FURTHER DEVELOPMENT OF RIKEN 18 GHZ ECRIS

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Abstract

We successfully produced intense beam of highly charged ions (e.g., 300 eμA of Ar^{11+}, 18eμA of Ar^{18+}, 15eμA of Kr^{24+} and 3eμA of Xe^{32+}) from the RIKEN 18 GHz ECRIS using the electrode. To investigate the function of the electrode, we measured the beam intensity of argon ions using electrode under the pulsed mode operation. We observed that the potential dip becomes deeper by increasing negative bias voltage. It is concluded that the electrode works to optimize the plasma potential and helps to increase the beam intensity of highly charged argon ions.

1. INTRODUCTION

Because the intense beams of medium mass heavy ions requested by users in RIKEN Accelerator Research Facility, a new ECRIS has been constructed as an external ion source of the RILAC(Riken heavy Ion Linear ACcelerator)-Ring cyclotron accelerator complex[1]. This ECRIS is also one of the constituents of the Radioactive Ion Beam Factory (RIBF) project, for whose aim is to supply the various unstable nuclei beams for the experiments in various fields.[2] According to the scaling low proposed by R. Geller, the beam intensity increases with its micro wave frequency and magnetic field strength.[3] Therefore, we have chosen the micro wave frequency of 18 GHz for the RIKEN ECRIS. It is successfully under operation now[4-6]. Recently, we install the electrode in the plasma chamber and observed the strong enhancement of beam intensities of highly charged ions. In this paper, we present the performance and mechanism to produce multi-charged heavy ions using the electrode.

2. DESCRIPTION OF RIKEN 18 GHz ECRIS WITH ELECTRODE

The detailed design of the ECRIS was described in ref. 5. A single 18 GHz-1.5 kW klystron supplies RF power to the source. The axial confinement of plasma is obtained by two solenoid coils which provide magnetic mirror field. The source is completely enclosed by an iron yoke to reduce the current of the solenoid coils. The maximum electrical power consumption is 140 kW. The mirror ratio is about 3.0 (B_{max} ~ 1.4 T, B_{min} ~ 0.47 T). To confine the plasma radially, we use a hexapole magnet which consists of 36 segments, made of Nd-Fe-B permanent magnets. The field strength at the surface of the magnets is about 1.4 T. Figure 1 shows the schematic drawing of the RIKEN 18 GHz ECRIS with the stainless steel electrode. The diameter and thickness of the electrode is 13 and 1 mm, respectively. It is possible to apply the negative bias voltage between the electrode and plasma chamber as shown in fig. 1. It is also possible to use the electrode at the floating potential by disconnecting it from the electric power supply. The position of the electrode was remotely controlled with accuracy of 0.1 mm.

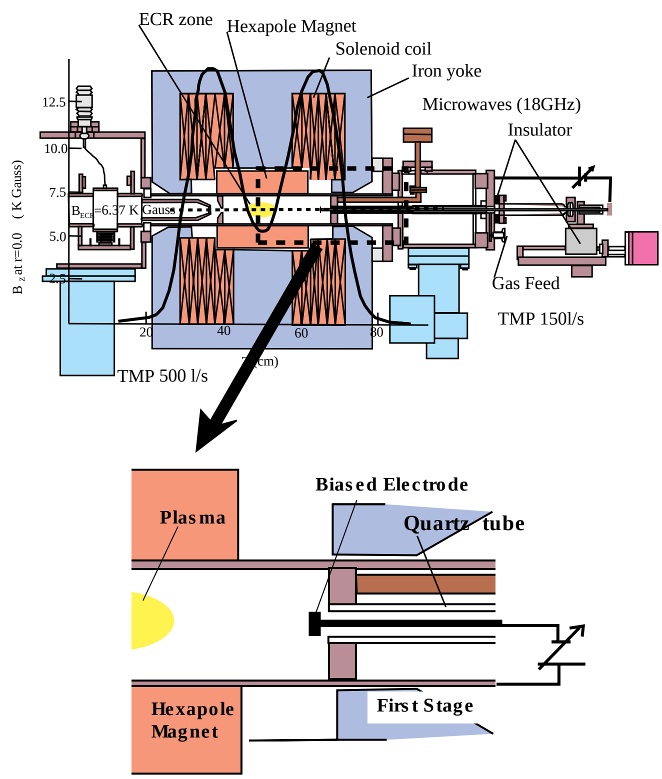

Fig.1 Schematic drawing of RIKEN 18GHz ECRIS with electrode

3. EXPERIMENTAL RESULTS AND DISCUSSION

3-1 Beam intensities of gaseous elements

Figure 2 shows the beam intensity as a function of the extraction voltage. The open and closed circles are the results obtained without and with using the electrode, respectively. At 15 kV, we obtained a beam intensity of 300 eμA for Ar^{11+} when using the electrode. Figure 3 shows the beam intensity of Ar^{11+} as a function of microwave power at the extraction voltage of 12 kV.

