Plasma parameter measurement during efficiently producing multicharged ions by selectively heating low-Z ions on Electron Cyclotron Resonance Ion Source in mixing low-Z gases

The University of Osaka

Shinji Tokuno [1*], Yushi Fujimura [1], Akinobu Ide [1], Daichi Inoue [1], Toyohisa Asaji [2], Masayuki Muramatsu [3], Atsushi Kitagawa [3], and Yushi Kato [1]

[1] The University of Osaka, Suita-shi, Osaka, Japan
[2] The University of Shiga Prefecture, Hikone-shi, Shiga, Japan
[3] National Institutes for Quantum Science and Technology, Chiba-shi, Chiba, Japan
* tokuno@nf.eie.eng.osaka-u.ac.jp

ICIS 2025 OXFORD

§ 1. Introduction

■Background

- Electron cyclotron resonance ion sources (ECRIS) are used in various fields, such as cancer treatment and accelerators. We are conducting research on ECRIS for efficient multicharged ion generation.
- One method of increasing multicharged ion is light element gas mixing, which introduces low-Z gases as mixed gases into the plasma of the operating gas.
- We conducted experiments based on the idea that gas mixing effects could be further enhanced by ion cyclotron resonance (ICR) heating using low frequencies (RF) electromagnetic waves for light element ions in ECR plasma.

■Objectives

- We conduct experiments in 2.45 GHz ECRIS. He or Ar is mixed with operating gas Xe in ECRIS. We introduced into the ECR plasma low frequency RF (He: 400 kHz, Ar: 40 kHz), and measure charge state distribution (CSD) of extracted multicharged ion beam.
- To confirm the change in plasma parameters caused by RF, two Langmuir probes are used to measure the plasma, and the current-voltage characteristics are obtained to measure the electron temperature T_e and the radial distribution of the ion saturation current I_{is} with or without low-frequency RF. I_{is} is proportional to electron density n_e. ($I_{is} = \kappa N_e e \sqrt{\frac{kT_e}{m_i}} S$)

§ 2. Experimental apparatus

■ECRIS in Osaka Univ.

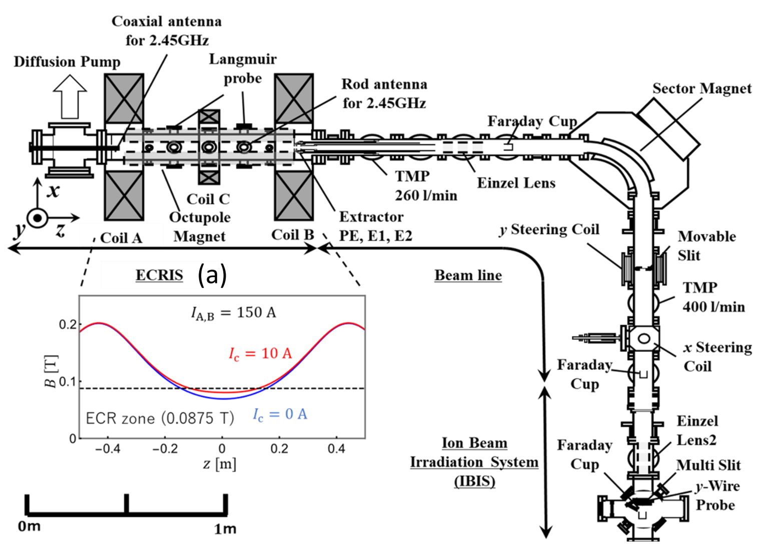


Fig.1: The top view of ECRIS, beam line, IBIS, and Magnetic field strength distribution of ECRIS (a)

