ISBN: 978-3-95450-226-4 ISSN: 2222-5692 doi:10.18429/JACoW-ECRIS2020-WEWZO04

PRODUCING MULTICHARGED IONS BY PULSE MODULATED MICROWAVES AT MIXING LOW Z GASES ON ECRIS

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Abstract

The multicharged ion source on the basis of electron cyclotron resonance (ECR) plasma has been constructed for producing various ion beams in Osaka Univ. We are aiming at producing and extracting multicharged, molecular, and synthesized ion beams ranged over wide mass/charge numbers (*m/q*) in the single device. Among them, we are now trying to increase the yield of multicharged ion beams. We try to enhance production efficiency of multicharged ions by enhancing loss channel of low *Z* ions and then cooling them with gas mixing and pulse modulated microwaves. Through these experiments, we explore the feasibility of selectively heating specific ions with pulse modulated microwaves. These experiments are conducted by keeping the total operating pressure constant and changing the mixing ratio of low *Z* gases. These effects are investigated by measuring charge state distributions (CSD's) of the extracted ion beams. Also, we can measure the plasma parameters using Langmuir probes. In this paper, we mainly describe the results of these active experiments at the ECRIS.

INTRODUCTION

We are aiming at increasing the yield of multicharged ions by advanced wave-heating mechanisms other than fundamental ECR. As a previous study, for example, we obtained the result that the multicharged ion yield of Xenon (Xe) increased in the upper hybrid resonance (UHR) heating experiment using 4-6 GHz X-mode microwaves [1]. Now we are focusing on heating in the frequency band much lower than conventional ECR, and trying to generate another resonance heating, *e.g.* ion cyclotron resonance (ICR), and lower hybrid resonance (LHR). Our ultimate goal is to increase the multicharged ion beam currents by using these resonances to selectively heat low *Z* ions during gas mixing to enhance loss channels of low *Z* ions, and then cooling multicharged ions. As a preliminary step, we conducted experiments to generate ECR plasma with pulse modulated microwaves under gas mixing.

Gas mixing is a well-known and effective method for producing multicharged ion beams [2]. In order to increase the yield of multicharged ions of Xe, we perform the gas mixing experiments using Argon (Ar) for low *Z* gas. These experiments are conducted by keeping the total operating pressure constant and changing the mixing ratio of Xe and Ar. After optimizing the Ar mixing ratio for producing multicharged Xe ions, pulse modulated microwaves are introduced to it. We survey and optimize the pulse frequency for producing multicharged ion beams. The optimum time scale of pulse modulated microwave is several tens of microseconds. We succeeded in further increasing the yield multicharged Xe ion beams by pulsing the microwaves. Also, the pulse frequency at that time is nearly equal to the ion cyclotron frequency of Ar^+. We plan to conduct emittance measurements in near future to further ensure that selective heating of ions is possible. In addition, we also plan to conduct experiments to actively launch RF waves to the ECR plasma under gas mixing.

EXPERIMENTAL APPARATUS

Figure 1 shows the top view of the ECRIS in Osaka Univ. [3]. Vacuum chamber is 160mm in diameter and 1074mm in length. Magnetic field is formed by mirror coils (Coils A and B), a supplemental coil (Coil C), and four permanent magnets (octupole magnets). We use the cartesian coordinates system (*x,y,z*) with the origin located at the center of the vacuum chamber. Xe and Ar gases are introduced to the vacuum chamber by mass flow controllers, and pressures are monitored directly by Bayard-Alpert (B-A) gauges. 2.45 GHz microwave is generated by a magnetron and launched from a rod antenna which installed on the top of the vacuum chamber (*z*=175mm). Microwave oscillation can be switched between continuous wave (CW) mode and external input mode, it can be modulated into waveforms according to the external pulses. The operating range of pulse modulation is usually 1-100 kHz in frequency and 20-80% in duty ratio. The incident power of microwaves is defined by P_{in}. Magnetic flux density B is controlled by currents fed to each coil (defined as I_A, I_B, and I_C). In these experiments, I_A=I_B=150A, and P_{in}=100W. Plasma parameters, namely the electron density n_e and the electron temperature T_e are measured by the Langmuir probe 1 (LP1, $z=-175$mm) and the Langmuir probe 2 (LP2, z=300mm) which have cylindrical Mo electrode (0.25mm in diameter) and can be moved vertically within x=0mm and ±50mm.