The beam intensity increases upon increasing the RF power up to 600 W. Figure 4 shows the summary of beam intensity for gaseous elements. The closed circles and open circles are the results with and without using the electrode. The beam intensities of highly charged ions are strongly enhanced with using the electrode.

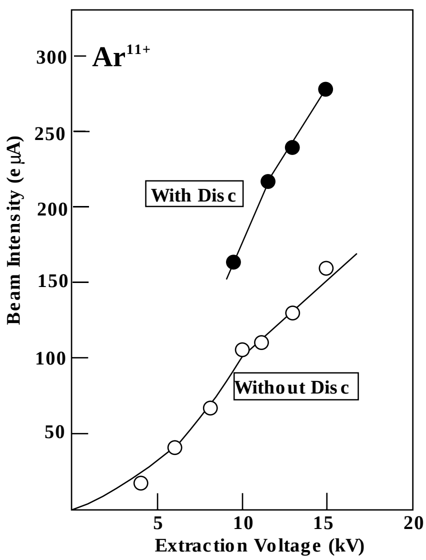

Fig.2 Beam inetnsity of Ar^{11+} as a function of extraction voltage. Open and closedcircles are the results witout and with using the electrode

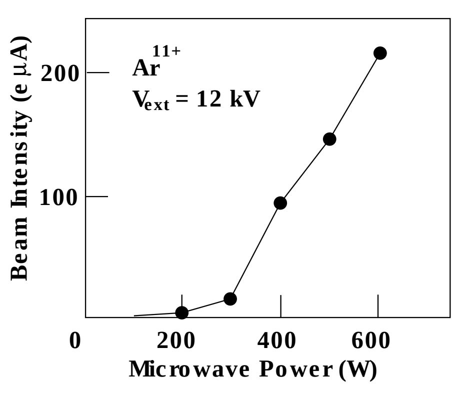

Fig.3 Beam intensity of Ar^{11+} as a function of microwave power.

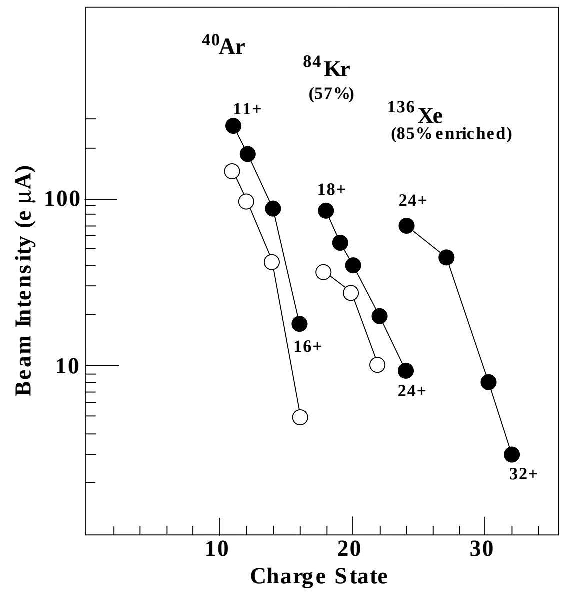

Fig.4 Beam intensity of highly charged heavy ions

3-2 Measurement of plasma potential dip

As described in the previous section, the beam intensity is strongly enhanced at 0 V or floating potential. Beam intensity decreases by increasing negative bias voltage. On the other hand, the total extraction current from the ECRIS is constant and independent of the bias voltage. These results suggest that the electrode may not work as an electron source, but instead works to change the plasma potential dip which traps the highly charged ions. The measurement of afterglow- and steady-currents under the pulsed mode operation gives information on potential dip in ECR plasma.[3] In order to study the effect of an electrode on the plasma potential dip, we measure the afterglow- and steady-currents under the pulsed mode operation using the electrode.

Under the pulsed mode operation, we kept same values of gas pressure, magnetic field strength, and extraction voltage as those under the CW mode operation which we obtained the best results. The pulse length was 40 ms which is long enough to reach the equilibration for producing the highly charged argon ions such as $Ar^{11+,\ 12+}$. Repetition rate was 10 Hz.