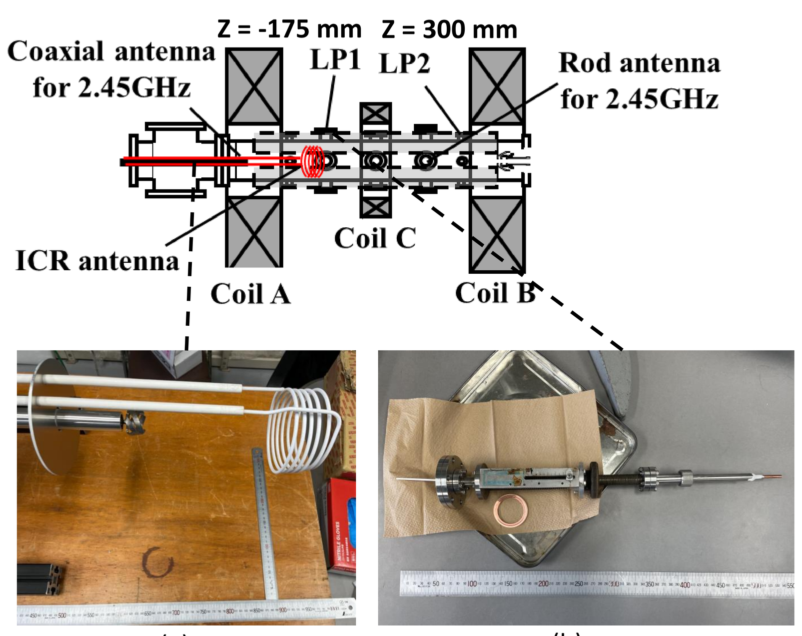
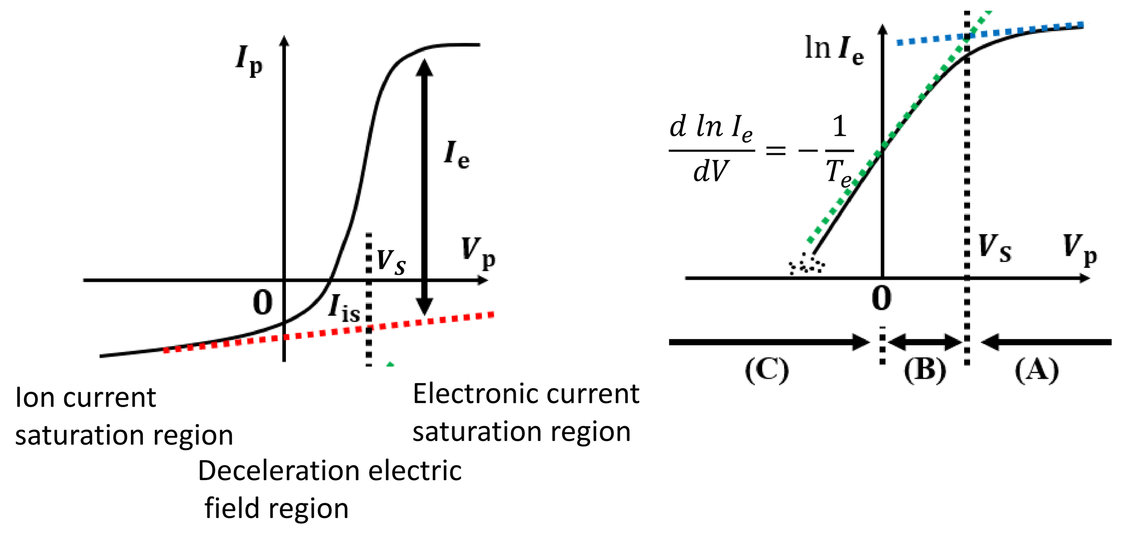


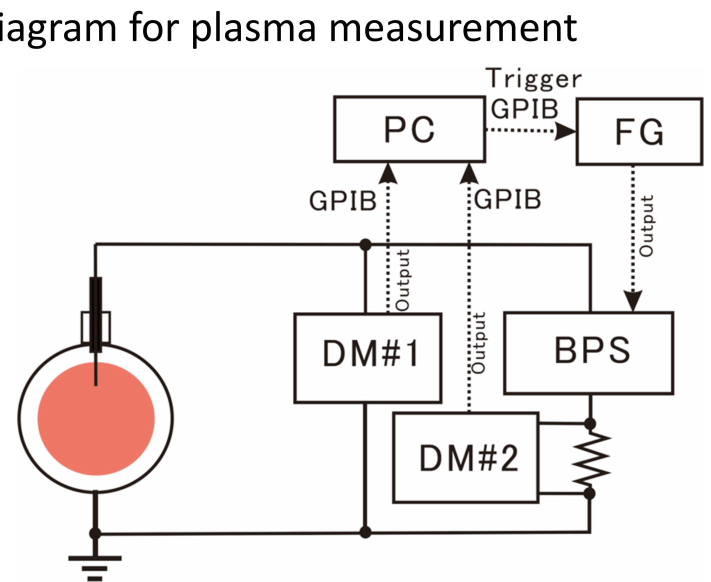
Figure 2: ECR plasma generation unit
(a)ICR antenna(b) Langmuir probe(LP1)

