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Producing Multicharged Ions by Pulse Modulated Microwaves at Mixing Low *Z* Gases on ECRIS

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Introduction

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◆ Background

- In the previous study, we succeeded in increasing the multicharged ion yield of Xe in UHR heating experiment using 4-6GHz X-mode microwaves (※).
- We are now exploring the feasibility of selectively heating specific ions by launching a frequency band much lower than conventional ECR.

⇒*e. g.*, ion cyclotron resonance (ICR), lower hybrid resonance (LHR)

- As a preliminary step, we try to enhance the ion cooling effect by heating low *Z* ions by pulsing microwaves under gas mixing.

◆ Objective

- We conduct the experiment to generate ECR plasma with pulse-modulated microwaves under gas mixing.
- By changing the pulse period, the optimum period for extracting Xe^{7+} ion beams is investigated.

(※)Y. Kato, *et al*., Rev. Sci. Instrum., 2020, **91**, 013315

Experimental setup

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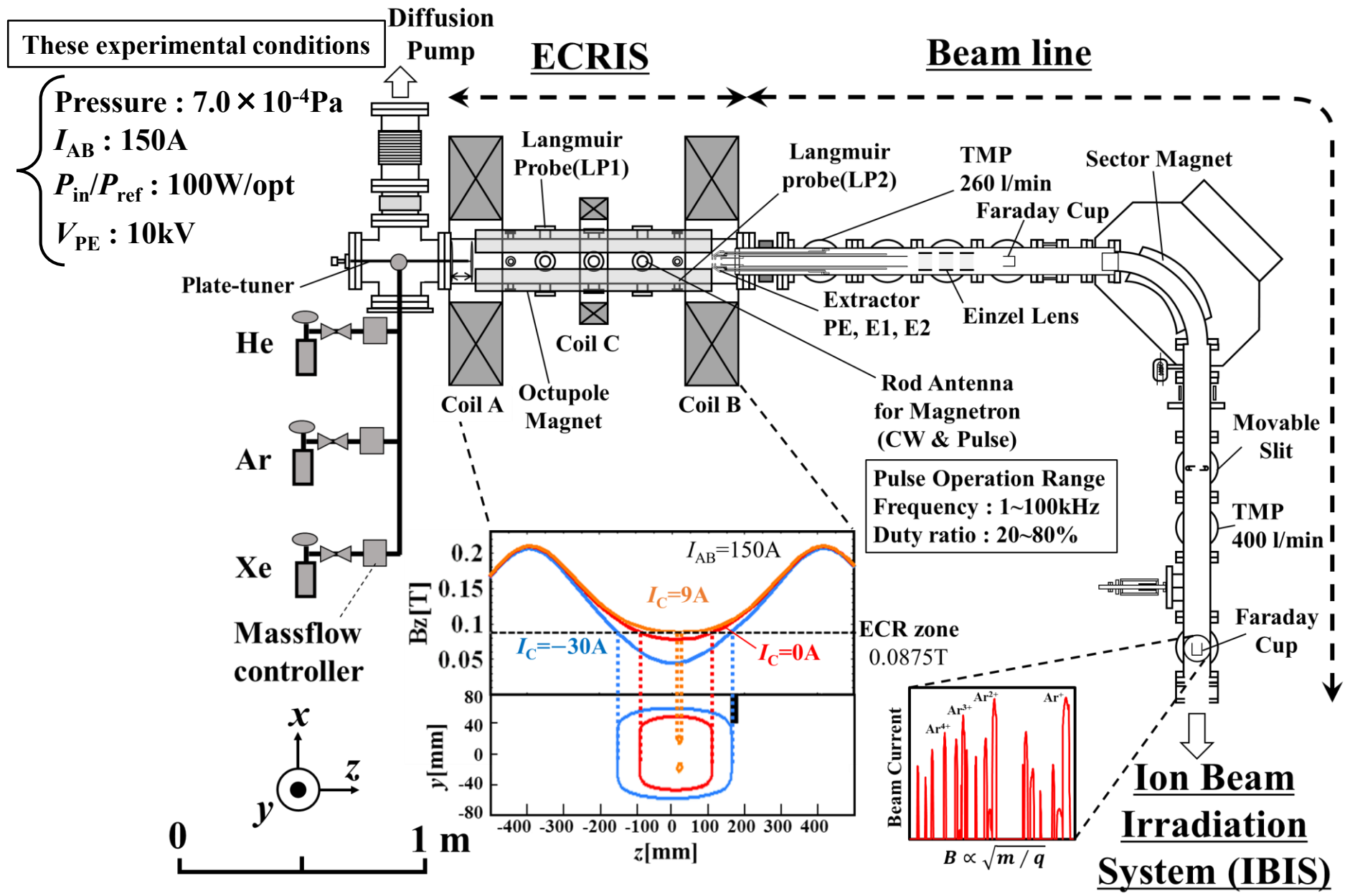
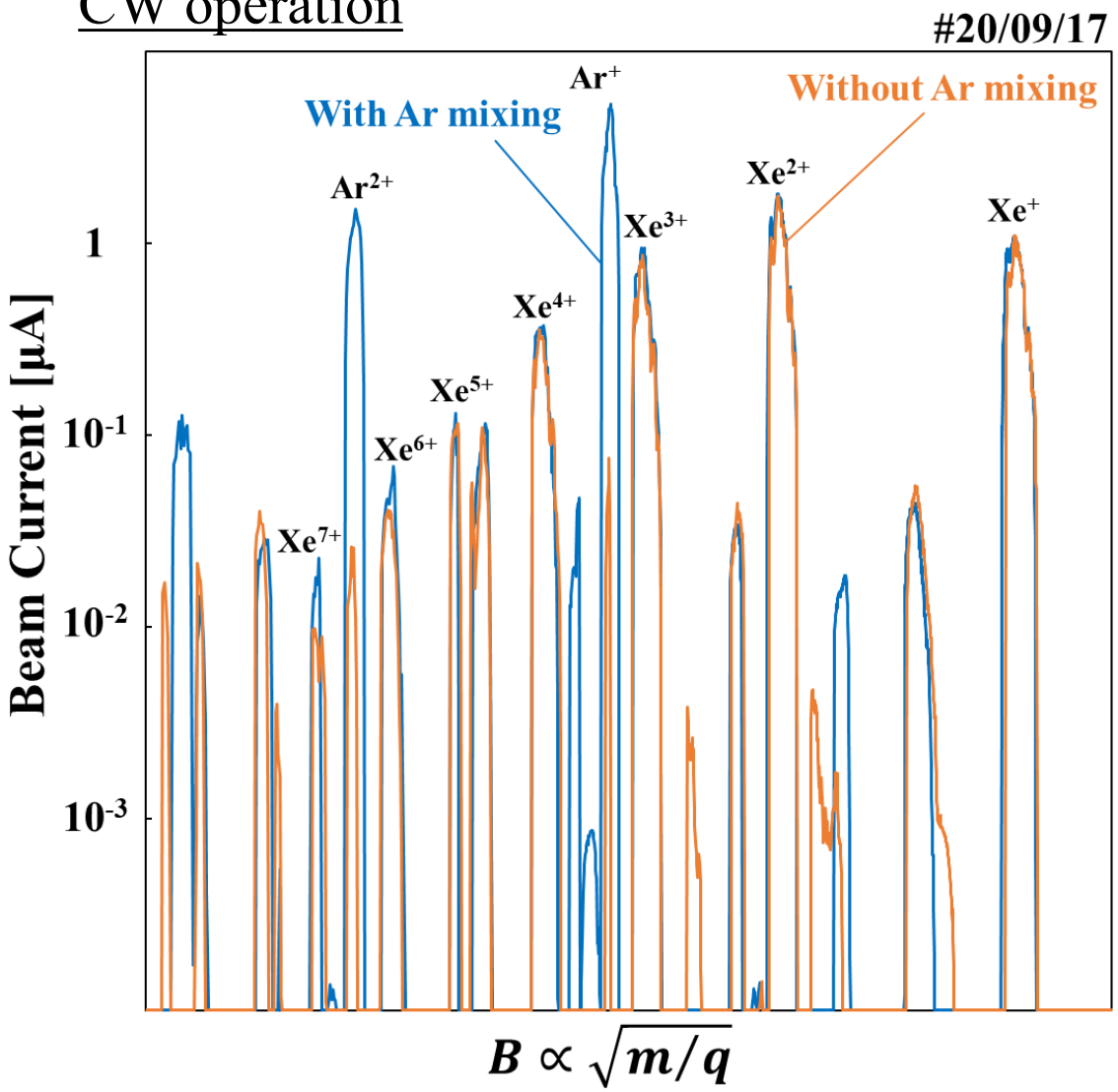


