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Recent Developments of RIKEN ECRISs (18 GHz ECRIS and Liquid He Free SC-ECRIS)

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Abstract

The RIKEN 18 GHz ECRIS successfully supplies intense beams of highly charged heavy ions to the RIKEN accelerator complex and will be used as an source for the RIKEN RI beam factory project. The beam intensities of highly charged ions are dramatically increased with using an electrode : e.g. 1mA of Ar^{8+}, 300 eμA of Ar^{11+}, 200 eμA of Kr^{15+}, 12 eμA of Xe^{30+} etc. To investigate the mechanisms, we measured the plasma potential dip under the pulsed mode operation when using the electrode.

Recently, we started to construct the SC-ECRIS . One of the main features of the SC-ECRIS is to use the Gifford-McMahon refrigerator for cooling directly the solenoid coils without using liquid He. Maximum and minimum mirror magnetic field is 3T and 0.5 T. Maximum field strength of hexapole is 1.4 T. In addition, we plan to use two frequency plasma heating (18 and 14 GHz).

1. Introduction

It is well-known that highly-charged ions are efficiently yielded mainly through the successive ionization process in the electron cyclotron resonance ion source (ECRIS). Therefore, to obtain higher beam intensities, it is crucial to increase the density of electrons and to optimize the exposure time of ions in the electron cloud. From this point of view, many laboratories have attempted to increase the beam intensity of highly-charged heavy ions from ECRIS using various methods.[1)] One of these methods involves the installation of the negatively-biased electrode in the plasma chamber.[1)] To improve the performance, we applied this method to the RIKEN 18 GHz ECRIS and successfully produced highly charged heavy ions using the electrode. In 1998, We started to construct the SC-ECRIS. One of the main features of the SC-ECRIS is to use the Gifford-McMahon refrigerator for cooling directly the solenoid coils without using liquid He. Maximum and minimum mirror magnetic field is 3T and 0.5 T. Maximum field strength of hexapole is 1.4 T. In addition, we plan to use two frequency plasma heating (18 and 14 GHz).

In this paper, we present the results of beam intensities with using electrode and its mechanisms. We also present the structure of the SC-ECRIS, the optimization of its size and the results of test experiments

2. Description of 18 GHz ECRIS with electrode

The design and performance of the RIKEN 18 GHz ECRIS without using the electrode are described in ref. 2. 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 It is also possible to use the electrode at the floating potential by disconnecting it from the electric power supply. The electrode is placed at the point of maximum magnetic field strength at axial direction The extraction voltage was 12~15kV.

3.Electrode method

3-1 CW mode operation

We have observed the strong enhancement of the beam intensity of highly charged heavy ions with using the electrode. The best performance was obtained when the 13 mm stainless steel electrode was placed around the highest magnetic value and worked at floating potential. At 15 kV ion source potential we obtained 300 eμA of Ar^{11+} for a short time (less than one hour). Figure 1 shows the summary of the highest beam intensity for gaseous elements. The closed and open circles are the results with and without using the electrode. The beam intensities of highly charged ions strongly enhanced with using the electrode. More systematic studies are described in ref. 3

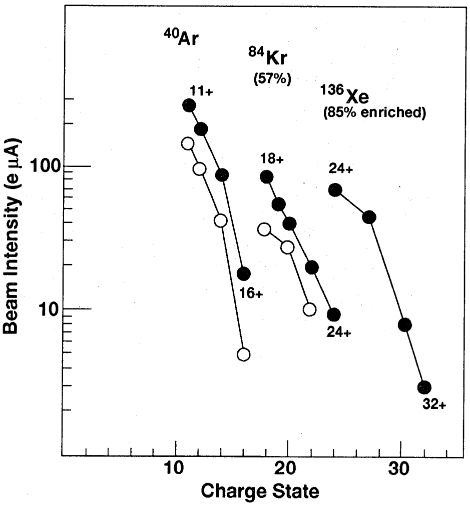

Fig.1 Beam intensities of highly charged ions.

3-2 Pulsed mode operation

Under the CW mode operation of the injected microwave, the beam intensity decreased with increasing the negative bias voltage. We obtained 160eμA of Ar^{11+} with using the electrode at floating potential at the extraction voltage of 10 kV. To check the beam intensity of Ar^{11+} ions without using electrode, the electrode was removed from the plasma chamber using the moving system without changing any other parameters. The beam intensity of Ar^{11+} was 100 eμA which is almost same as the best result(105 eμA) without using the electrode at microwave power of 550W and extraction voltage of 10 kV . The argon gas was used as an ionized gas. The gas pressure of the plasma chamber was 3×10^{-7} Torr. The extraction voltage was 10 kV.

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. The pulse length under the pulsed mode operation 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. 1, if depressed potential $\Delta\phi$ exist in central plasma , the ratio between $I_{afterglow}$ and I_{steady} can be written as follows,

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

where q, $\Delta\phi$ and T_i are the charge state of ions, depressed potential and ion temperature, respectively. Using this equation and experimental results, we obtained the value of $\Delta\phi/kT_i$ as a function of negative bias voltage. It is clearly seen that the value of $\Delta\phi/kT_i$ increases with increasing the negative bias voltage in fig. 2. 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.1, 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.

