

STATUS OF THE RIKEN ELECTRON CYCLOTRON RESONANCE ION SOURCE (ECRIS)

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Abstract

RIKEN ECRIS consist of 2 stages and has an operating frequency of 10 GHz for both stages. The enhancement of performance of highly charged ions has been observed after producing the Al and Mg ions. This effect is due to the coating effect of chamber wall. The beam intensity of highly charged ions was measured when the electrode was used in the first stage of the ECRIS. The beam intensity is strongly dependent on the current of the electrode. When we used the electrode after coating the chamber wall with Al_2O_3 , the beam intensity of highly charge ions becomes larger than that observed when only the electrode was used. We only need 10-20 watts of RF power of the first stage to obtain these results. The beam intensity of highly charged ions becomes stable compared to that before setting the electrode.

Introduction

In the last decade, Electron Cyclotron Resonance Ion Source (ECRIS) has been developed from a complex prototype into a compact, high-performance source for accelerator and atomic physics. The coupling of an ECRIS to a cyclotron has achieved a significant performance in the energy, intensity and variety of ions.

At RIKEN Accelerator Research Facility (RARF), A K70 AVF cyclotron[1] was constructed as an injector of the RRC[2] on 1988. Our ECRIS has been constructed for the external ion source of K70 AVF cyclotron and for the experiment of low energy atomic physics. A role of RIKEN ECRIS as the external ion source of the cyclotron is to make highly charged ions. Because the M/q values accepted by the K70 AVF cyclotron is smaller than 4.5, where M and q are the mass and charge of ions produced by the ECRIS, respectively.

The RIEN ECRIS has been constructed on 1988 and are supplying the highly charged ions for many experiments stably. Furthermore, Several improvements have been done up to now.

In section 2 the design of the RIKEN ECRIS is described. A few authors have reported that the condition of chamber wall is very important to produce the highly charged ions and the enhancement of current of highly charged ions has been observed after coating the wall with thorium[3] or SiO_2 [4]. We also found the same effect using the Al_2O_3 and MgO . In section 3 we report this effect in detail. Recently, two laboratories (Lawrence Berkeley National Laboratory and CENG/SPHAt Grenoble) have succeeded to increase the beam intensity of highly charged ions by supplying the electrons to the second stage plasma of the ECRIS. One of methods is to put the electrode near the gas injection and supply the bias voltage to supply the electrons to the second stage plasma [5]. We also put the electrode in the first stage and measured this influence carefully. When we use both methods simultaneously, we should obtain larger current. In section 4 we report not only the effect of electrode, but also the influence to the beam intensity by using the both methods (coating the chamber wall and the electrode) simultaneously.

RIKEN ECRIS

The design and performance of the RIKEN ECRIS was described in refs. 6 and 7. Figure 1 shows the schematic drawing of the RIKEN ECRIS. The source consists of 2 stages. The first stage, 6 cm in diameter and 26 cm long, is used to make a dense plasma and the second stage, 10 cm in diameter and 52 cm long is for production of highly charged ions. The operating frequency of the source is chosen to be 10 GHz for both stages. Maximum RF powers for the first and second stages are 1 and 2.5 kW, respectively.

The gas is fed into the first stage. To avoid the diffusion of the fed gas into the waveguide, a quartz tube of 20 mm in inner diameter is installed in the first stage chamber. An axial field is produced by solenoid coils which are divided into 8 sections. The mirror ratio and minimum values of the magnetic field at the second stage are easily controlled by varying the electric current for six axial coils. In the second stage, a SmCo_5 sextupole magnet is installed to produce the radial magnetic field. The strength of the magnetic field is about 4 kG at the surface of each pole.

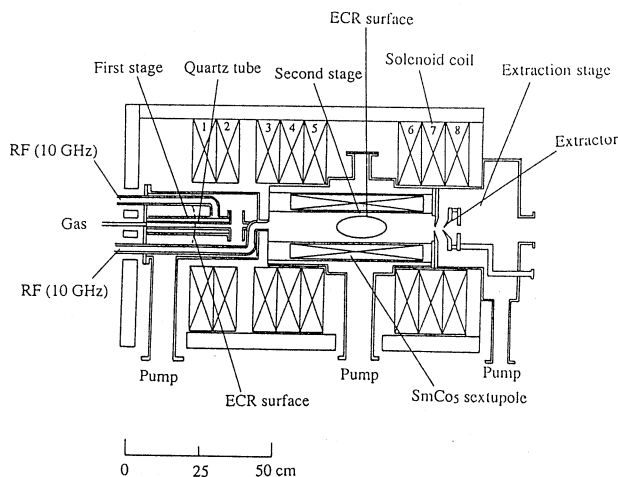


Fig.1 schematic drawing of the RIKEN ECRIS

Effect of Coating the Chamber Wall

Several authors have suggested that the condition of chamber wall is very important to produce the intense highly charged ions. Grenoble group reported that the beam intensity has been enhanced after coating the chamber wall of FERROMAFIOS with thorium[3]. Lawrence Berkeley National Laboratory group reported that the enhancement have been observed after producing the Si ions[4]. We also found the same effect after producing the Al and Mg ions.[8]

