The University of Osaka

Emittance measurement of ion beam current in selectively heating low Z ions on electron cyclotron resonance ion source in mixing low Z gases

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§ 1. Introduction

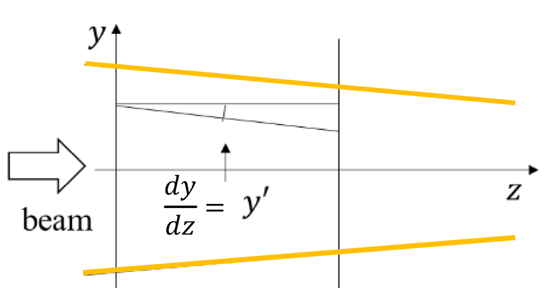
■ Background

- Electron cyclotron resonance ion source (ECRIS) is used in various fields *e.g.*, cancer therapy, accelerator physics, *etc.* We have been studying efficient production of multicharged ions in electron cyclotron resonance ion source.
- We are conducting experiments in mixing low Z gases, which is widely known empirically as a method for efficient production of multicharged ions. Furthermore, low-frequency RF electromagnetic waves have been introduced to the ECRIS to enhance the effect of the low Z gas mixing.
- In order to experimentally verify that low-frequency RF electromagnetic wave is caused heating low Z gas, it is necessary to measure parameters related to ion temperatures. In this work, we measured root mean square emittances ε_{rms} as the parameters.

■Objectives

- We conduct experiments in which Ar and He gases are introduced into Xe operation gases and then selectively heat low Z ions (Ar^+ and He^+) by ion cyclotron resonance (ICR) to actively enhance the cooling effect of multicharged Xe ions.
- Experiments of ICR selectively heating are conducted by using RF electromagnetic waves with frequencies of 40kHz for Ar in Xe operating gas, and 400kHz for He in Xe operating gas.
- We confirmed the effect of ICR selectively heating He^+ and Ar^+ from ε_{rms} values derived from multi-slit and wire probe method and corresponding primary profiles of beam current. We conduct the same measurements for multicharged Xe ions in progress.