We measured ratio of the afterglow current ($I_{afterglow}$) to steady current (I_{steady}) for charge state from 8+ to 12+ as a function of negative bias voltage. As described in ref. 6, if the central plasma shows a depressed potential $\Delta\phi$, the ratio between the beam currents of steady state and the afterglow can be written as follows,

$$I_{afterglow}/I_{steady} = \exp(q\Delta\phi/kT_i) \quad (1)$$

where q, $\Delta\phi$ and T_i are the charge state of ions, depressed potential and ion temperature, respectively. Figure 5 shows the ratio of $I_{afterglow}$ to I_{steady} as a function of charge state. Closed circles, open circles, and open squares are the results at the negative bias voltage of 0, -500 and -1000 V, respectively. As shown in fig. 6, the value of $\Delta\phi/kT_i$ increases with increasing the negative bias voltage. This result suggests that the potential dip in ECR plasma becomes deeper with increasing the negative bias voltage. Dashed line shows the value of $\Delta\phi/kT_i$ without using electrode. The potential dip at floating potential or 0 V is shallower than that without using the electrode.

In ref.3, the ion confinement time of highly charged ions is written by

$$\tau_q \propto \exp(q\Delta\phi/kT_i) \qquad (2)$$

The extracted ion current(I_q) can be written as follows,

$$I_q \propto n_q q r^2 L/\tau_q \qquad (3)$$

where n_q, r, L and τ_q are the density of ions, average radius of plasma, length of plasma and ion confinement time, respectively. In order to obtain the higher current of ions, ion confinement time should be shorter at the fixed n_q, r, and L. The ion confinement time should be longer than the ionization time(τ_i). When we reduce the ion confinement time, but as to longer than ionization time at fixed n_q, r, and L, the ion current increases.

Using the electrode at 0 V, the ion confinement time becomes shorter compared to that without using the electrode. The ionization time seems shorter than the ion confinement time. As a result, the beam intensity of highly charged ions increases.

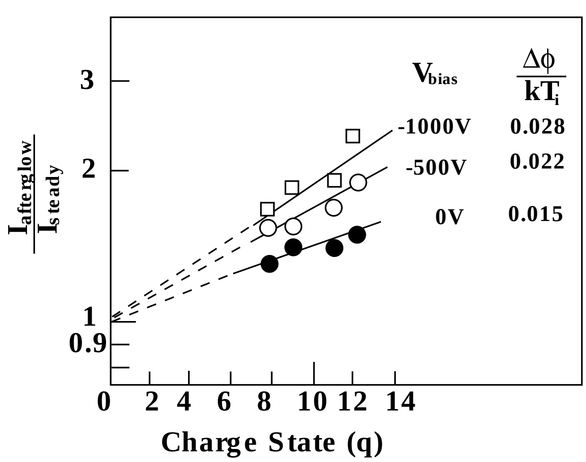

Fig. 5 Ratio of afterglow to steady current as a function of charge state

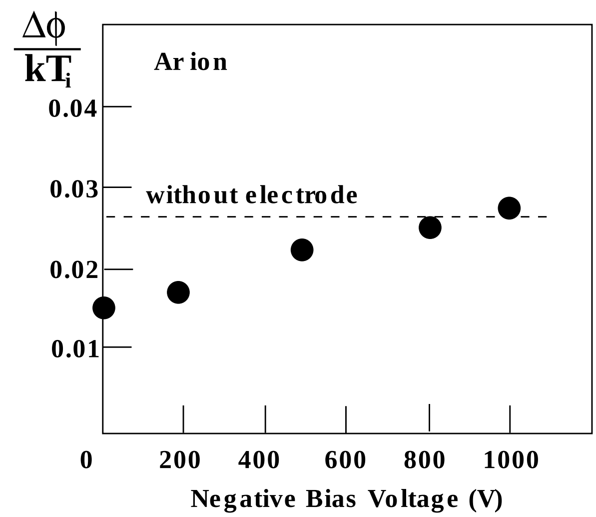

Fig. 6 $\Delta\phi/kT_i$ as a function of negative bias volatge. Dashed line shows $\Delta\phi/kT_i$ without using electrode.

5. CONCLUSION

We observed the strong enhancement of beam intensity of highly charged ions (300 eμA of Ar^{11+}, 18eμA of Ar^{18+}, and 15eμA of Kr^{24+}, 3eμA of Xe^{32+}) from the RIKEN 18 GHz ECRIS when using the electrode. We measured the beam intensity of argon ions as a function of negative bias voltage of an electrode under the pulsed mode operation. We observed that the potential dip becomes deeper by increasing negative bias voltage. We concluded that the electrode works to optimize the plasma potential and helps to increase the beam intensity of highly charged argon ions.

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