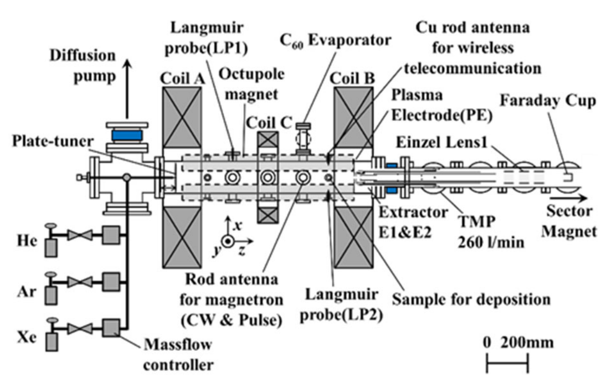

Figure 1: The top view of the ECRIS (Osaka Univ.).

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Ion beam is extracted to the beam line, which is composed of extractor and einzel lens 1 (EL1). The extractor assembly is constituted by a plasma electrode PE (15mm in single hole diameter, 10kV applied voltage), mid-electrode E1 (13mm in single hole diameter), and E2 (13mm in single hole diameter, usually grounded voltage). Voltages applied to the PE, the E1, the E2 electrodes, and the EL1 are defined as V_{PE}, V_{E1}, V_{E2}, and V_{el1}, respectively. They are used in optimizing extraction of each ion species. Ion beam is bent by the sector magnet. Ion beam currents are measured by several Faraday cups, and we obtain charge state distributions (CSD's) of them.

In addition, Ion Beam Irradiation System (IBIS) is connected to the rear end of the beam line [4]. The ECRIS and the IBIS are separated by gate valve 1 (GV1), and the IBIS itself is also divided into two parts by gate valve 2 (GV2). We call GV1 to GV2 the measurement part, and GV2 and later the irradiation part. It is described in detail in Ref. [4].

EXPERIMENTAL RESULTS AND DISCUSSION

Typical CSD's with and without Gas Mixing Application

Figure 2 shows typical CSD's of extracted Xe ion beams. Operating pressure is 7.0×10^{-4}Pa. The I_A and the I_B are 150A. P_{in} is 100W. The V_{PE} is 10kV. The I_C, the V_{E1} and the V_{el} are optimized for extracting Xe^{7+} ion beam. The black line is the CSD of Xe ion beams without Ar gas mixing. We can confirm Xe of q=1~7, and the beam current of Xe^{7+} is 1.1×10^{-8}A. Where q is charge state. The blue line is the CSD of Xe ion beams with Ar gas mixing. The current of Xe^{7+} is further increased than that of no gas mixing, and the beam current is 1.8×10^{-8}A.

The Dependence of Xe Ion Beams on Ar Mixing Ratio

Figure 3 shows the dependence of each Xe ion beam current on Ar mixing ratio. The horizontal axis is the Ar mixing ratio, which is determined by the partial pressures of Xe and Ar under the operation. The experiment is conducted at a constant total operating pressure, which is 7.0 $\times10^{-4}$Pa. The V_{PE} is 10kV. The I_C, the V_{E1} and the V_{el1} are optimized for extracting Xe^{7+} ion beam. As the Ar mixing ratio is increased, the extracted Ar^{+} beam current increases, and the Xe^{7+} ion beam reaches the maximum value at Xe:Ar=50:50.

Typical CSD's with and without Pulse Modulated Microwaves Application

Figure 4 shows typical CSD's of extracted Xe ion beams. Operating pressure is 7.0×10^{-4}Pa. The I_A and the I_B are 150A. P_{in} is 100W. The V_{PE} is 10kV. The I_C, the V_{E1} and the V_{el} are optimized for extracting Xe^{7+} ion beam. The blue line is the CSD of Xe ion beams under simple gas mixing.