§ 2. Theory and Analytical Method of Emittance

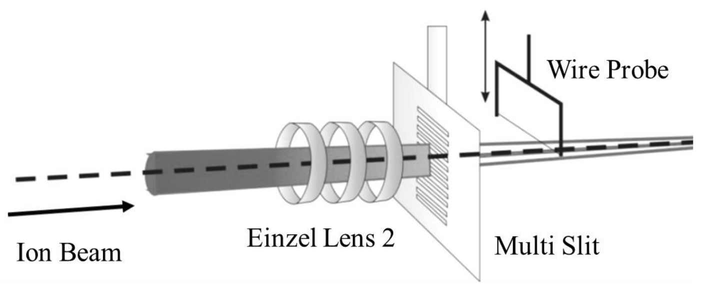


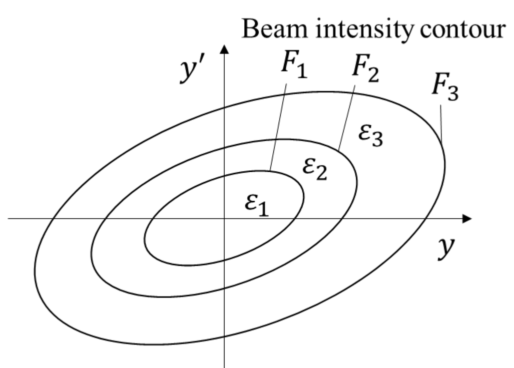
- Emittance ε is defined by

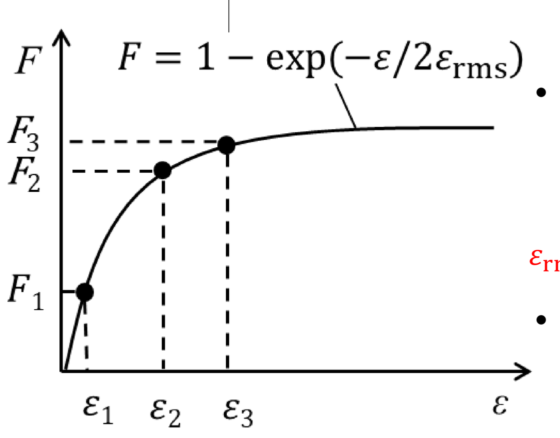
$$\varepsilon = \int y' dy$$

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

- Typical ion beam profiles and ion beam profiles when a multi-slit is inserted are measured by wire probe.







- 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 integrated ion beam currents function F is calculated from the typical ion beam profile.*
- The root mean square emittance ε_{rms} is measured by fitting the points to theorical formula.