§ 3. Experimental method

■Plasma parameter analysis method



■Circuit diagram for plasma measurement



§ 4. Experimental results

■CSDs for Xe/He mixing plasma

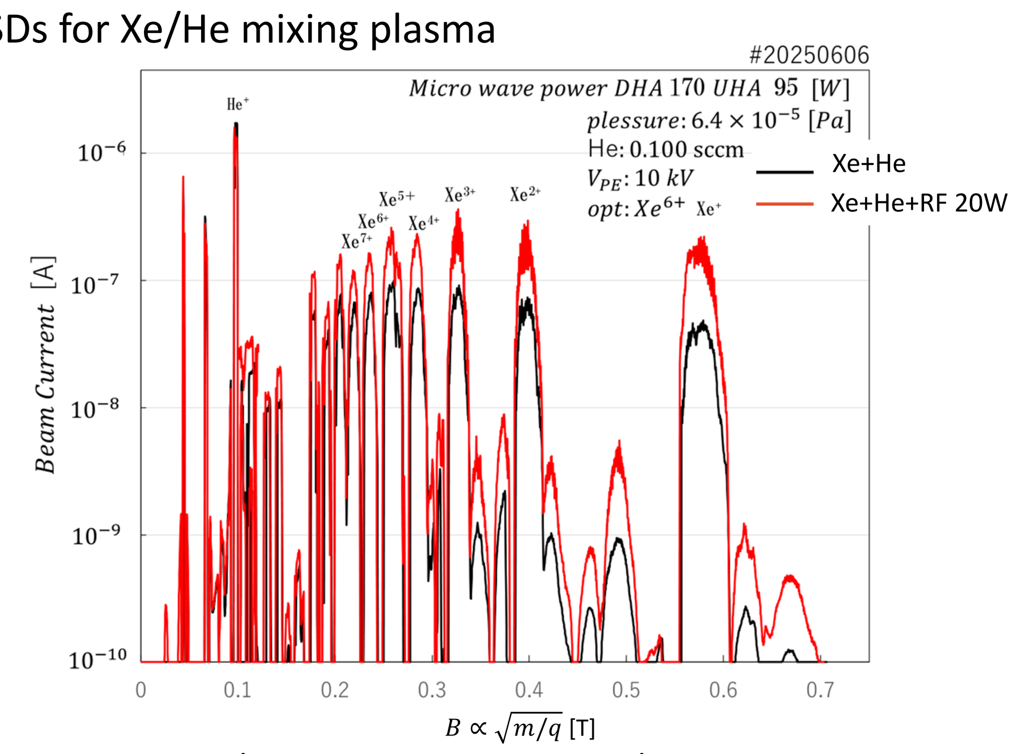


Fig.3: CSDs for Xe/He mixing plasma and Xe/He mixing plasma with 400 kHz RF for ICR heating.