Typical CSD's of gas mixing application

CW operation



Experimental condition

Pressure : 7.0×10^{-4}Pa

I_{AB} : 150A

P_{in}/P_{ref} : 100W/10W

V_{PE} : 10kV

I_C, V_{E1}, V_{el1} : Opt Xe^{7+}

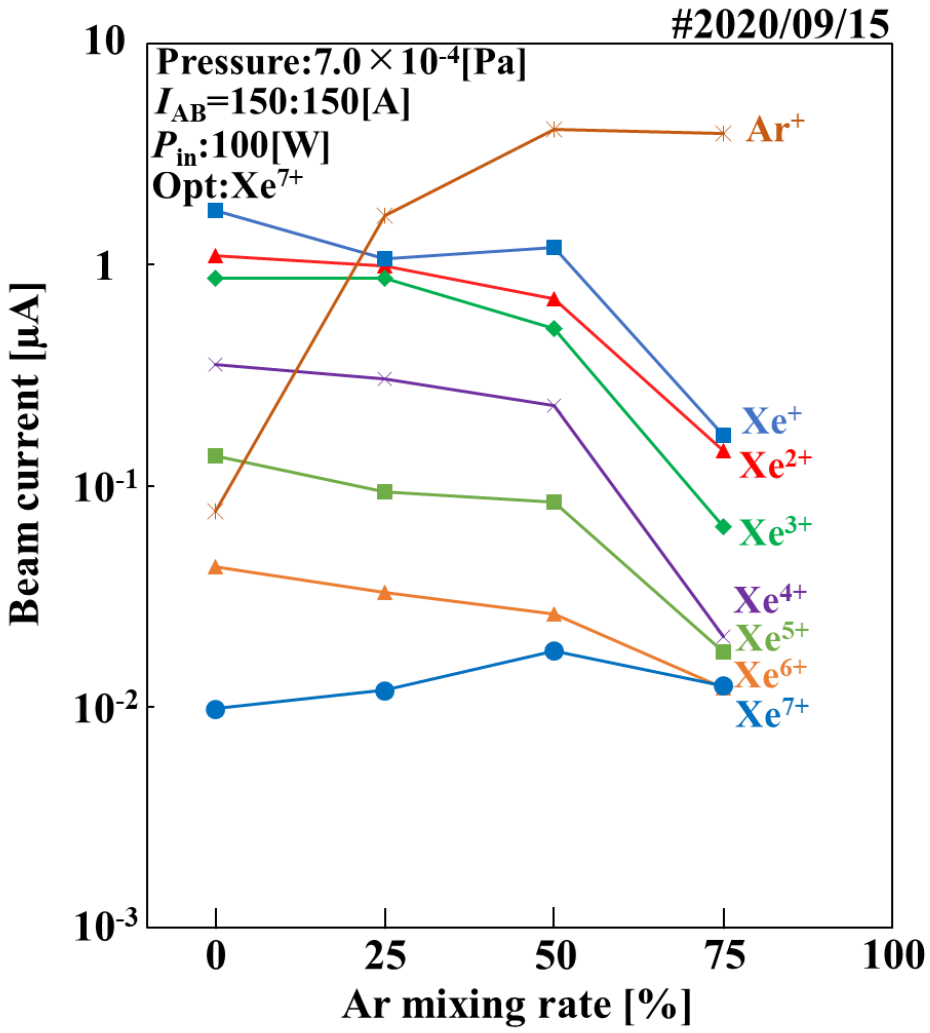
- Without Ar mixing

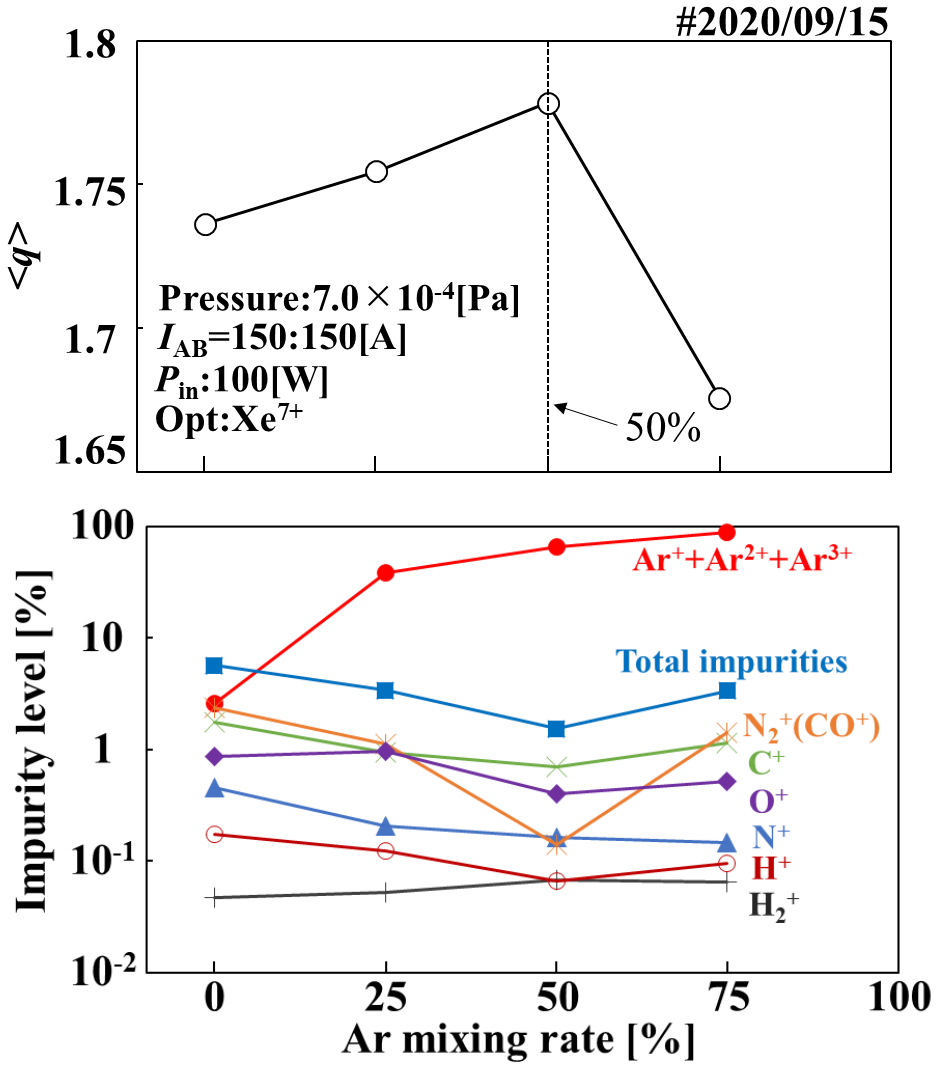
  Xe : Ar = 100 : 0 [%]
- With Ar mixing

  Xe : Ar = 50 : 50 [%]

➢ Increased Xe^{7+} ion beam current by introducing Ar gas

The dependence of Xe^{q+} on Ar mixing ratio





Average charge state $< q >$

$$< q > = \frac{\sum_{q=1}^{7} I_{\mathrm{Xeq+}}}{\sum_{q=1}^{7} I_{\mathrm{Xeq+}}/q}$$

$$\text{Impurity level [\%]} = \frac{I_{\mathrm{imp}} \text{ or } \sum_{q=1}^{3} I_{\mathrm{Arq+}}}{\sum_{q=1}^{7} I_{\mathrm{Xeq+}} + \sum_{q=1}^{3} I_{\mathrm{Arq+}} + \sum I_{\mathrm{imp}}} \times 100$$