$$\varepsilon_{rms} = \sqrt{\overline{x^2}\,\overline{x'^2}} = \frac{a}{2}\left(\frac{k_B T_i[K]}{m v_z^2}\right)^{\frac{1}{2}} = \frac{a}{2}\left(\frac{T_i[eV]}{2ZV}\right)^{\frac{1}{2}} \propto T_i^{\frac{1}{2}}$$

- Emittance changes are attributed to ion temperature, as the magnetic field remains nearly constant and has a comparable effect in our 2.45GHz ECRIS.

*A.J.T.Holmes, "Beam Transport" In Ian G. Brown(Ed.), The Physics and Technology of Ion Sources , Berkeley, California, pp.95

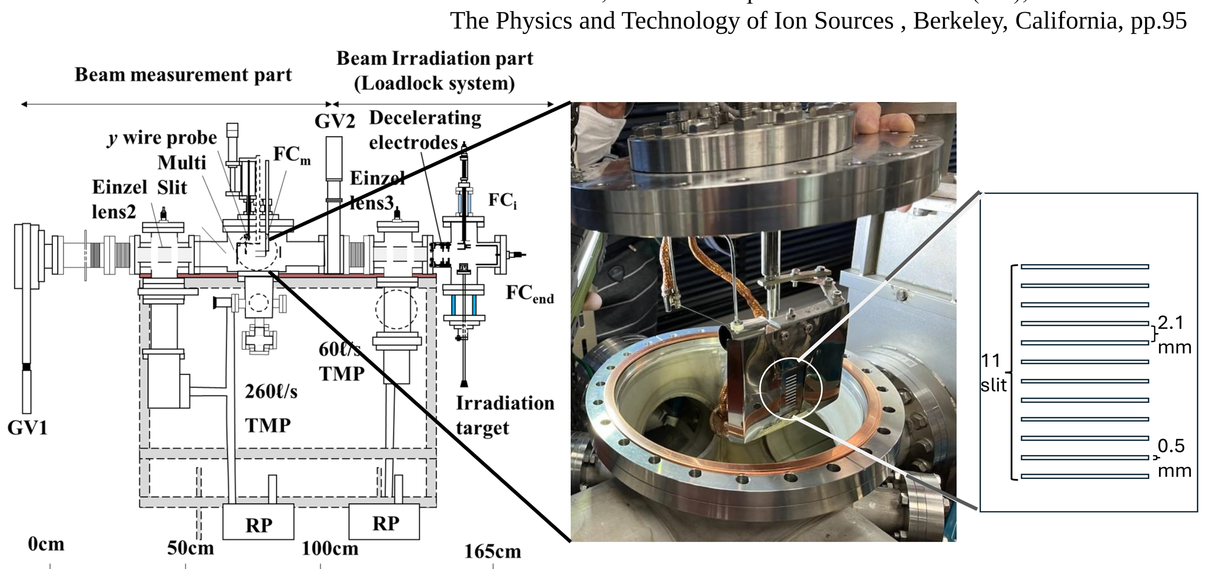


Fig.1: The side view of measurement part of ECRIS.