■CSDs for Xe/Ar mixing plasma

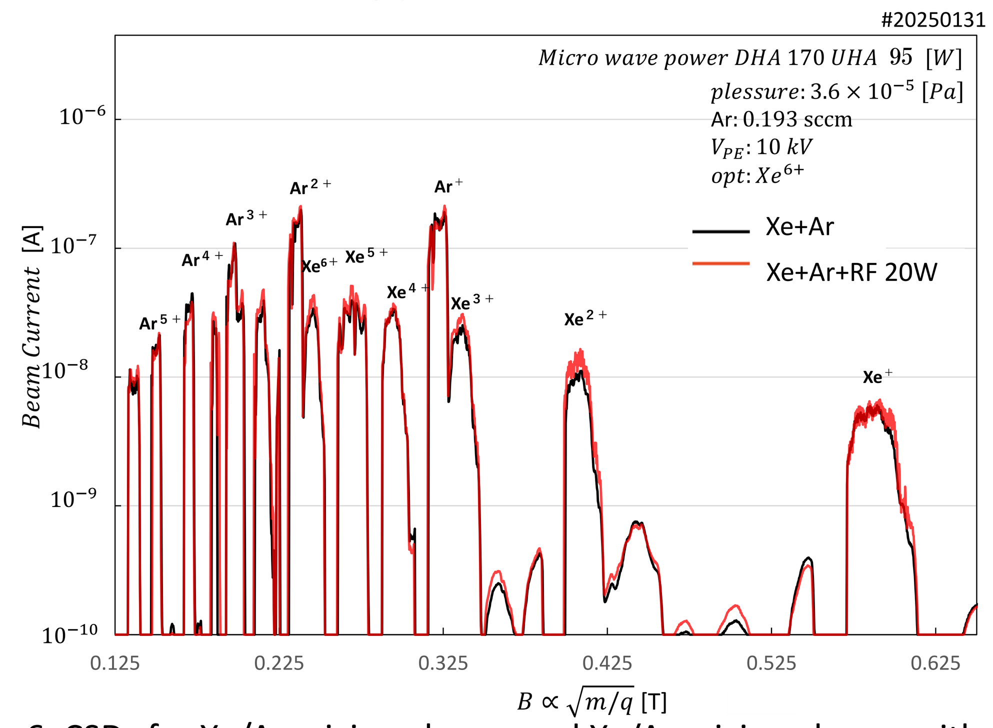


Fig.6: CSDs for Xe/Ar mixing plasma and Xe/Ar mixing plasma with 40 kHz RF for ICR heating

■Plasma parameter measurement for Xe/He mixing plasma

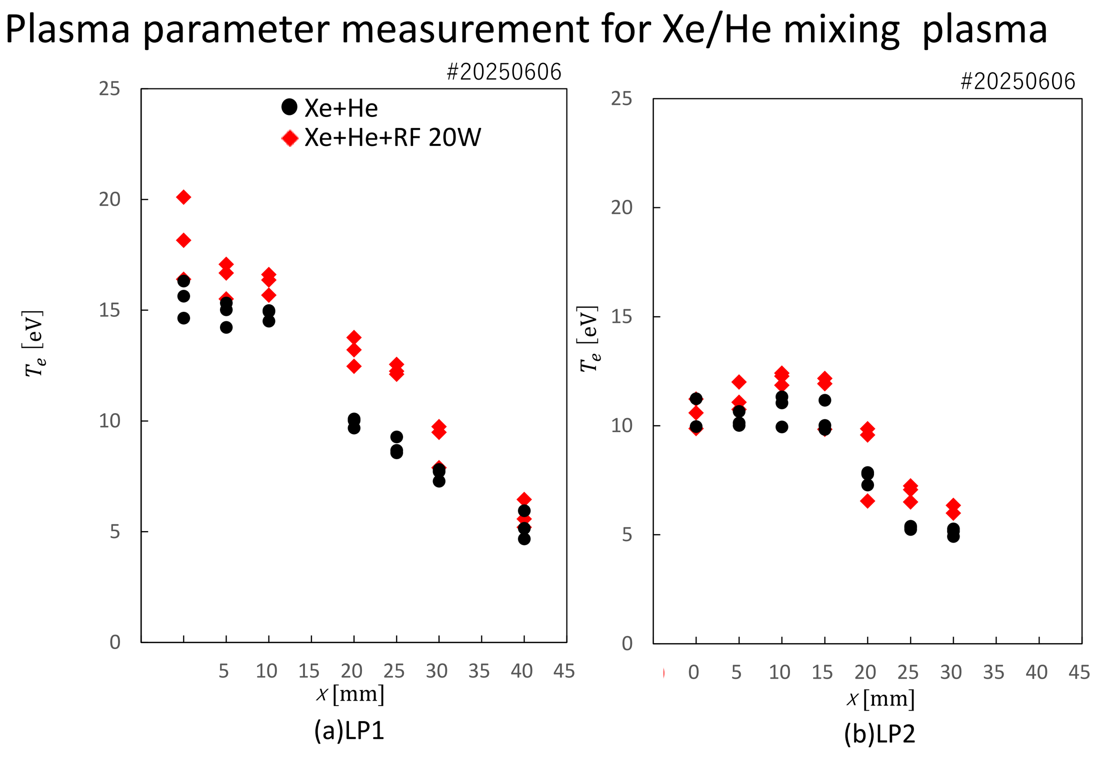


Fig.4: T_e distribution diagrams for Xe/He mixing and Xe/He mixing plasmas with 400 kHz RF for ICR heating with (a)LP1 and (b)LP2

