Various Parameter Measurements in Dual-ECR Heating on Electron Cyclotron Resonance Ion Source

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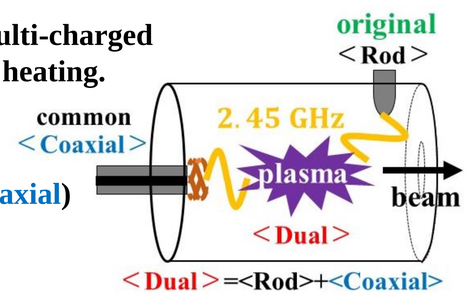
§ 1. Introduction

Background

■ We succeeded in generating multi-charged Ar ions effectively by Dual-ECR heating.

■ Dual-ECR heating means we introduced microwaves from both the upstream side (Coaxial) and the downstream side (Rod).

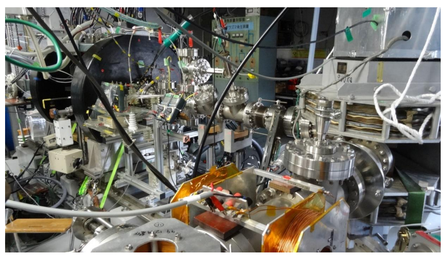


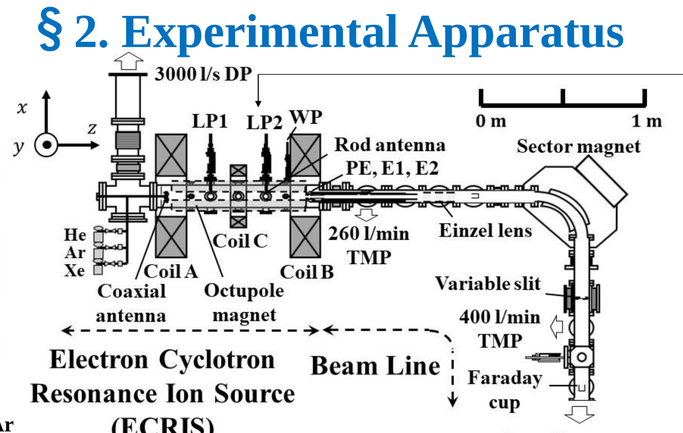
Objectives

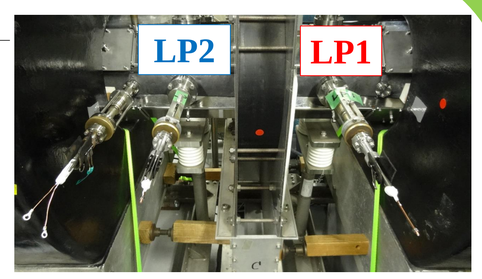
■ We obtained the relationship between net microwave powers and the beam currents of multi-charged Ar ions by Rod, Coaxial, and Dual-ECR methods.

■ We measured the beam currents and plasma parameters such as electron density (n_e) and electron temperature (T_e), and we obtained their spatial distributions by each method.

§ 2. Experimental Apparatus







Experimental procedure
1. Main gas:Ar
2. Applying currents to Coil A, B, and C
3. Introducing microwaves from antennas (Coaxial, Rod)
4. Extraction voltage 10 kV and ions are measured by Faraday cup

Figure 1: Experimental apparatus (Osaka Univ.).

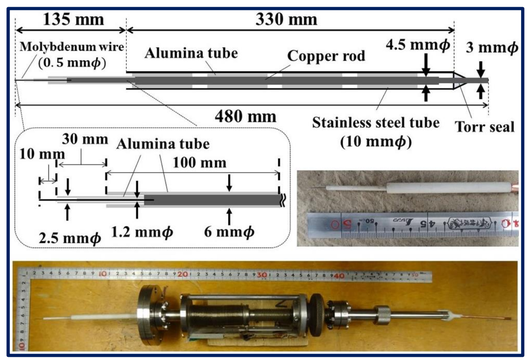
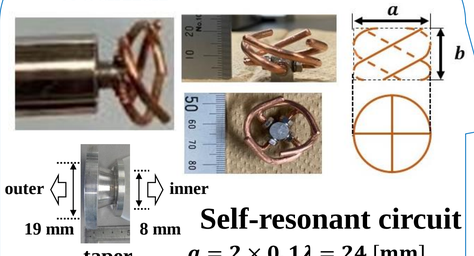


Figure 3: The design and photographs of Langmuir probe 1, 2 (LP1, LP2).