- Emittances are measured by using a W wire-probe (Diameter is 0.05 mm) and a multi-slit.
- The wire-probe is movable in the y direction, and its position is measured by voltage of variable resistor.
- 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.

§ 3. Experimental Apparatus

■ ECRIS in the University of Osaka.

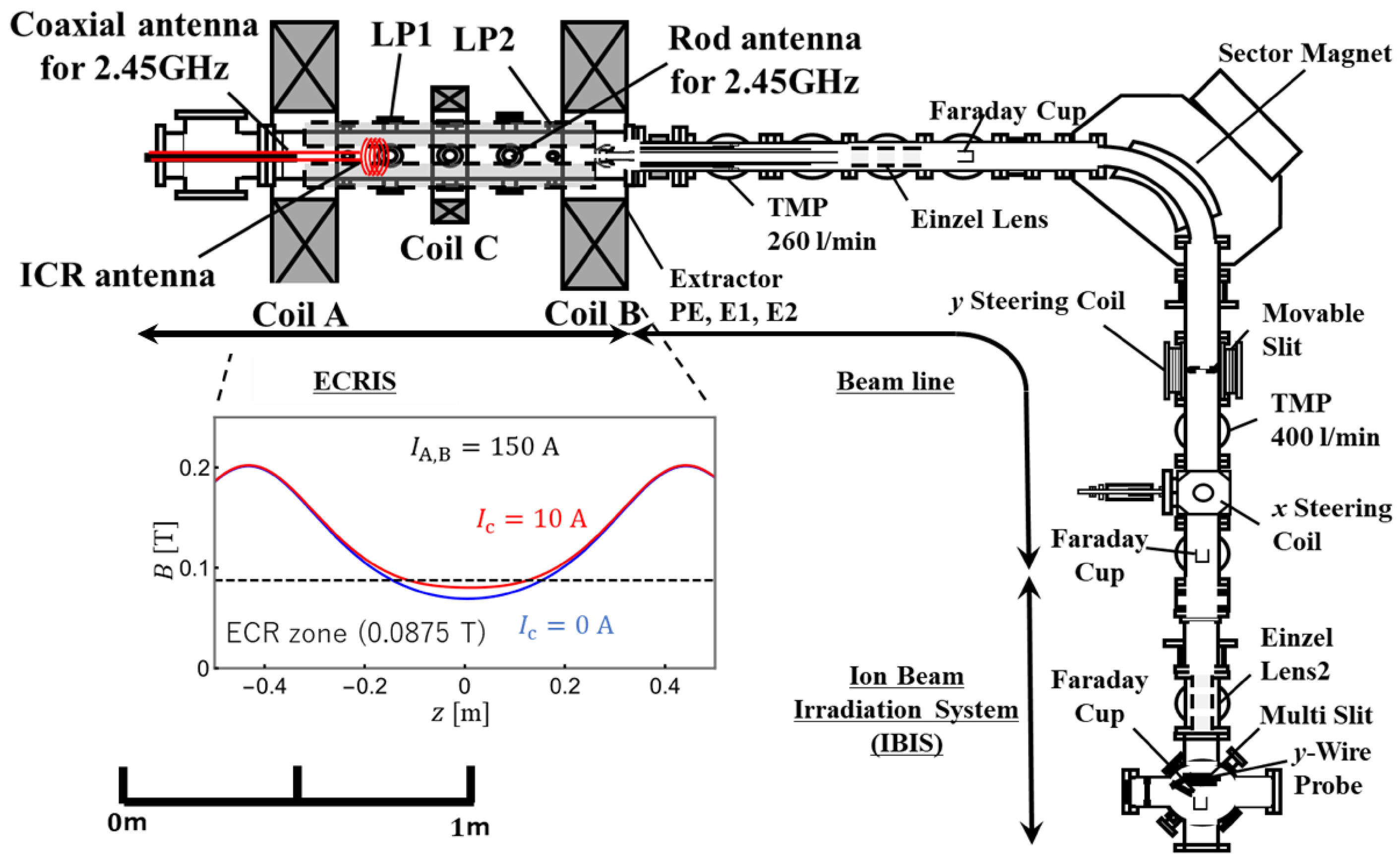


Fig.2 The top view of ECRIS.