■Plasma parameter measurement for Xe/Ar mixing plasma

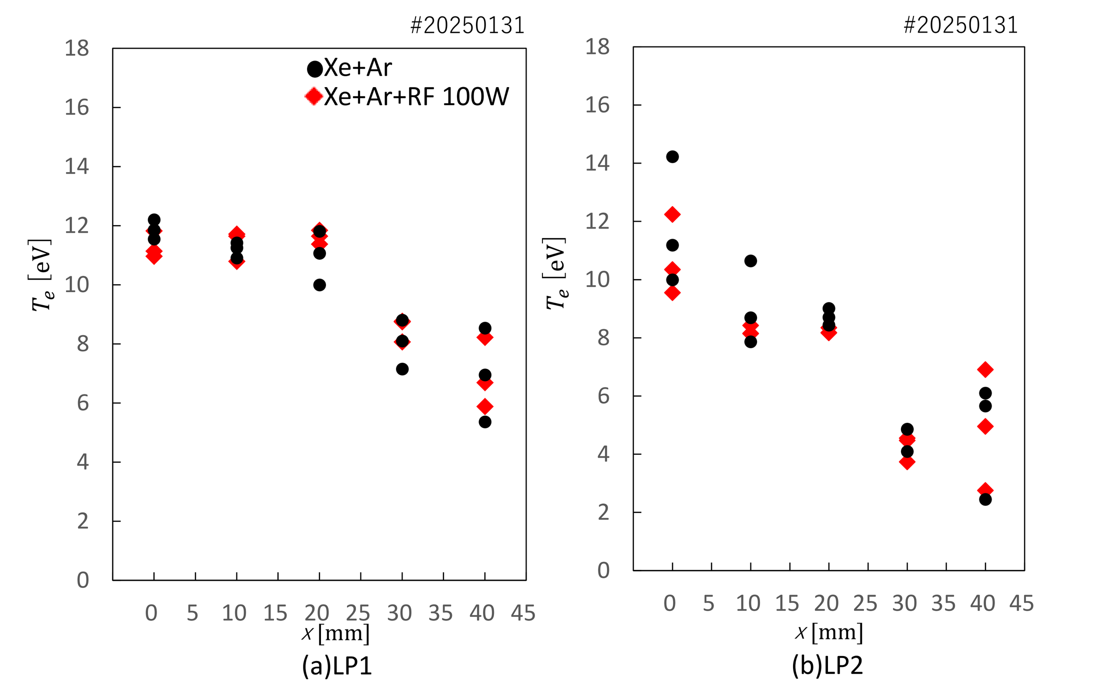


Fig.7: T_e distribution diagrams for Xe/Ar mixing and Xe/Ar mixing plasmas with 40 kHz RF for ICR heating with (a)LP1 and (b)LP2

