Enhanced Production of Multicharged Ions by Mixing Low Z Gas and Emittance Measurement on Electron Cyclotron Resonance Ion Source

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§ 1. Introduction

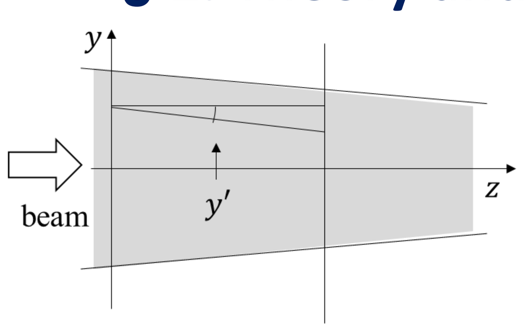
Background

- Electron cyclotron resonance ion source (ECRIS) is used in various fields *e.g.*, cancer therapy, accelerator physics, etc. We have studied to increase the efficiency of multicharged ion production on ECRIS.
- An empirically method of efficiently producing multicharged ions is to mix low Z gas into the plasma. The gas mixing method is considered to result from cooling of the heavier ions by collisions between ions of different masses. In order to experimentally verify that gas mixing effect is caused by cooling ions, it is necessary to measure parameters related to ion temperatures. In this work, we measured root mean square emittances as the parameters.
- Moreover, it is expected to further enhance the yield of multicharged ions by introducing a low-frequency electromagnetic wave into the plasma for ion cyclotron resonance (ICR) heating low Z ions. This is due to contributing to the cooling effect.

Objectives

- We confirmed the effect of the gas mixing method to increase the yield of multicharged ions in ECRIS, and also compared the parameters related to ion temperature.
- In order to confirm the effect to increase the yield of multicharged ions, we compared the result of charge state distribution (CSD) measurement for Ar ion beam current when He was mixed (Ar/He mixing) with that for pure Ar plasma.
- In order to compare parameters related to ion temperature, Ar^{2+} beam emittances were measured for pure Ar and Ar/He mixing.
- We also measured electron densities and electron temperatures for pure Ar plasma and Ar/He mixing plasma.

§ 2. Theory and Analytical Method

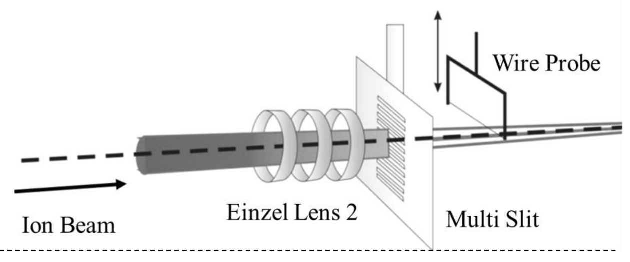


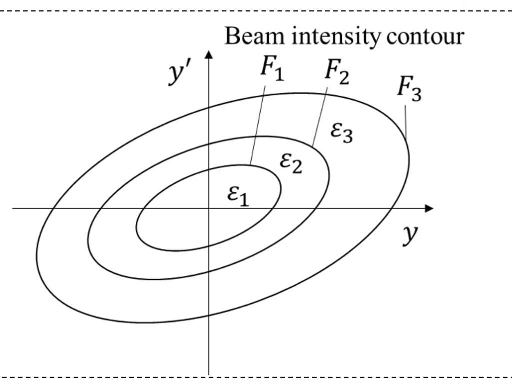
- Emittance ε is defined by

$$\varepsilon = \int y' dy$$

where y' is angle spread in y direction of an ion beam.

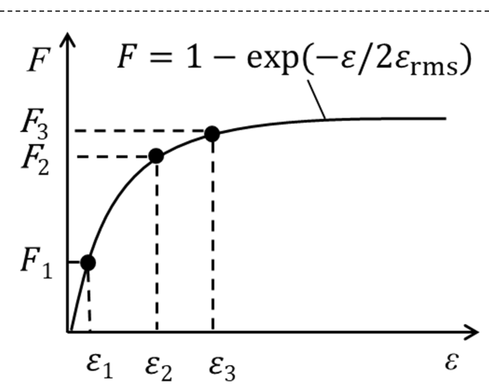
- We measured typical ion beam profiles and ion beam profiles when a multi slit is inserted.