§ 4. Experimental Results

■ Charge state distributions (CSDs) of Xe/He + RF(400kHz) plasma on ECRIS

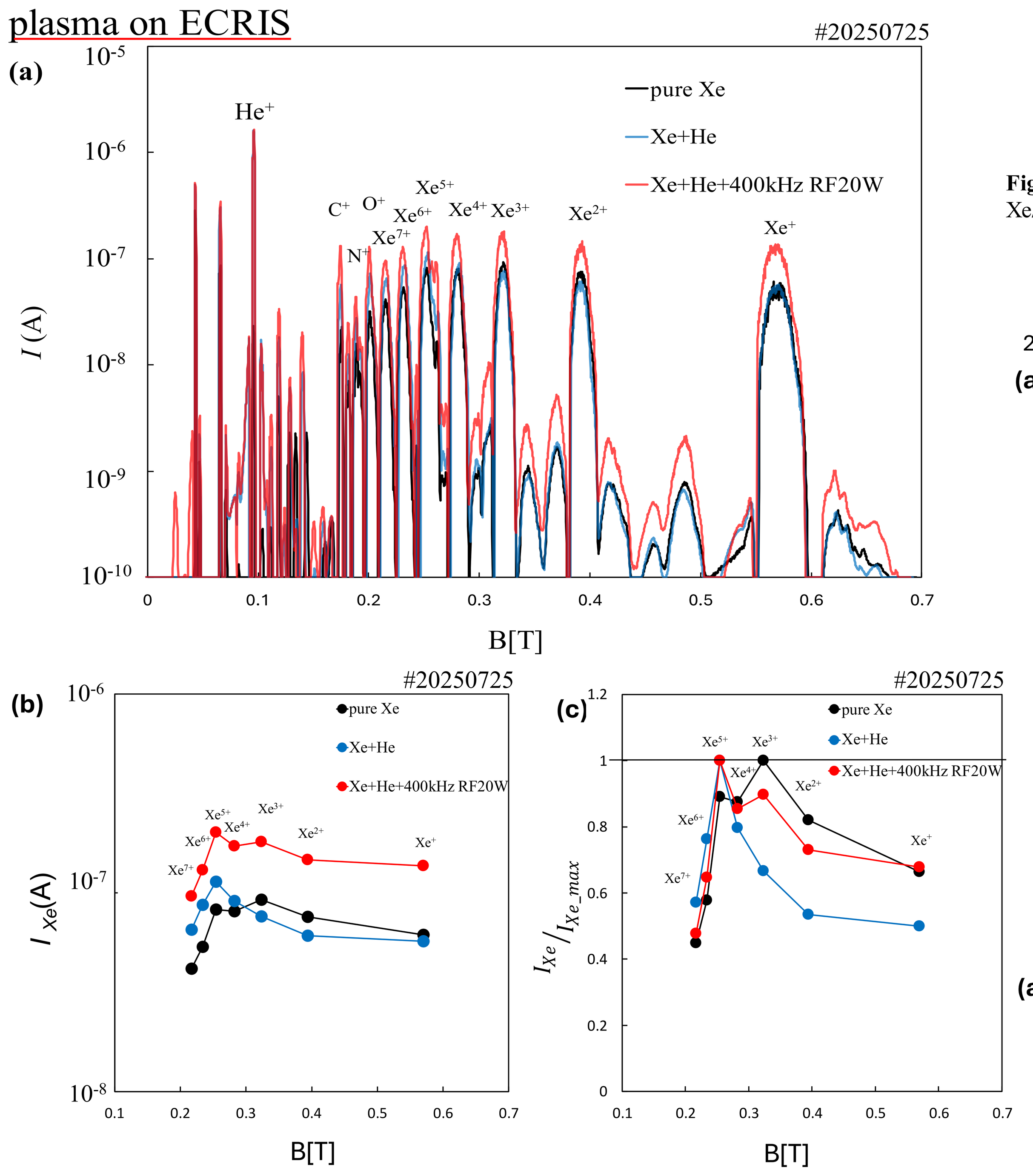


Fig.3(a) CSDs of ion beam currents for pure Xe, Xe/He mixing without RF and with 100W RF. **(b)**The peak of each charge state of Xe ion beam current at CSD for pure Xe, Xe/He mixing without RF and with 20W RF.**(c)**The ratio of each charge state of Xe ion beam current to its maximum current for pure Xe, Xe/He mixing without RF and with 20W RF.