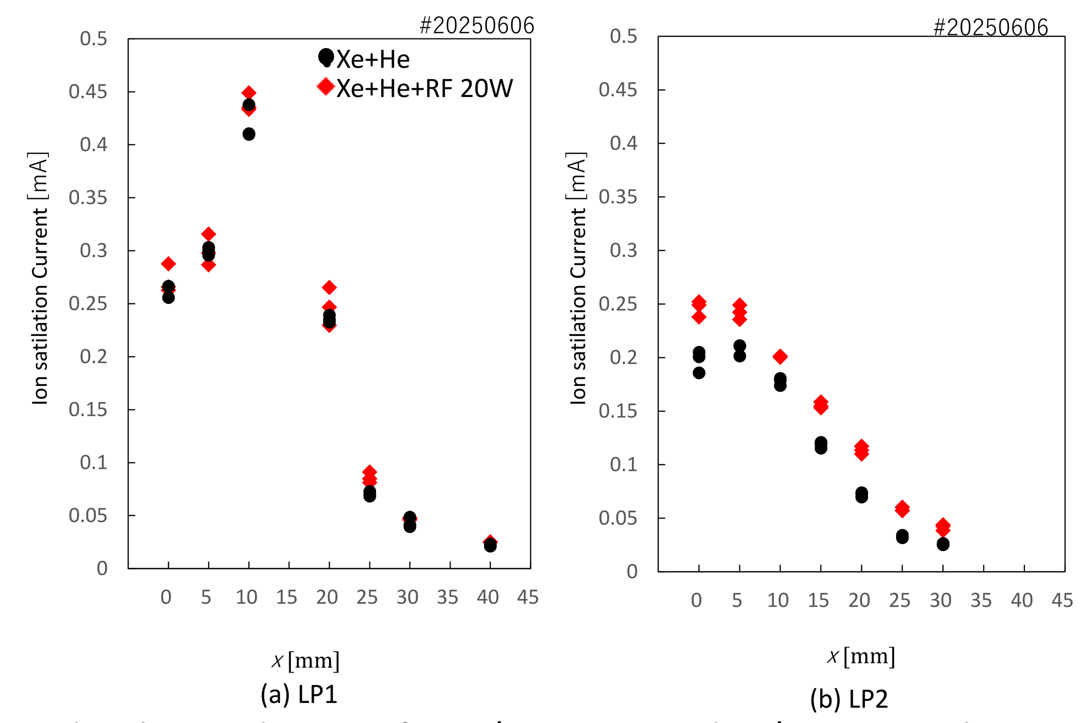


Fig.5: n_e distribution diagrams for Xe/He mixing and Xe/He mixing plasmas with 400 kHz RF for ICR heating with (a)LP1 and (b)LP2

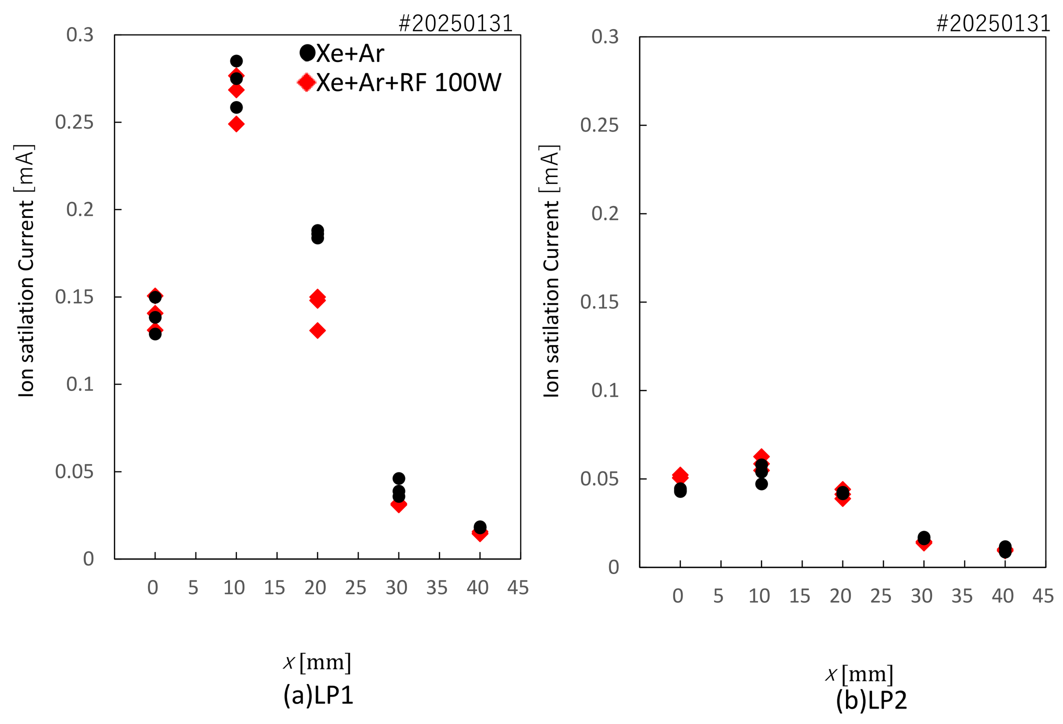


Fig.8: n_e distribution diagrams for Xe/Ar mixing and Xe/Ar mixing plasmas with 40 kHz RF for ICR heating with (a)LP1 and (b)LP2