In order to produce Al ions, an Al_2O_3 ceramic rod was directly inserted into the plasma in the second stage and heated to obtain the sufficient vapor pressure. The support gas was oxygen. The diameter and length of the rod were 4 and 200 mm, respectively. The consumption rate was 0.1 mm/10 min.. The evaporated aluminium oxide was ionized in the plasma and extracted from the ECRIS. Part of them were attached to the chamber wall. The RF powers of the first and second stage are about 50 and 800 W, respectively. In Fig. 2, open and closed circles are the beam intensity for each charge state before and after producing the Al ions for 30 min. The mixing ratio of the main gas (CO_2 , N_2 and Ar) to mixing gas (He and O_2) was almost fixed to 1:5. In order to minimize other effects in the beam intensity, other parameters (gas pressure, RF power, axial and radial magnetic fields and gas-mixing ratio) were not changed before or after producing Al ions. The beam current of Ar^{11+} ions increased from 30 to 45 μA . The Ar^{12+} current increased from 10 to 30 μA . In the case of Ar^{14+} , the beam intensity increased from 0.5 to 5 μA .

It is clear that the beam intensity of highly charged ions was strongly enhanced after producing Al ions. This effect continued for several months. Then the beam intensity decreased with the same parameter set of RIKEN ECRIS.

We have observed the same effect after producing Mg ions. Mg ions were produced by inserting a MgO ceramic rod into the plasma in the second stage. The diameter and length were 4 and 200 mm, respectively. The consumption rate was 0.1 mm/15 min.. The performances of the higher-charge states of argon, nitrogen, and carbon ions after producing Mg ions were the same as those after producing Al ions.

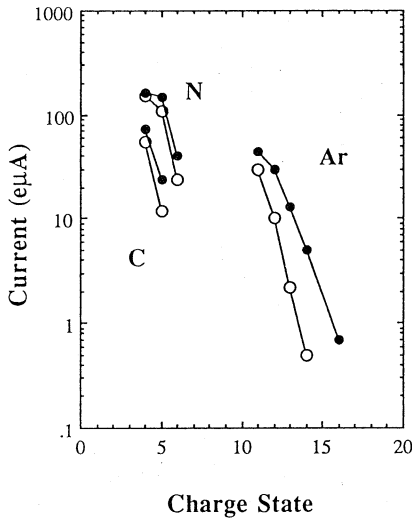


Fig.2. Beam intensity of carbon , nitrogen, and argon ions as a function of charge state Open and closed circles are the beam intensities before and after producing Al ions.

Effect of Electrode

The probability of the producing highly charged ions by single electron impact falls off rapidly with increasing the ion charge. Therefore, the only efficient way to obtain highly charged ions is by successive ionization. For this reason, in order to obtain intense highly charged ions, the exposure time of ions to the cloud of electrons or the electron density has to be increased.

Up to now, we have two methods to increase the electron density. One is to use the electron gun to supply electrons in the plasma.[4] Another one is to put the electrode near the gas injection and supply the bias voltage to push out electrons to the plasma in the second stage.[5] We put the electrode in the first stage. The advantage of the RIKEN ECRIS compared to the MINIMAFIOS is that two separated RF power supplies can be controlled independently. Hence, we can control the RF power of the first stage by itself. The first stage may work as an electron gun. As described in previous chapter, the condition of the chamber wall is also very important to produce the intense highly charged ions. If we use both methods, We should obtain larger current. In this chapter, we described not only the effect of electrode, but also the enhancement of the highly charged ions by using the both methods simultaneously.

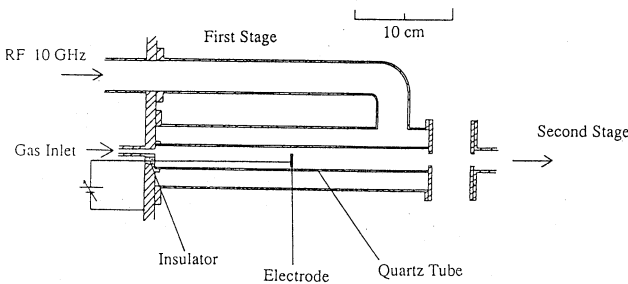


Fig.3 Schematic drawing of the first stage

Figure 3 shows the schematic drawing of the first stage of the RIKEN ECRIS. An electrode made of copper is placed at the middle of the first stage as shown in Fig.3 The diameter and thickness of the electrode are 10 and 2 mm, respectively. The RF power of the second stage was about 800 W. Figure 4 shows the beam intensity of argon ions as a function of charge state. Open circles are the "best result" before setting the electrode. Open triangles are the beam currents when we used the electrode (bias voltage is -300 V). Open squares are the beam currents when we used the electrode after coating the chamber wall with Al₂O₃ . The beam intensity of ⁴⁰Ar¹²⁺ increased from 10 to 18 eμA when we used the electrode. Furthermore, the beam intensity of ⁴⁰Ar¹²⁺ increased from 18 to 32 eμA when we used the electrode after coating the chamber wall with Al₂O₃ . In the case of ⁴⁰Ar¹⁶⁺, the intensity increased from 0.5 to 1 eμA.[9]

Usually the RF power of first stage is 50 - 100 W. The beam intensity becomes unstable with increasing RF power of the first stage. We should stress that we need only 10 - 20 watts of RF power of the first stage to obtain these results and beam intensity becomes stable compared to that before setting of the electrode.