＜Coaxial＞



Self-resonant circuit

$a = 2 \times 0.1\lambda = 24$ [mm]

$b = 0.1\lambda = 12$ [mm]

$\left(\lambda = \frac{c}{f} = \frac{3.0 \times 10^8}{2.45 \times 10^9} \approx 0.12 \text{ [m]}\right)$

Microwave for 2.45 GHz

$B = \frac{m\omega_c}{q} \approx 0.0875$ [T]

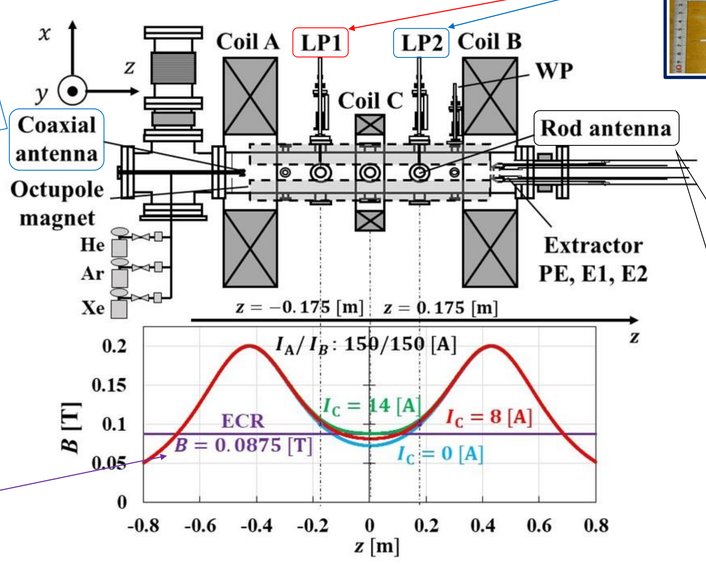
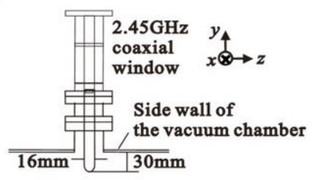


Figure 2: The ECRIS and the distribution of the magnetic field.

＜Rod＞



§ 3. Theoretical Background

§ 3.1 ω-k diagram and cutoff (only electron)

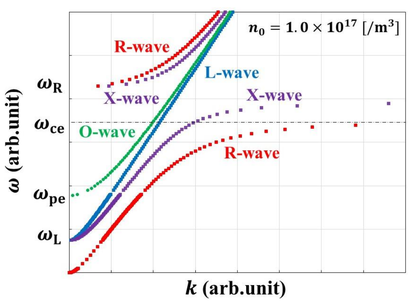


Figure 4: ω-k diagram.

R-wave : $k^2 = \left(\frac{\omega}{c}\right)^2 \left\{1 - \frac{\omega_{pe}^2}{\omega(\omega - \omega_{ce})}\right\}$

L-wave : $k^2 = \left(\frac{\omega}{c}\right)^2 \left\{1 - \frac{\omega_{pe}^2}{\omega(\omega + \omega_{ce})}\right\}$

X-wave : $k^2 = \left(\frac{\omega}{c}\right)^2 \frac{\left\{1 - \frac{\omega_{pe}^2}{\omega(\omega - \omega_{ce})}\right\}\left\{1 - \frac{\omega_{pe}^2}{\omega(\omega + \omega_{ce})}\right\}}{1 - \frac{\omega_{pe}^2}{\omega^2 - \omega_{ce}^2}}$

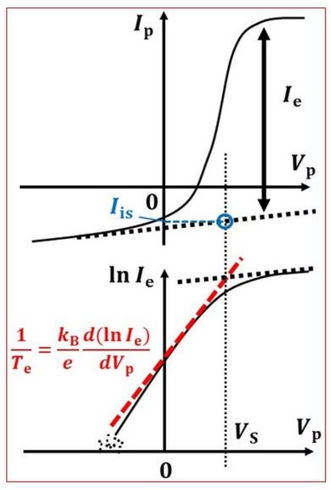
O-wave : $k^2 = \left(\frac{\omega}{c}\right)^2 \left(1 - \frac{\omega_{pe}^2}{\omega^2}\right)$

