PLASMA CATHODE METHOD FOR RIKEN ECRIS

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Abstract

A negatively biased electrode was set in the first-stage chamber of the RIKEN 10 GHz ECR (electron cyclotron resonance) ion source. By use of this electrode, the beam intensities of highly charged ions have been markedly increased. We studied the mechanism of this phenomenon, investigating the dependence of highly charged ion intensity upon the electrode bias voltage and current as well as the gas pressure of the first-stage chamber. Based on the results of this method, we changed the structure of the first stage. The first stage was isolated from the second stage electrically and negative bias was supplied to the first stage(plasma cathode method). We also observed that the beam intensity of highly charged ions was enhanced by using this method.

1. Introduction

In the last decade, ECRISs (electron cyclotron resonance ion sources) have been developed from a complex type into a compact and high performance ion source for accelerators and atomic physics experimental apparatus. The coupling of the ECRIS to heavy ion accelerator, in particular, has brought about a significant upgrade of their performance in energy, intensity and variety of ions.

Many laboratories have made an effort to upgrade the beam intensity of highly charged ions produced by ECRISs, using several methods. [1-6] In order to increase the electron density in the plasma, the Lawrence Berkeley Laboratory group has used an electron gun to supply electrons to the plasma of advanced ECRIS[2]. On the other hand, the Grenoble group has put a negatively biased probe near the gas injection of MINIMAFIOS to push electrons into second stage plasma. [4] The latter method is very useful for an ECRIS which consists of two stages, such as the RIKEN ECRIS.[7]

In the previous study on the RIKEN 10GHz ECRIS, we examined a method on setting up negatively biased electrode placed in the first stage.[5] This method has allowed us to significantly upgrade the beam intensity of highly charged ions: 160eμA $^{14}N^{5+}$, 150eμA $^{16,18}O^{6+}$, 60eμA $^{40}Ar^{11+}$ and 6eμA $^{84}Kr^{20+}$ have been successfully obtained. We have thus been supplying experimentalists with intense intermediate-energy heavy-ion beams from the AVF-Ring cyclotron complex.[8,9] In this paper, we present the mechanism of the phenomenon mentioned above, investigating the dependence of the output intensity of highly charged ions upon the electrode bias voltage and current as well as the pressure of the first stage chamber. Based on these results, we tried to change the structure of the first stage itself as an electron source (plasma cathode method). We also present this method and results in detail.

2. Negatively biased electrode

We measured the dependence of intensity of highly charged ions upon the bias voltage of the electrode , gas pressure and electrode current. The experimental set up is the same as described in Ref. 5. Figure 1 shows the schematic drawing of the first stage. The electrode is made of copper . The diameter and thickness are 10 and 2 mm, respectively.

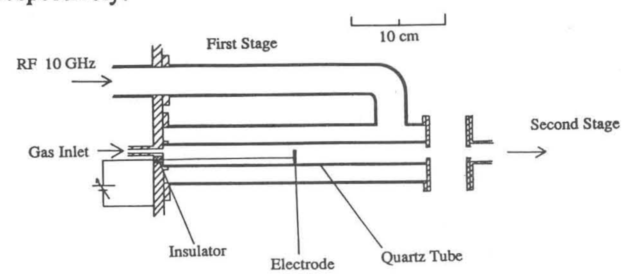

Fig.1 Schematic drawing of the electrode placed in the first stage

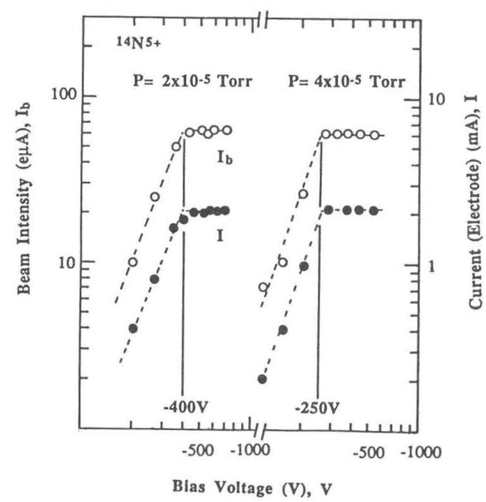

Fig. 2. Output intensity, I_b ,of $^{14}N^{5+}$ (open circles) and electrode current, I ,(closed circles) measured as a function of bias voltage, V ,at different pressures of 2 and 4×10^{-5} Torr in the first stage.