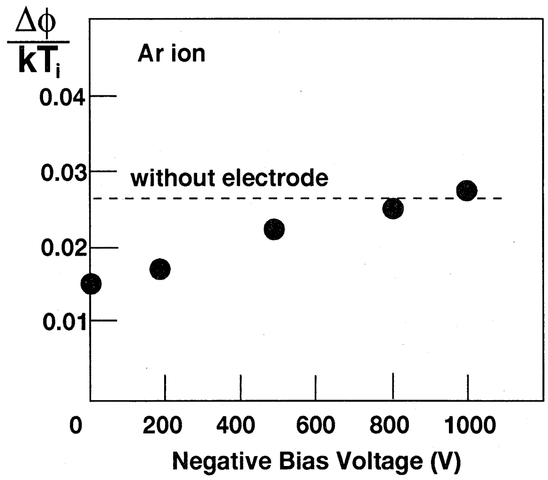

Fig.2 $\Delta\phi/kT_i$ as a function of negative bias voltage. Dashed line indicates the value of $\Delta\phi/kT_i$ without using the electrode.

4. Liquid He Free SC-ECRIS

Since the success of high B mode operation at Michigan state university, we recognize that large mirror ratio and strong magnetic field are the essential points to produce the intense beams of highly charged ions. When using the normal temperature solenoid coils, the limitation of field strength is about 1.4~1.7T. In order to overcome this limitation and improve the performance, Catania and Grenoble group constructed a super conducting ECRIS(SERSE).[4] and successfully produce the intense beam of highly charged heavy ions.

Recently, we started to construct the Liquid He-free super conducting ECRIS at RIKEN. The one of the main feature is that a compact refrigerator of Gifford-McMahon type are used to cool the solenoid coils. Using this system, we do not need to supply the liquid He for operation. Figure 3 shows the cross sectional view of the ECRIS. . Main drawback is the low cooling power at 4.2 K (about 1W). To minimize the resistance, we use the high-temperature super conducting material leads current placed between 50K and 4.5 K region. The current lead of copper is used between 300K and 50 K region. Three set of dynodes located inside the cryostat are used for quench protection. Four solenoid coils are set in vacuum vessel as shown in fig.3 The role of the coil III, which works with reverse fields, is to decreases the minimum mirror magnetic field strength. The coils are power by three 60A-10V power supplies which were manually controlled. The maximum axial field strength were 3T. To confine the plasma radially, we used a hexapole magnet which consists of 24 segments made of Nd-Fe-B permanent magnets. The outer diameter (OD) and inner diameter (ID) are 200 mm and 80 mm, respectively. The field strength at the surface of magnets is about 1.4 T. To protect the hexapole magnet from demagnetization by high temperature, a water-cooled plasma-chamber (ID= 74 mm, OD= 80 mm) has been constructed.

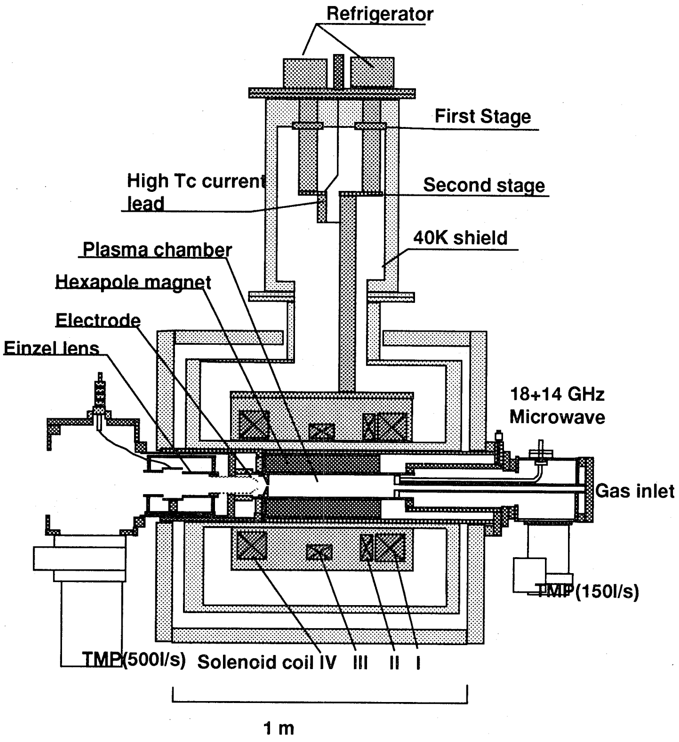

Fig.3 Cross sectional view of Liquid He free SC-ECRIS

5. Conclusion

The beam intensities of highly charged ions are dramatically increased with using an electrode at floating potential: e.g. 1mA of Ar^{8+}, 300 eμA of Ar^{11+}, 200 eμA of Kr^{15+}, 12 eμA of Xe^{30+} etc.

To investigate the mechanism, we measured plasma potential dip under the pulsed mode operation when using the electrode. We found that the electrode changes plasma potential dip to increase the beam intensities

In 1998, we have started to construct the SC-ECRIS . One of the main features of the SC-ECRIS is to use the Gifford-McMahon refrigerator for cooling directly the solenoid coils without using liquid He. Maximum and minimum mirror magnetic field is 3T and 0.5 T. Maximum field strength of haxpole is 1.4 T. In addition, we plan to use two frequency plasma heating (18 and 14 GHz).

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