■ Charge state distributions (CSDs) of Xe/Ar + RF(40kHz) plasma on ECRIS

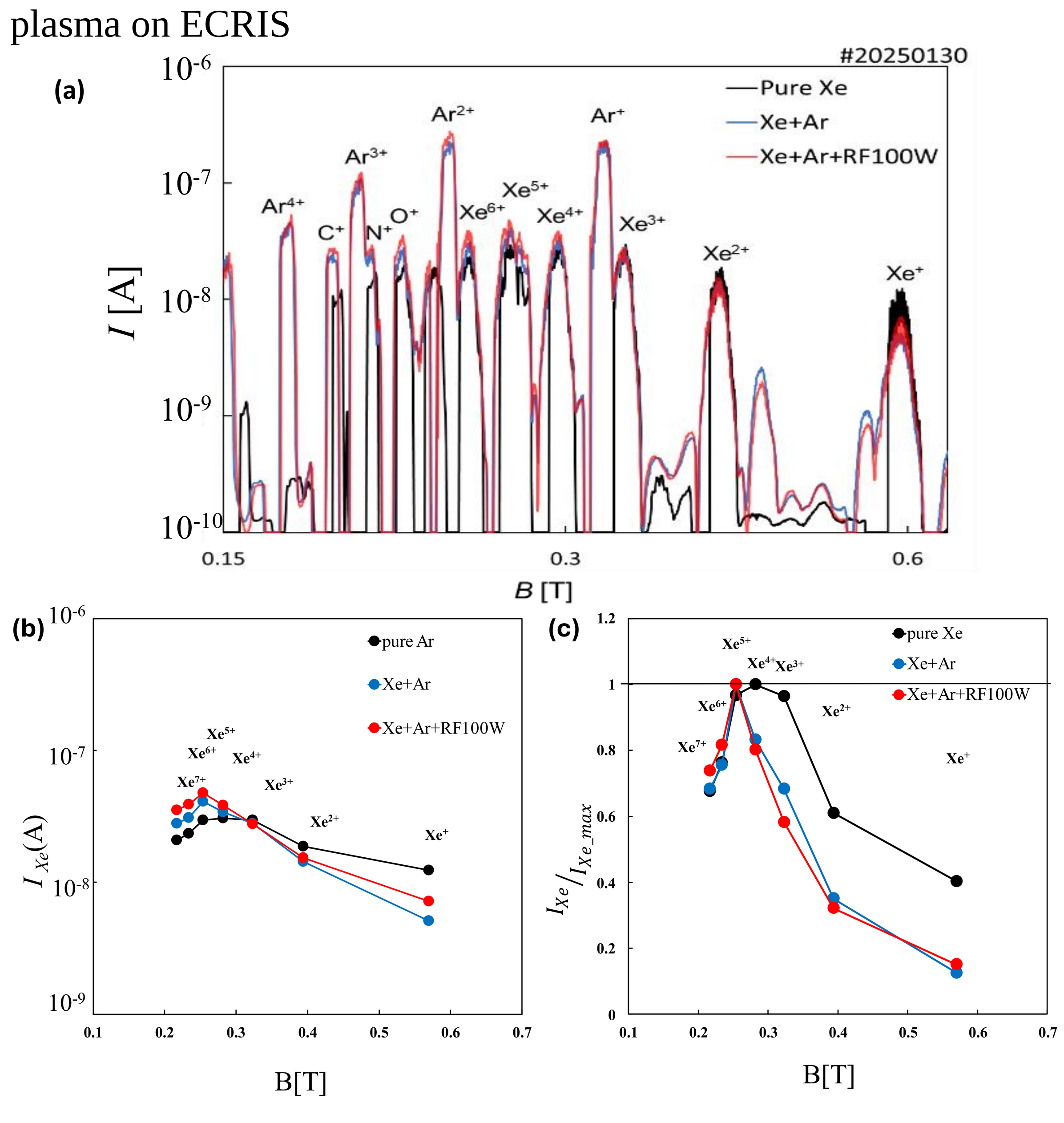


Fig.4(a) CSDs of ion beam currents for pure Xe, XeAr mixing without RF and with 100W RF. **(b)**The peak of each charge state of Xe ion beam current at CSD for pure Xe, XeAr mixing without RF and with 100W RF **(c)**The ratio of each charge state of Xe ion beam current to its maximum current for pure Xe, Xe/Ar mixing without RF and with 100W RF.

■ He^+ & Xe^{4+} & beam profiles and emittance diagrams for Xe/He mixing plasmas

2025/7/25, Xe gas:5.1 × 10^{-5}Pa He:0.100sccm, Microwave power DHA 150W/60W UHA 120W/95W