■CSDs for Xe/He mixing plasma with increasing He flow rate

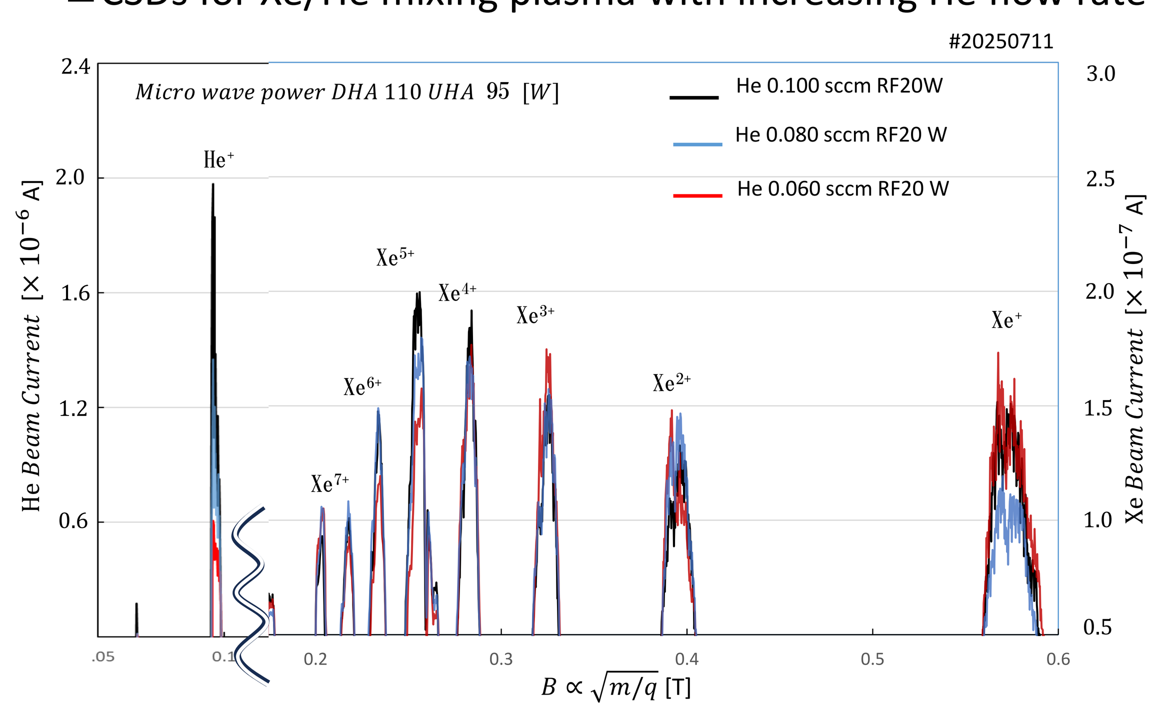


Fig.9:CSDs for Xe/He mixing plasma with 400 kHz RF for ICR heating when He flow rate is changed