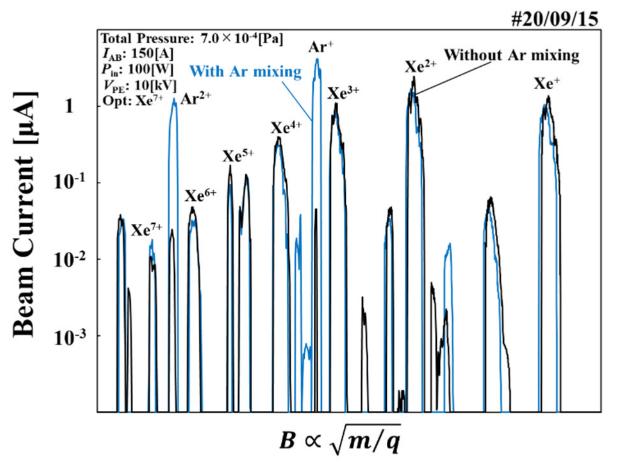

Figure 2: Comparison of typical CSD's of Xe ion beams with and without gas mixing.

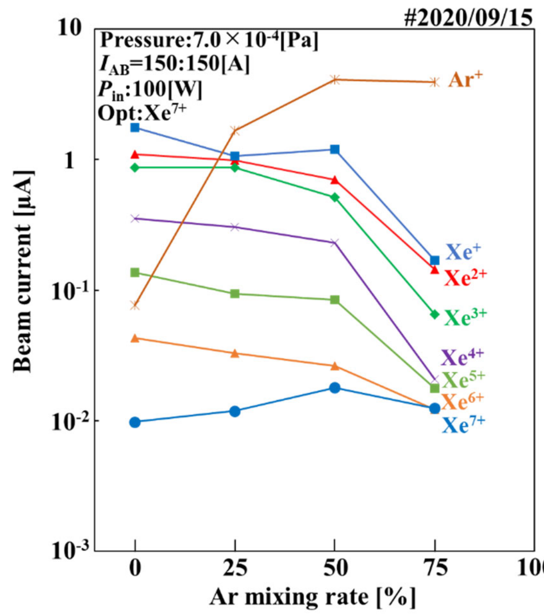

Figure 3: The dependence of each Xe ion beam current on Ar mixing ratio.

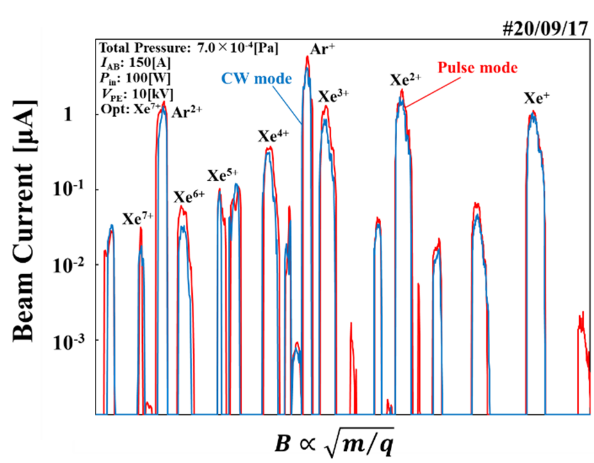

Figure 4: Comparison of typical CSD's of Xe ion beams in CW and Pulse mode.

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We can confirm Xe of q=1~7, and the beam current of Xe^{7+} is 1.1×10^{-8}A. The red line is the CSD when pulse wave is applied under gas mixing. The yield of Xe^{7+} is further increased than that of simple gas mixing, and the beam current is 3.5×10^{-8}A.

