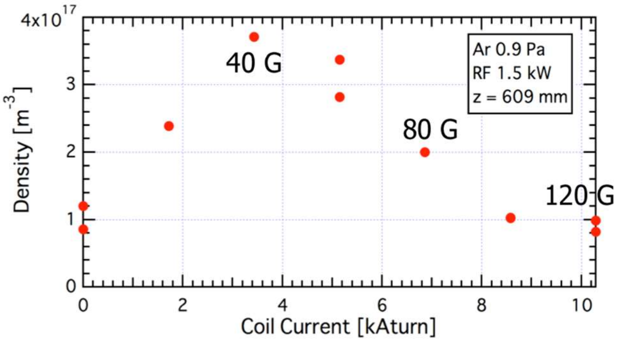

Fig. 7 Plasma density as a function of the coil current in the Mini-RT/L experiments. It is observed that the plasma density has a peak at B ~ 40 G.