Typical CSD's of pulse application

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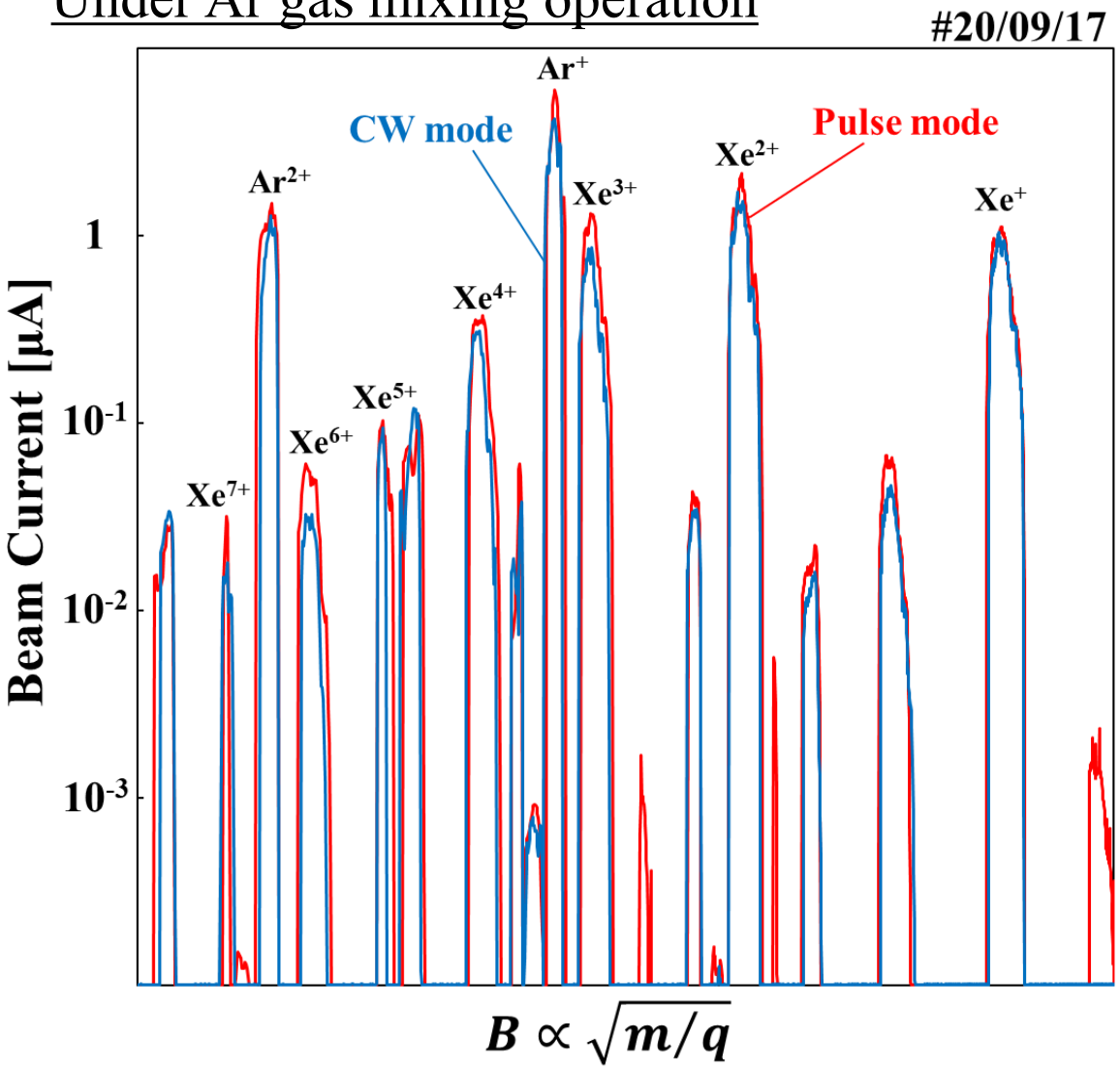
Under Ar gas mixing operation



Experimental condition

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I_{AB} : 150A

V_{PE} : 10kV

I_C, V_{E1}, V_{el1} : Opt Xe^{7+}

Xe : Ar = 50 : 50 [%]