$\left(\omega_{ce} = \frac{eB}{m}, \omega_{pe} = \sqrt{\frac{n_0 e^2}{\epsilon_0 m}}\right)$

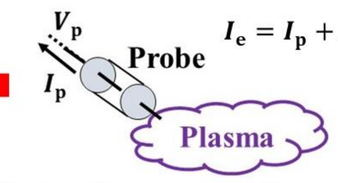
♦In the electromagnetic waves, there exist right-hand polarization wave (R-wave) and left-hand polarization wave (L-wave) and two cutoffs (ω_R, ω_L).

$$\omega_R = \frac{\omega_{ce} + \sqrt{\omega_{ce}^2 + 4\omega_{pe}^2}}{2}, \omega_L = \frac{-\omega_{ce} + \sqrt{\omega_{ce}^2 + 4\omega_{pe}^2}}{2}$$

§ 3.2 Plasma parameters derivation



♦Plasma parameters were derived by Langmuir probe methods.



$I_e = I_p + I_i$

- Electron Temperature: T_e

$$\frac{1}{T_e} = \frac{k_B}{e}\frac{d(\ln I_e)}{dV_p}$$

- Electron density: n_e

$$n_e = \frac{I_{is}}{0.61eS}\sqrt{\frac{M}{k_B T_e}}$$

(M: ion mass, S: surface area of probe)

Figure 5: Langmuir probe methods.

§ 4. Experimental Results

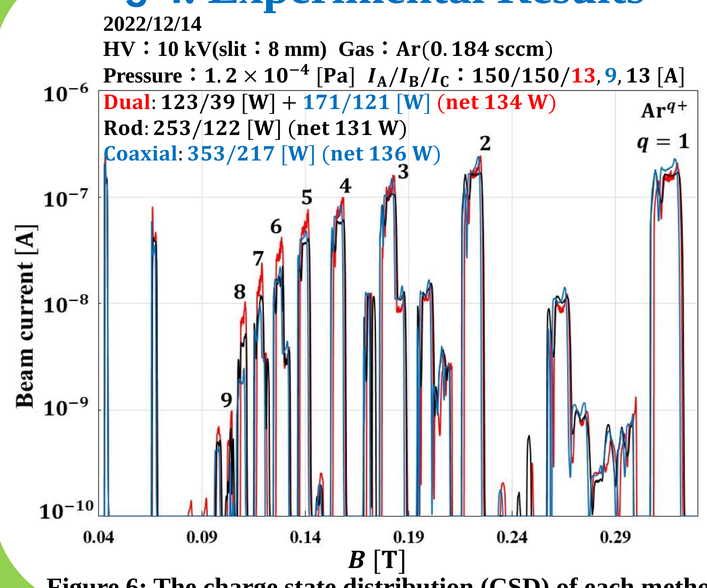


Figure 6: The charge state distribution (CSD) of each method.