Figure 2 shows the beam intensity (I_b)of $^{14}N^{5+}$ and electrode current(I) as a function of the bias voltage (V). To clarify the dependence of the gas pressure of the first stage, only N_2 gas was fed into without any mixing gas; the other parameters such as microwave powers to the first stage and second stage and mirror magnetic fields were kept constant. I_b shows the same tendency as I. I_b saturates at -400V at a gas pressure of 2×10^{-5}Torr in the first stage, while the saturation occurs at -250V at a pressure of 4×10^{-5} Torr. In order to investigate this correlation of I_b vs I systematically, we examined several gaseous elements such as He, CO_2, N_2, O_2, and Ar. In this study, gas mixing was used, because it is very effective to obtain a higher intensity of highly charged ions for elements heavier than carbon. The optimum mixing ratio of the main gas to the auxiliary gas was nearly 1:5. the measurements were made at the pressure between $2\text{-}4\times10^{-5}$ Torr in the first stage. Figure 3 shows the beam intensity as a function of electrode current, where the highest intensities are saturated ones. Almost the same correlation has been observed for these ions except $^4He^{2+}$.

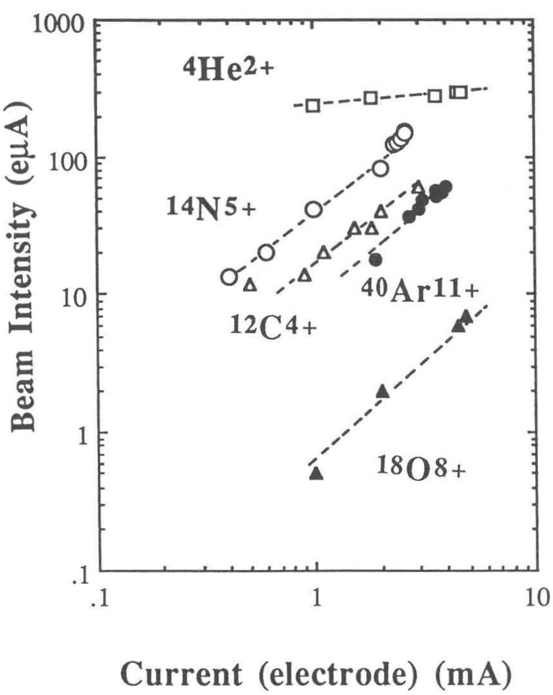

Fig. 3. Correlation between I_b and I observed for typical high-charge states of different ions. Highest intensities correspond to saturated ones. Dashed lines are guidelines.

The interpretation of the experimental results is illustrated by a schematical diagram shown in Fig. 4. It is well known that highly charged ions are produced in the successive ionization process. The production probability is assumed to be proportional to the product of $T_e{\cdot}\tau_i{\cdot}n_e$, where T_e, τ_i, and n_e are the electron temperature, ion confinement time and electron density in the second-stage plasma, respectively. Since the microwave power, gas pressure and gas mixing ratio were kept constant in the second stage, T_e and τ_i were considered to be constant. Thus $I_b \propto n_e$. The density n_e is expressed by $n_e = n_e^0 + \Delta n_e$, where n_e^0 is the density of electrons generated in the second stage and Δn_e is that of electrons (I_e') entering over the mirror field barrier in the first stage. Figure 2 shows that when $V \to 0$ V, I_b decreases to a faint intensity. This indicates that $n_e \cong \Delta n_e$, and thus $I_b \propto n_e \cong \Delta n_e \propto I_e'$.