- The emittance diagram is drawn by measuring y' from the ion beam profile when the multi slit is inserted. This phase space area is known as emittance ε.

- The cumulative emittance distribution function is measured from the typical ion beam profile.
- The root mean square emittance ε_{rms} is measured by fitting the points to theorical formula.



§ 3. Experimental Apparatus

ECRIS in Osaka Univ.

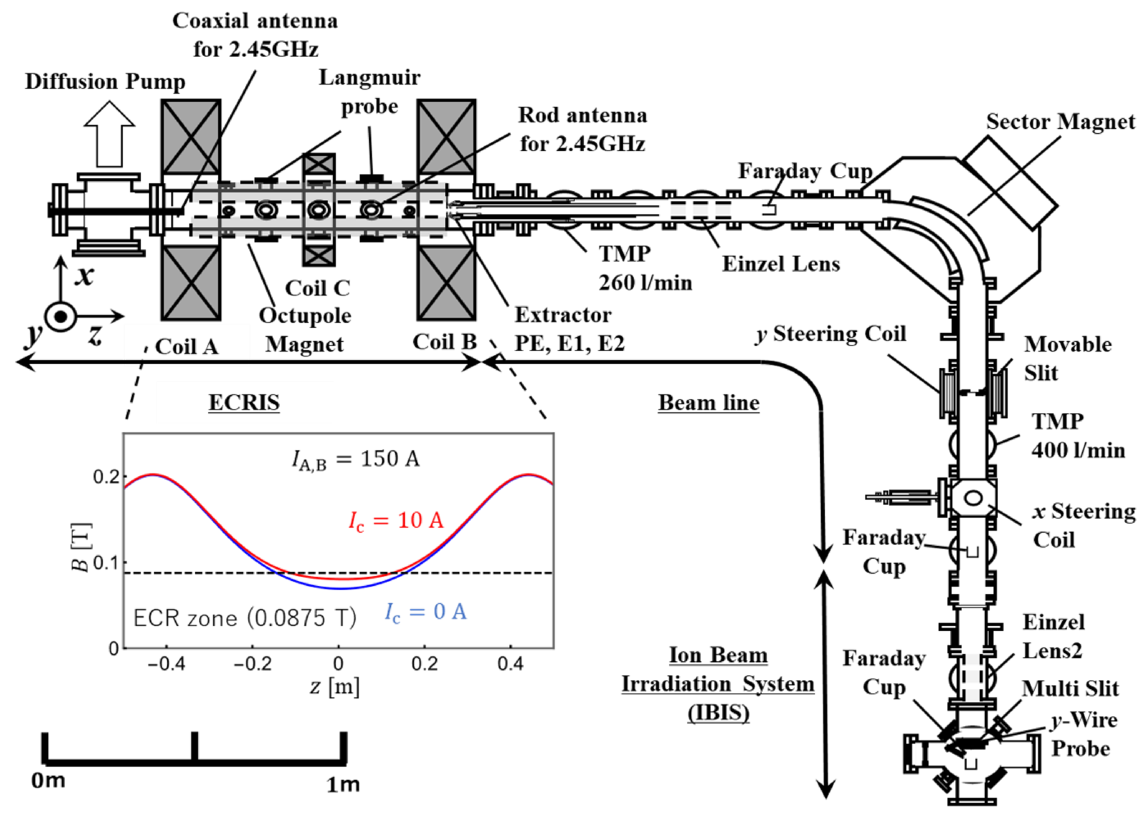


Figure 1: The top view of ECRIS (Osaka Univ.)