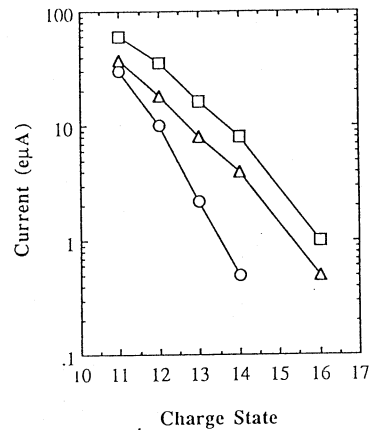


Fig.4 The Beam intensity of argon ions as a function of charge state. Open circles are the best result before setting the electrode in the first stage. Open triangles are the beam intensity when the electrode was used. Open squares are the beam intensity when the electrode was used after coating the Al₂O₃ on the chamber wall by inserting the Al₂O₃ ceramic rod into the second stage plasma. Lines are drawn to guide the eye through the data points.

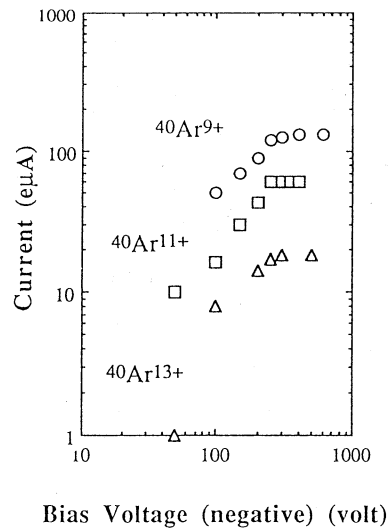


Fig.5 Beam intensity of argon ions as a function of the bias volatage of the electrode.

Figure 5 shows the extracted current of Ar ions as a function of bias voltage. The pressure of the first, second and extracted stages are 2×10^{-5} , 1×10^{-6} , and 1×10^{-7} Torr, respectively. The beam current increases with increasing the bias voltage and then becomes constant. The beam intensity is strongly dependent on the bias voltage of the electrode. We also measured the dependence of extracted current on the current of the electrode. The beam intensity of highly charged ions are strongly depend on the current of the electrode. The beam intensity increases with increasing the current of the electrode. Figure 6 shows the beam current of various ions as a function of the current of the electrode.[10] It is clear that if we can increase the current of the electrode, we obtain the larger current. It may conclude that the first stage works same as a electron gun.

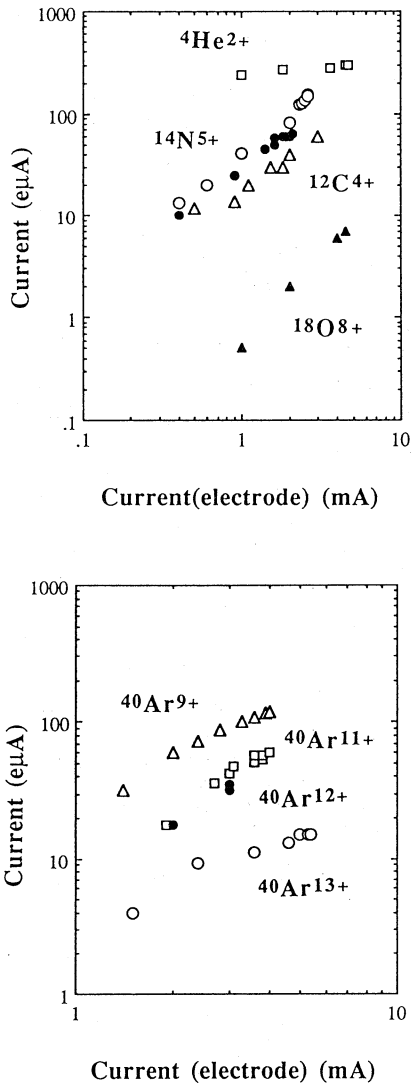


Fig. 6 Beam intensity of the various ions as a function of the current of the electrode

Conclusion

RIKEN ECRIS consist of 2 stages and has an operating frequency of 10 GHz for both stages. This source has successfully operated with not only gaseous element, but also solid materials. The enhancement of performance of highly charged ions has been observed after producing the Al and Mg ions. These ions are produced by inserting the ceramic rod into the second stage plasma. This effect is due to the coating effect of chamber wall. The beam intensity of highly charged ions was measured when the electrode was used in the first stage of the ECRIS. The enhancement of the beam current was observed. The beam intensity is strongly dependent on the current of the electrode. When we used the electrode after coating the chamber wall with Al_2O_3 , the beam intensity of highly charge ions becomes larger than that observed when only the electrode was used. We only need 10-20 watts of RF power of the first stage to obtain these results. The beam intensity of highly charged ions becomes stable compared to that before setting the electrode.

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