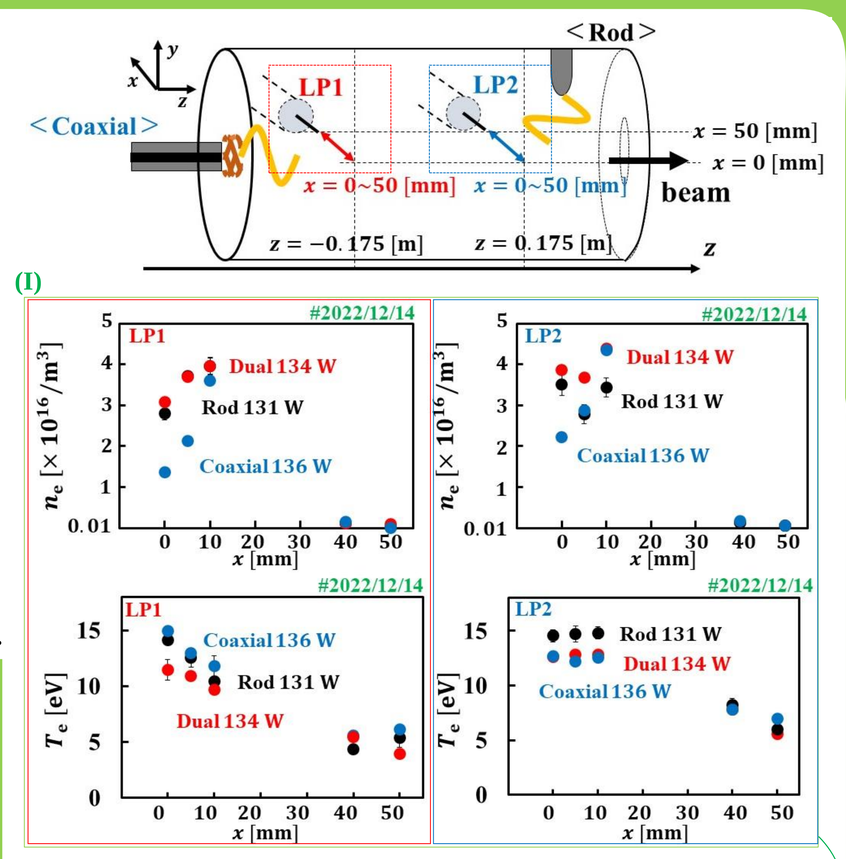


Figure 7: The distribution of plasma parameters at high microwave powers.

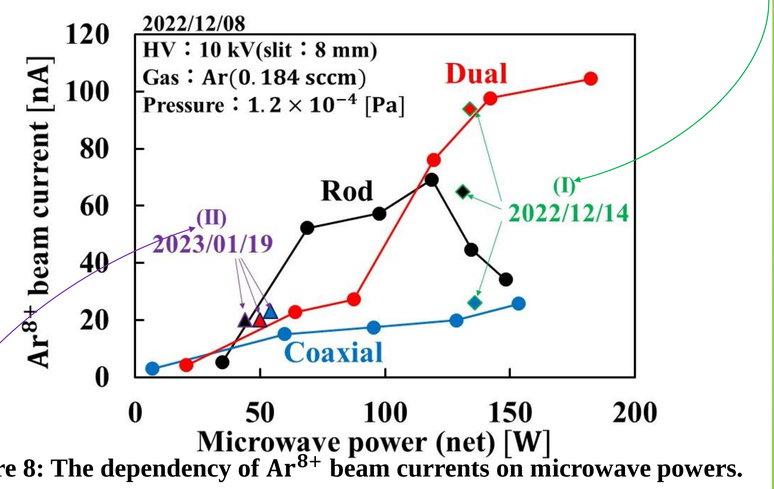


Figure 8: The dependency of Ar^{8+} beam currents on microwave powers.

We found: ♦Rod: Ar^{8+} increased around 120 W and decreased after that.
♦Coaxial: Ar^{8+} increased but the value was lowest.
♦Dual: Ar^{8+} increased and didn't go lower.

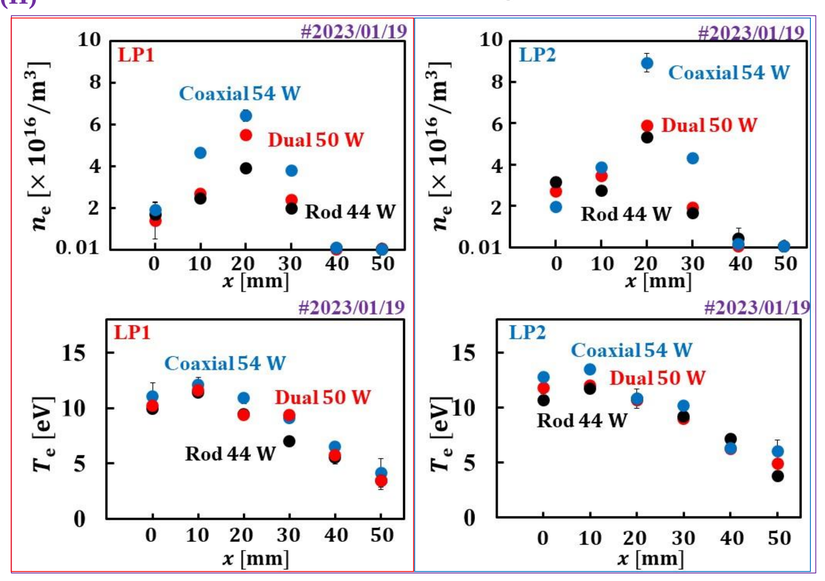


Figure 9: The distribution of plasma parameters at low microwave powers.