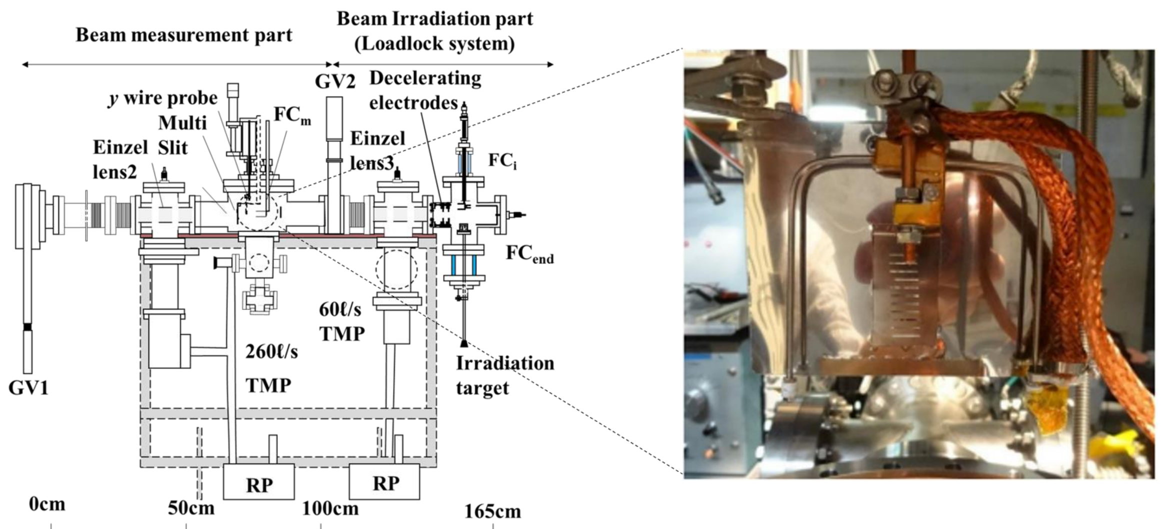


Figure 2: The side view of measurement part of ECRIS

- Emittances are measured by using a wire-probe (0.02 mm in diameter) and a multi-slit.
- The wire-probe is movable in the y direction.
- The multi-slit can be inserted. It has 11 slits, each with a width of 0.5 mm. The width of slit spacing is 2.1 mm.

Plasma parameter measurements by using the Langmuir probes (LP1 & LP2)

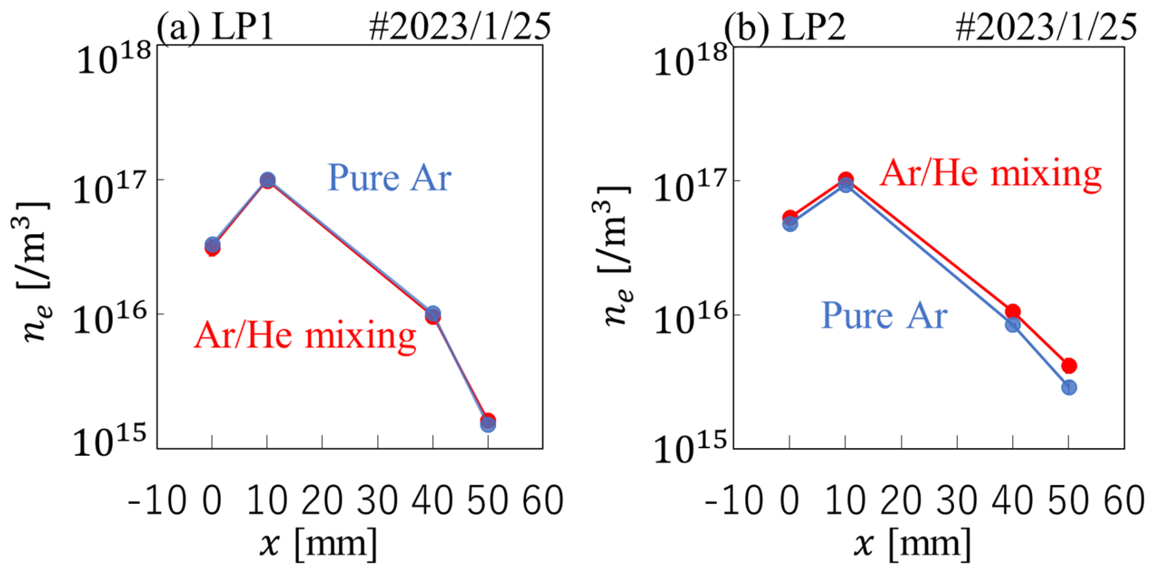


Figure 7: Electron density n_e distribution diagrams for pure Ar (a) and Ar/He mixing (b).