Microwave Pulse Period Dependence of Multicharged Xe Ion Beam

Figure 5 shows the dependence of Xe^{7+} ion beam current on microwave pulse period. The horizontal axis is the pulse period, and the vertical axis is the beam current of Xe^{7+}. The experimental conditions except for microwaves operation are the same as in Fig. 3. Pulsed microwaves are launched against the mixed gas of Xe:Ar=50:50. When the pulse period is changed in the range of 10-100 microseconds, the yield of Xe^{7+} changed and peaked at a period of 25 microseconds. The time-averaged incident and reflected microwave powers are almost the same in CW and pulse mode. This period corresponds to the ion cyclotron frequency of Ar^{+} in the magnetic field of our ECRIS. The current of Xe^{7+} when microwaves are incident in CW mode is shown by the dotted red line, and the value is 1.8×10^{-8}A. On the other hand, the maximum current of Xe^{7+} in pulse mode is 3.5×10^{-8}A.

Comparison of the Plasma Parameters between CW and Pulse Mode

Figure 6 shows the distribution of the n_e and the T_e in CW mode and pulse mode. The period in pulse mode is 25 microseconds. The measurement is performed three times at each x position by using the LP1, and the figure shows the average value and standard error. When pulse mode is introduced, the n_e is slightly higher than that of CW mode at x=0~40mm. The T_e is lower than that of CW mode at all x positions. Therefore, the increase in multicharged ion beam yield is not considered to be the effect of plasma parameters. We expect that the cause of the increase in the multicharged ion beam yield is the enhancement of the gas mixing effect by pulse waves.

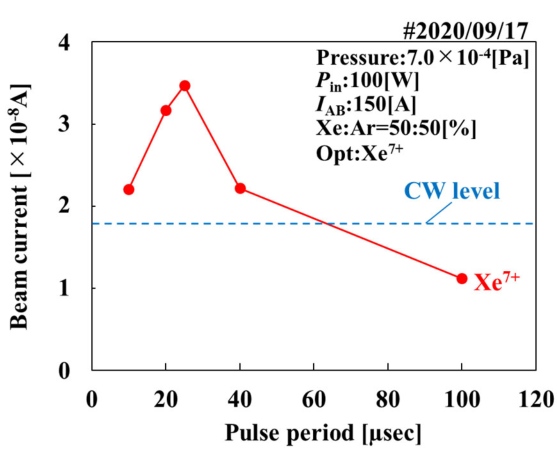

Figure 5: The dependence of Xe^{7+} ion beam current on microwave pulse period.

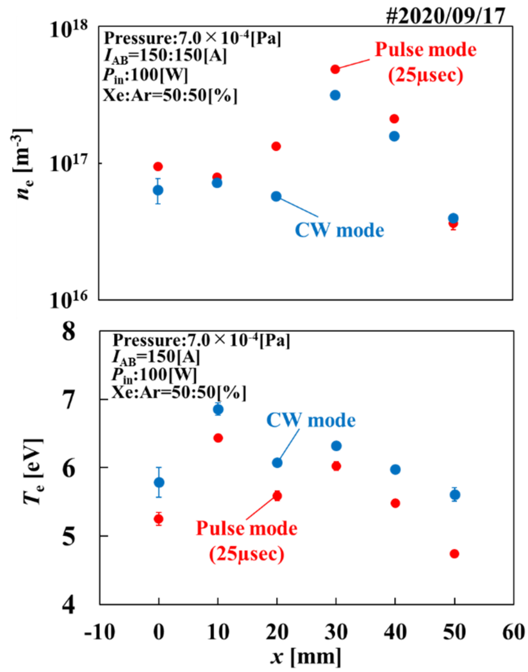

Figure 6: The distribution of the n_e and the T_e in CW mode and pulse mode.

Summary and Future Planning

We launched pulse modulated microwaves under simple gas mixing to increase the yield of multicharged Xe ion beams. The yield of Xe^{7+} was increased by 3.2 times compared with pure Xe ion beams. Furthermore, the probe measurements were conducted to confirm that these results were not due to the effects of the plasma parameters. Except for the enhancement of the gas mixing effect, the afterglow effect may affect the production of multicharged ions.

To obtain more confirmation about selective heating of low Z ions, we plan to perform emittance measurements to estimate the ion temperature T_i before and after the introduction of pulsed microwaves. In addition, we also plan to conduct the experiments that cause ICR and LHR by injecting RF waves into the ECR plasma under gas mixing.

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