§ 5. Discussion

Q. Why was n_e at Dual-ECR heating highest?

-We thought R-wave cutoff was one of the primary factor.

The magnetic field B values by z-coordinate.

R-wave can't pass towards the opposite side of ECR point. (Figure 11) (Case ＜Coaxial＞)

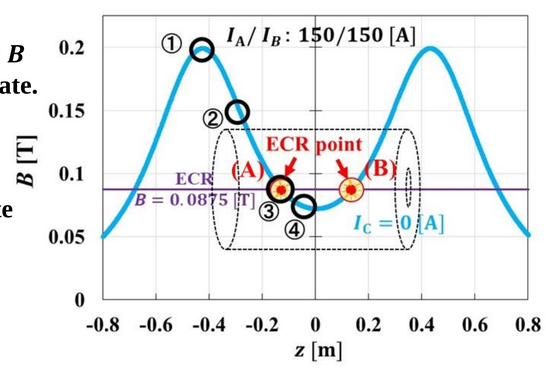
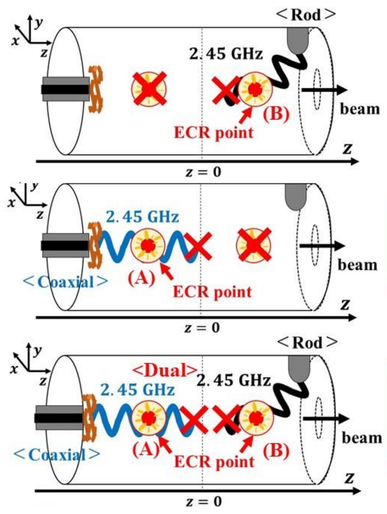


Figure 10: The distribution of magnetic field and ECR points.



Case ＜Rod＞…
Resonates only at (B)
♦Electrons were supplied only by (B).

Case ＜Coaxial＞…
Resonates only at (A)
♦Electrons were supplied only by (A).

Case ＜Dual＞…
Resonates at both (A) and (B)
♦Electrons were supplied by both (A) and (B).

♦n_e at Dual-ECR heating was highest in three ways.

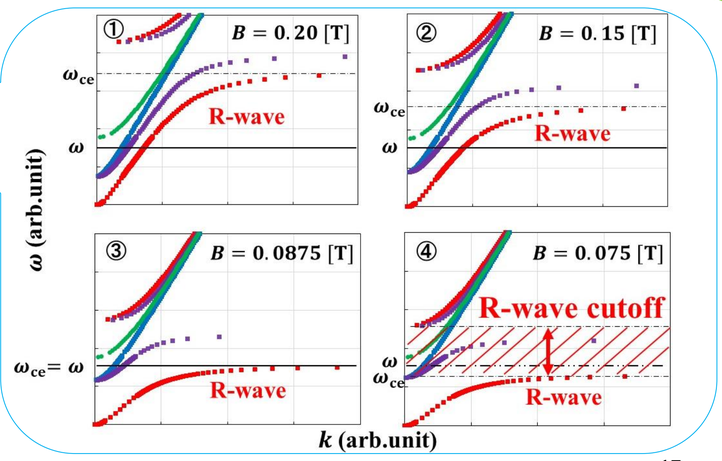


Figure 11: The ω-k diagrams and R-wave cutoff ($n_0 = 1.0 \times 10^{17}$ [/m^3]).

§ 6. Conclusion

■ Ar^{8+} beam currents of Rod, Coaxial, and Dual:

♦Ar^{8+} beam currents at Dual-ECR heating was highest in three ways of introducing microwaves.

♦There was an instability at Rod and the values were low at Coaxial.

We can generate multi-charged Ar ions stably by Dual-ECR heating.

■ Plasma parameters of Rod, Coaxial, and Dual:

n_e: highest at Dual-ECR heating

T_e: higher at the microwave introducing side

■ From Discussion…

It is reasonable that n_e at Dual-ECR heating was highest in three ways.