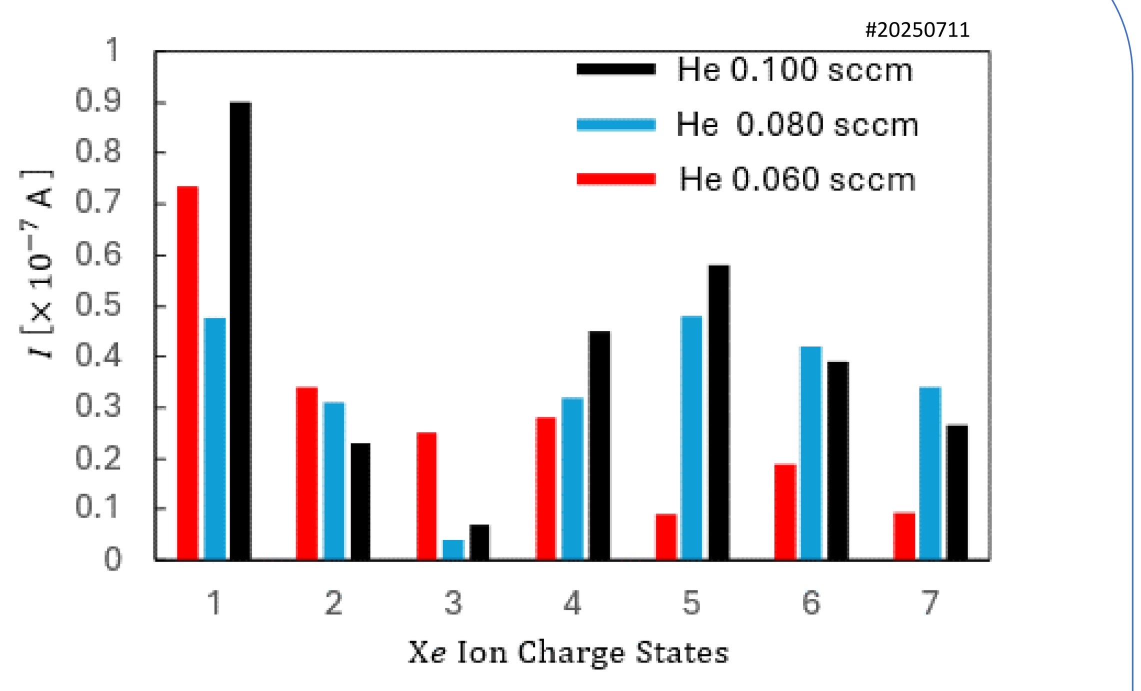


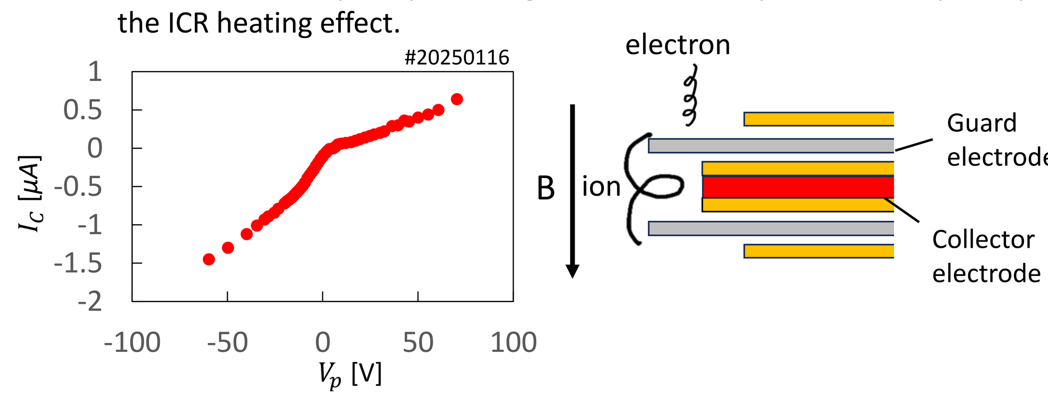
Fig.10: Xe beam current increase with low frequency RF into Xe/He mixing plasma

§ 5. Discussion and Conclusion

- Probe measurements confirmed an increase in electron temperature and ion saturation current during RF introduction. We conducted the experiments in the two cases Xe/Ar mixing and Xe/He mixing, the difference was more pronounced in the case of Xe/He mixing.
- The results in Fig. 10 show that increasing the He flow rate while keeping microwave and RF power constant led to an increase in beam current on the high-current side. This suggests that the improved ion confinement efficiency resulting from ICR heating enhanced electron confinement
- The introducing of low frequency RF electromagnetic waves cause higher multicharged ions beam increased, resulting in a change in the average mass. Currently, the average mass is calculated using partial pressure, so its value remains unchanged even with RF . However, when calculated the average mass using by the extracted beam currents derived from the CSD measurement, the average mass increases, so the handling of electron density is under consideration.

§ 6. Future Planning

- We will measure the ion temperature inside the ion source with and without low-frequency RF using an ion-sensitive probe. Directly verify the ICR heating effect.



- We will control the Xe gas flow rate and mix low-Z gases while maintaining a constant total pressure to conduct experiments with higher reproducibility.
- The heating tendency of He obtained from the emittance measurement. We will also confirm it by the ion-sensitive probe.
- The electron density in ECR plasma involves multiple ion species, so we will examine how to handle it.