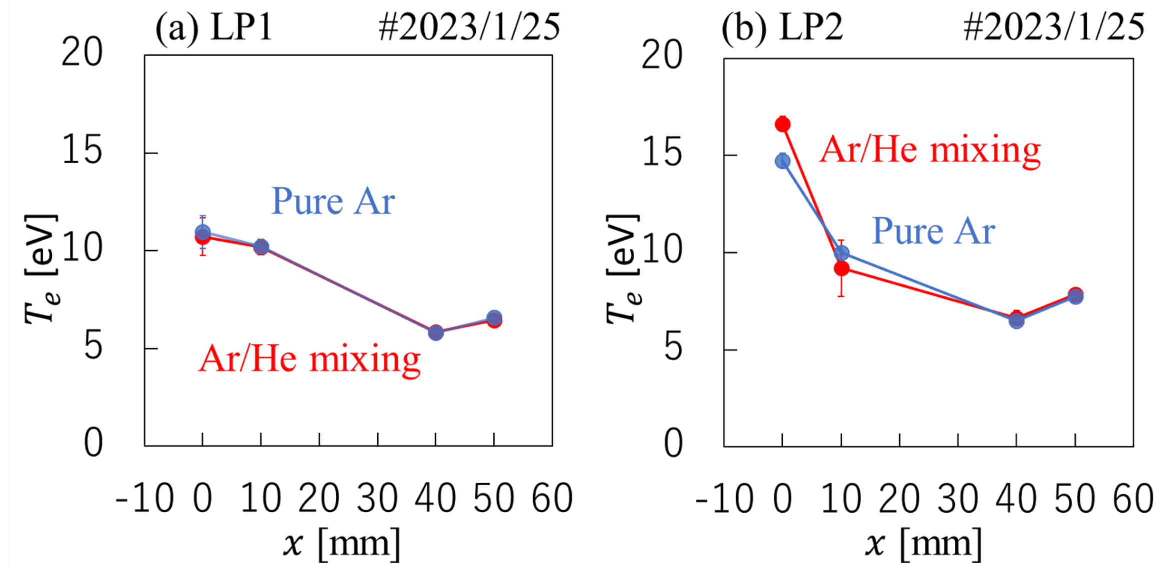


Figure 8: Electron temperature T_e distribution diagrams for pure Ar (a) and Ar/He mixing (b).

- Electron densities and temperatures were almost the same between pure Ar plasma and Ar/He mixing plasma.