- CW mode

P_{in}/P_{ref} : 100W/10W

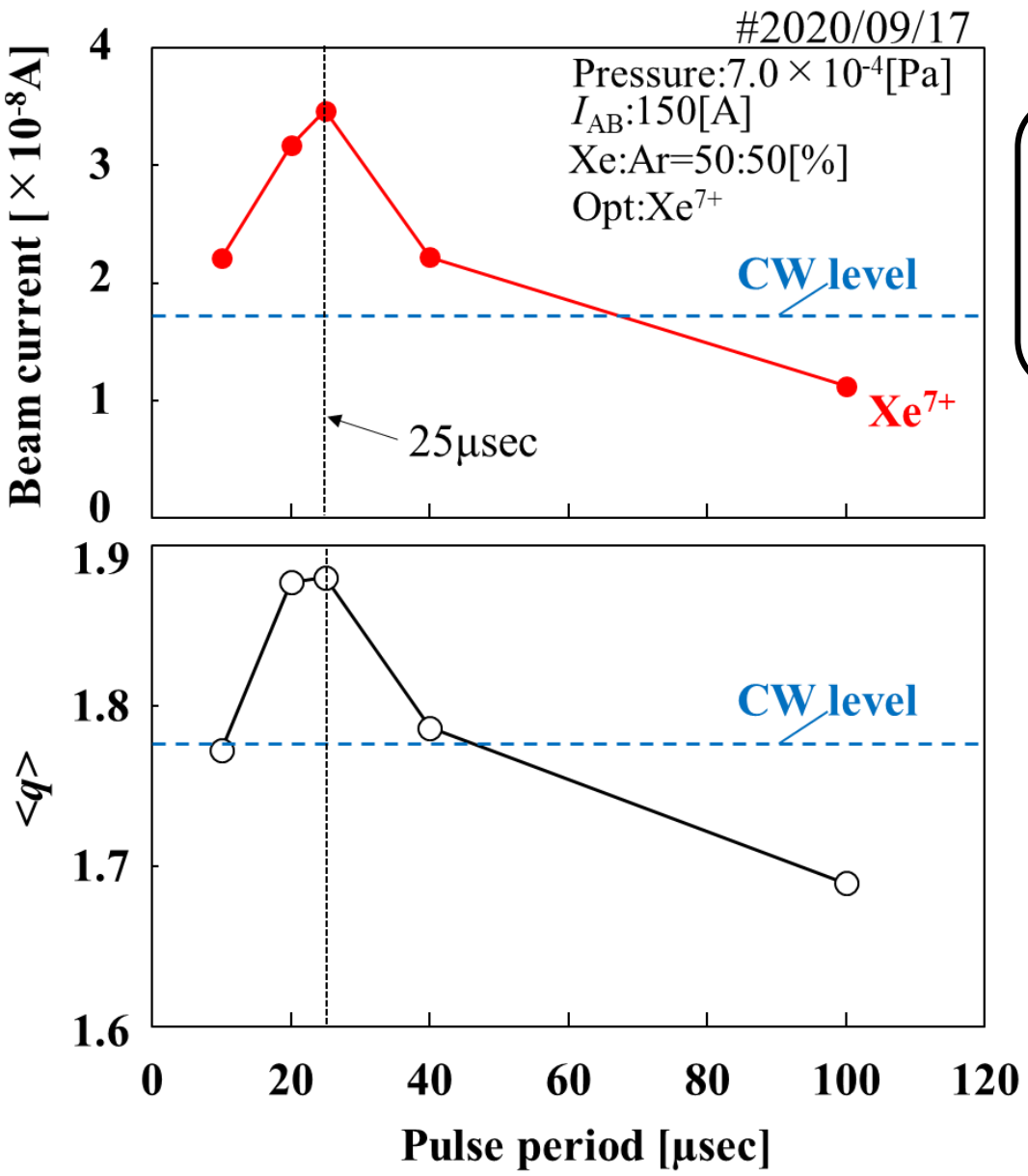
- Pulse mode

P_{in}/P_{ref} : 100W(ave.)/10~20W

Duty ratio : 50%

➢ Increased Xe^{7+} ion beam current by launching pulsed microwaves

The dependence of Xe^{7+} on pulse period



Average charge state $< q >$

$$< q > = \frac{\sum_{q=1}^{7} I_{\mathrm{Xeq+}}}{\sum_{q=1}^{7} I_{\mathrm{Xeq+}}/q}$$