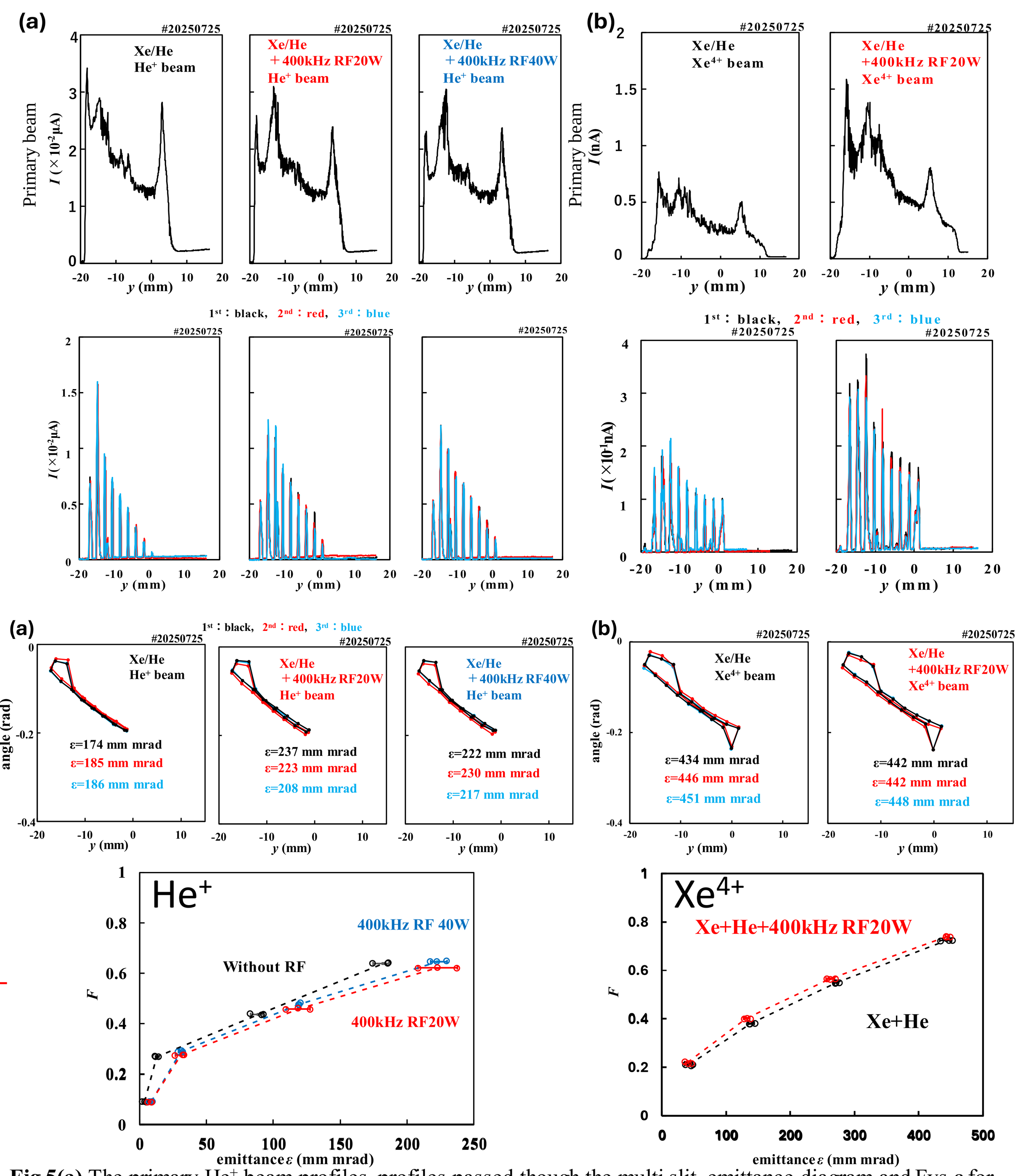


Fig.5(a) The primary He^+ beam profiles, profiles passed though the multi-slit, emittance diagram and Fvs.ε for Xe/Ar mixing without RF, with 20W , and with 40W of 400kHz RF. **(b)** Similar diagram in the case of Xe^{4+} beam.

■ Ar^+ & Xe^{4+} beam profiles and emittance diagrams for Xe/Ar mixing plasmas

2025/1/30, Xe gas:3.6 × 10^{-5}Pa Ar:0.195sccm, Microwave power DHA80W/50W UHA 100W/90W