§ 4. Experimental Results

Charge state distributions (CSDs) of Ar plasma on ECRIS

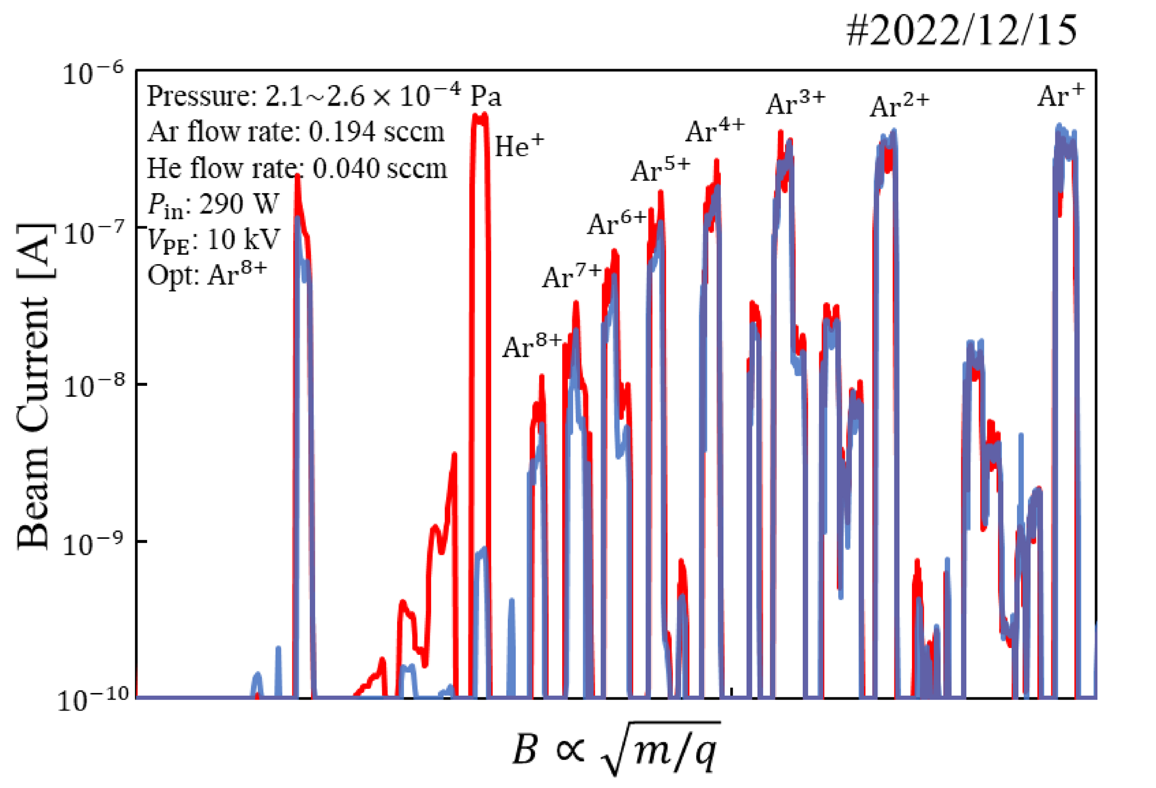


Figure 3: CSDs of Ar plasma for pure Ar and Ar/He mixing.

Ar^{2+} beam profiles and emittance diagrams

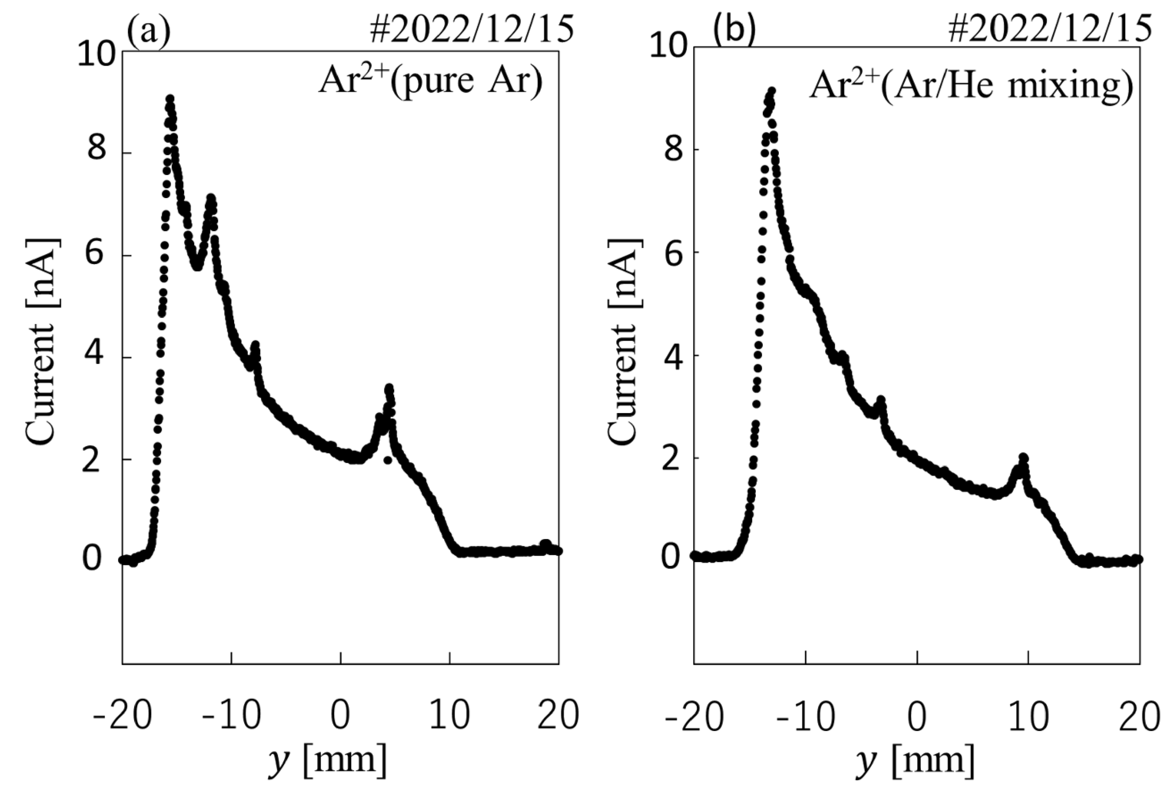


Figure 4: Typical Ar^{2+} beam profiles for pure Ar (a) and Ar/He mixing (b).