Microwaves operation

CW mode

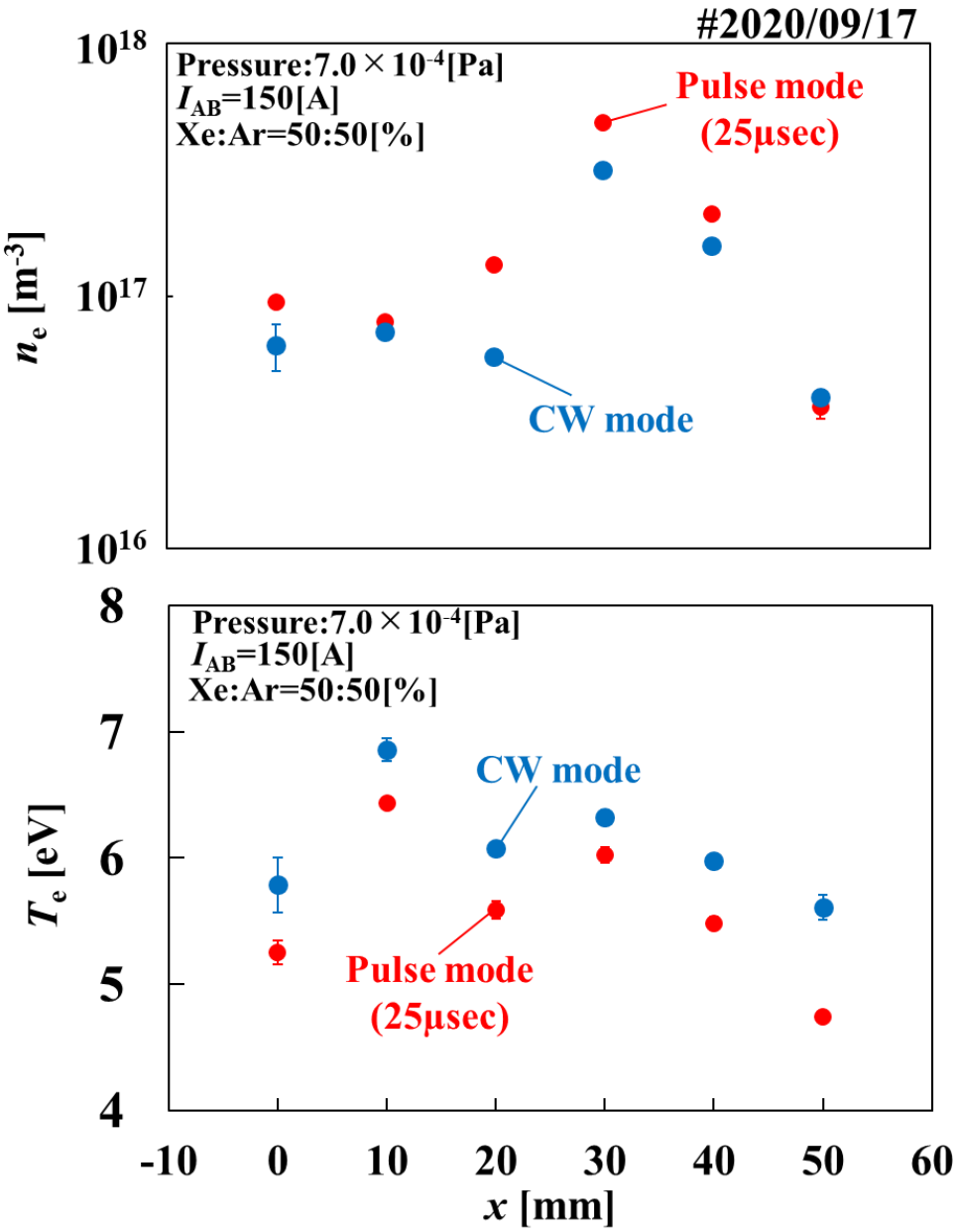
P_{in}/P_{ref} : 100W/10W

Pulse mode

P_{in}/P_{ref} : 100W(ave.)/10~20W

Duty ratio : 50%

Comparison of the n_e and the T_e



Langmuir probe method

$$n_e \equiv \frac{I_{is}}{0.61eS}\sqrt{\frac{m_i}{k_B T_e}}$$

$$T_e \equiv \frac{k_B}{e}\frac{d \ln I_e}{d V_p}$$

Microwaves operation

CW mode

P_{in}/P_{ref} : 100W/10W

Pulse mode

P_{in}/P_{ref} : 100W(ave.)/10~20W

Duty ratio : 50%

Conclusion

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◆ Summary

- We increased the beam current of Xe^{7+} by pulsed microwave launching under gas mixing.
- The T_e decreases when the pulsed microwave is applied, so the increase in the average charge state $<q>$ is not due to it.
- The increase in Xe^{7+} seems to be due to the selective heating of ions, but another possibility is the effect of the afterglow (※).

◆ Future plan

- We will estimate the ion temperature T_i and obtain confirmation of the cooling effect of the ions.

⇒Conducting emittance measurements

- We will conduct the experiments to generate ICR and LHR to selectively heat low Z ions.

⇒Injection of RF waves (typically 13.56MHz) into ECR plasma under gas mixing

(※)Y. Kato, *et al*., Rev. Sci. Instrum., 2000, **71**, 657