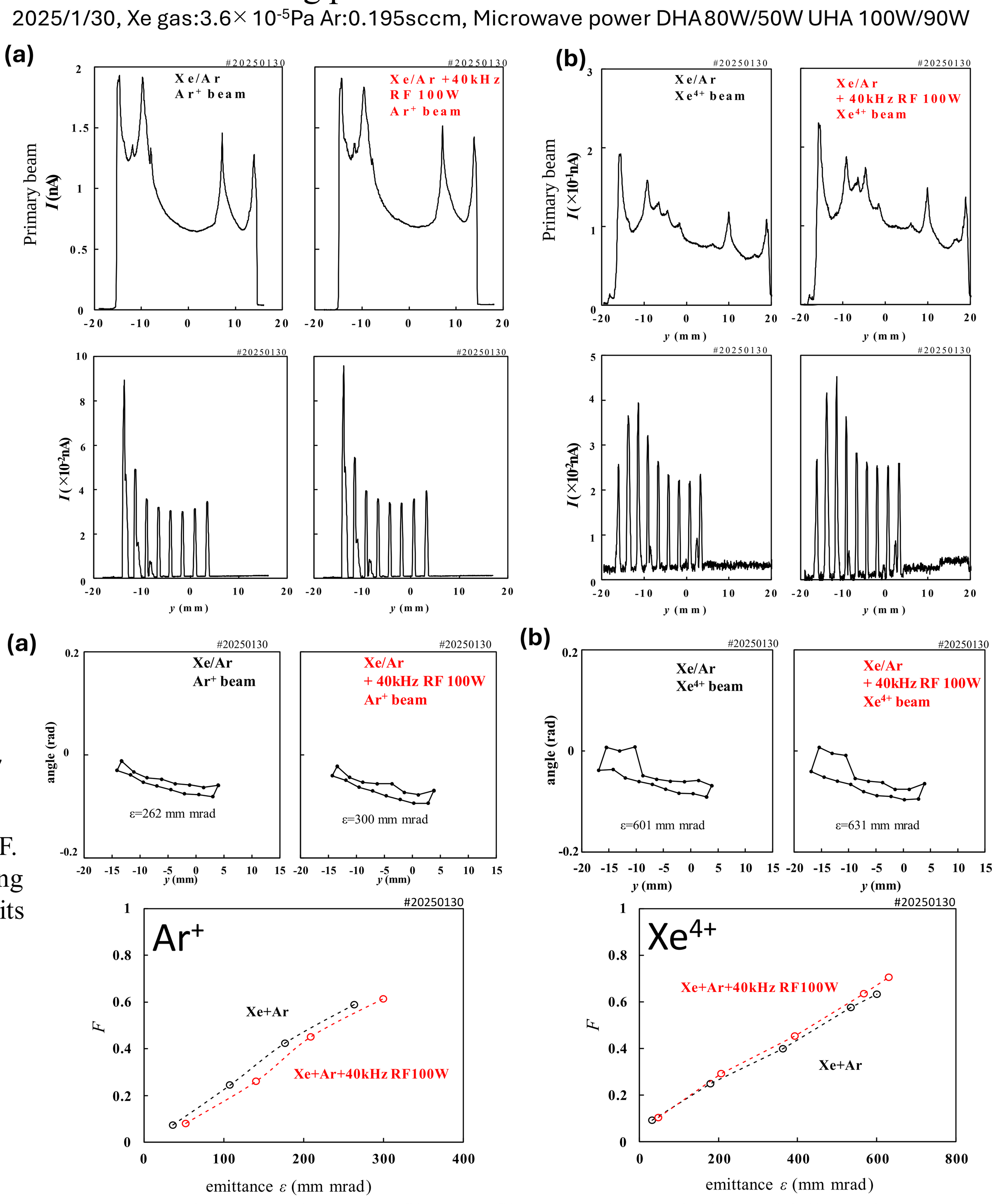


Fig.6(a) The primary Ar^+ beam profiles, profiles passed though the multislit, emittance diagram and Fvs.ε for Xe/Ar mixing without RF and with 100W of 40kHz RF. **(b)** Similar diagram in the case of Xe^{4+} beam.

§ 5. Discussion and Conclusion

- The CSD results confirmed the mixing effect of Ar or He in pure Xe plasma. Furthermore, introducing low-frequency RF electromagnetic waves increased the beam current of high charged Xe ions. This suggests that low-frequency RF electromagnetic waves enhance the gas mixing effect and cooling effect.
- In addition, emittance measurements confirmed that ε_{rms} of the target ions (Ar or He) increased when low-frequency RF electromagnetic waves were introduced. It is considered to be the result of the target ions being heated by ion cyclotron resonance.
- Similarly, when the same measurement was performed on multicharged Xe ions, there was almost no change in ε_{rms}. According to probe measurements, the electron temperature is increased when low-frequency RF electromagnetic wave was introduced.* We considered that cooling effect and heating by electron was caused this. *Please refer to Tokuno's Poster 71

§ 6. Future planning

- When measuring pure Xe and Xe+He, we conduct under constant total pressure to obtain reproducible data.
- In addition to measuring the emittance, we will cross-check the effect of ICR by fabricating probes to measure directly the ion temperature inside the chamber or optical measurement.
- Currently, impurities increase when 400kHz RF is introduced, so we conduct baking the ICR coil before conducting experiments.