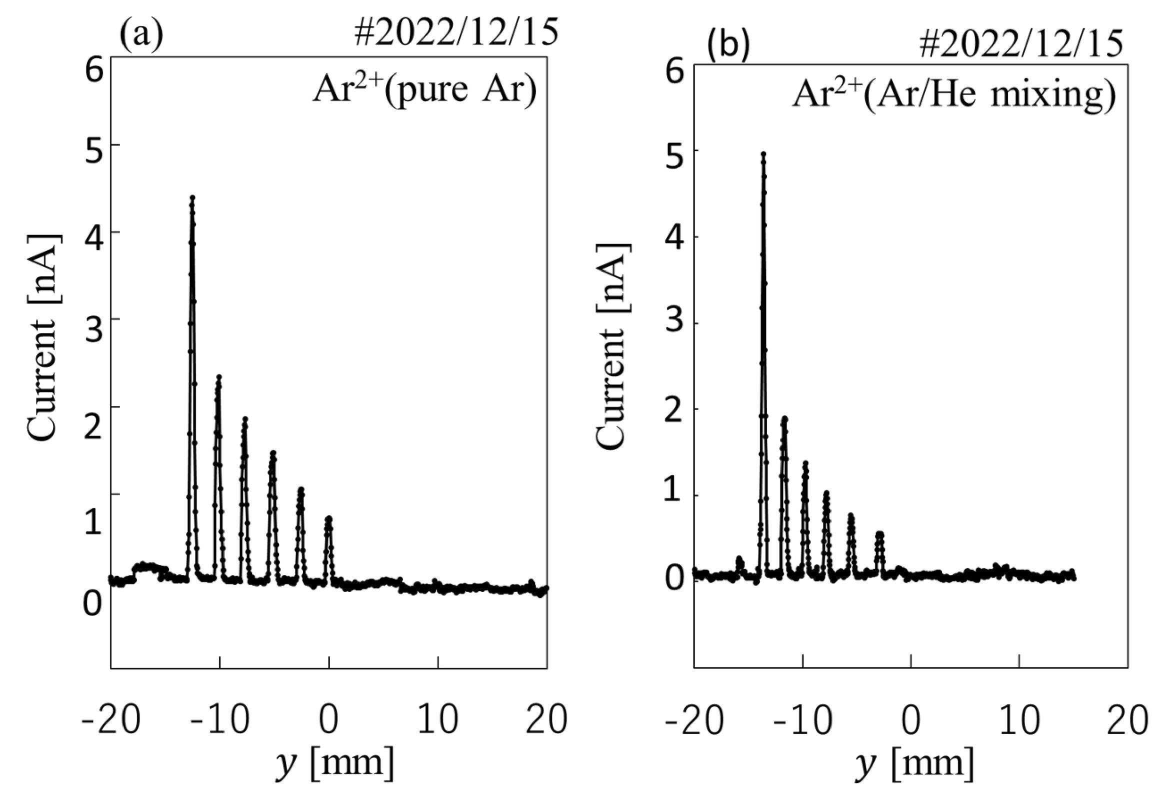


Figure 5: Ar^{2+} beam profiles when the multi slit was inserted for pure Ar (a) and Ar/He mixing (b).

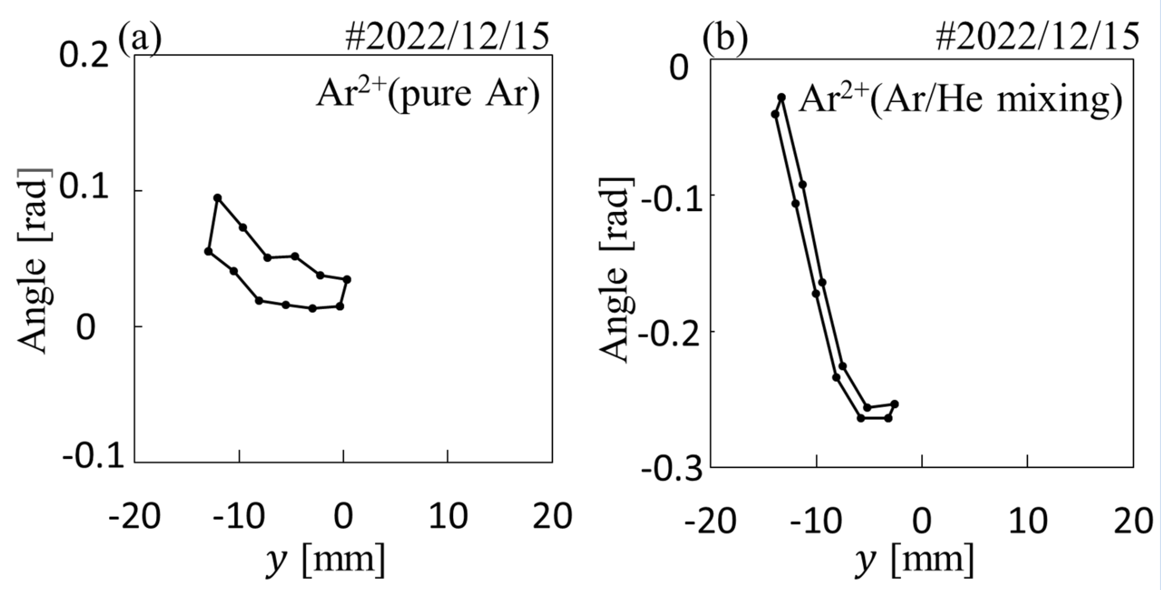


Figure 6: Emittance diagrams of Ar^{2+} beams for pure Ar (a) and Ar/He mixing (b).

§ 5. Discussion

Comparison of root mean square emittances of Ar^{2+} beams for pure Ar and Ar/He mixing

■ Analytical method 1

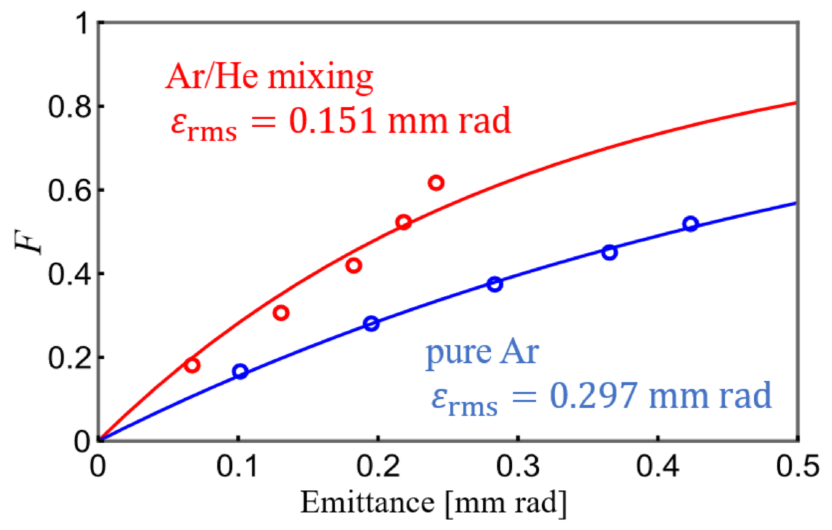


Figure 9: Cumulative emittance distribution function F vs. emittance ε.

■ Analytical method 2

- There is another method to calculate root mean square emittance. This method uses the formula $\varepsilon_{rms} = \sqrt{\overline{x^2}\,\overline{x'^2} - \left(\overline{xx'}\right)^2}$. It can be calculated by using an ion beam profile when multi slit is inserted.

Table 1: Comparison of Results Using Two Methods

	Analytical method 1*	Analytical method 2*
Ar^{2+} beam (pure Ar)	ε_{rms} = 297 mm mrad	ε_{rms} = 95.1 mm mrad
Ar^{2+} beam (Ar/He mixing)	ε_{rms} = 151 mm mrad	ε_{rms} = 76.7 mm mrad

- The results using method 1 and 2 were different. However, rms emittance decreased when He was mixed in both analytical methods.

§ 6. Conclusion

- The gas mixing effect was confirmed by measuring CSDs of Ar plasmas for pure Ar and Ar/He mixing. Moreover, this effect was confirmed with good reproducibility.
- The root mean square emittance of Ar^{2+} beam for Ar/He mixing was about half of that for pure Ar.
- Electron densities and temperatures of Ar plasmas were almost the same between pure Ar and Ar/He mixing.

§ 7. Future Planning

- We will measure root mean square emittances of higher charged Ar ion beams. And, we will compare those for pure Ar and Ar/He mixing.
- We will try to further enhance the efficiency of the production of multicharged Ar ions by introducing low frequency electromagnetic waves for ICR heating.