On the other hand, the relationship observed between I and V inheres in the so-called Langmuir probe. If I_i and I_e are the currents of ions and electrons plunging into the electrode, then $I = I_i - I_e$. When the microwave power and the pressure, P ,in the first stage are kept constant, the ion density remains the same, and accordingly I_i is constant. As V increases, I_e decreases to zero, because I_e is the current of electrons plunging over the repulsive potential wall, and then I saturates to the constant value of I_i. The P-dependence on the saturation bias voltage seen in Fig. 2 implies that with increasing P the electron temperature in the first stage drops.

Since the plasma is always electrically neutral, I is proportional to the current of electrons escaping from the plasma. These electrons partially enter the second stage over the mirror field barrier, which leads to $I_e' \propto I$. Thus, $I_b \propto I_e' \propto I$. This consequence contradicts the experimental results of $I_b \propto I^k$ (k= 1.2 ~ 1.3). To explain the contradiction, we should assume that the production probability of high-charge states in the successive ionization process is proportional to the product of $T_e{\cdot}\tau_i{\cdot}n_e^k$ except for $^4He^{2+}$, but further investigation of this is beyond the aim of the present study.

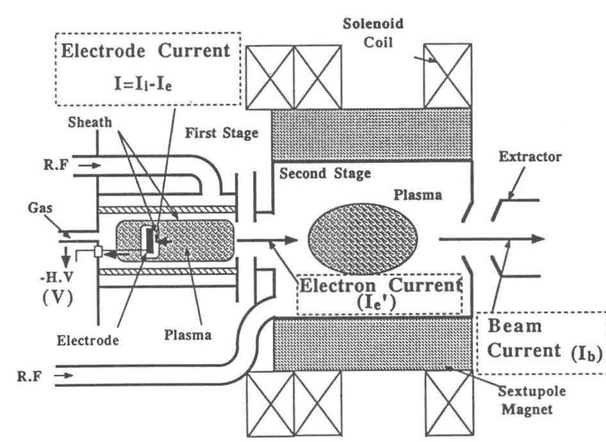

Fig. 4. Schematic diagram of the RIKEN 10 GHz ECR ion source equipped with a negatively biased electrode in its first stage, the electrode serving as the so-called Langmuir probe. Details are given in the text.

3. Plasma cathode method

If we make the potential difference between the first stage and second stage, we do not need the biased electrode in the first stage, because it is the same condition as that of negatively biased electrode method. In order to make this condition, we have changed the structure of the first stage for the plasma cathode method as shown in Fig.5. The first stage is isolated electrically from the second stage by the insulator. The negative bias is supplied to the first stage. The aperture plate placed in front of the first stage is isolated from the first stage electrically and connected to the second stage.

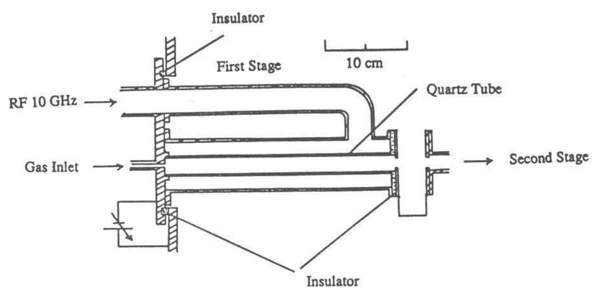

Fig.5. Schematic drawing of the first stage for plasma cathode method.

We investigated the beam intensity of $^{40}Ar^{11+}$ ions upon the bias voltage. The current increased very steeply between 0 to -100 V , whereas between -100 to -200 V the increase is about 20 % and then above -200 V the beam intensity is constant. Figure 5 shows the beam intensity as a function of current of the first stage. The intensity increases with increasing the current of the first stage. This tendency is the same as that observed when we used the negatively biased electrode.

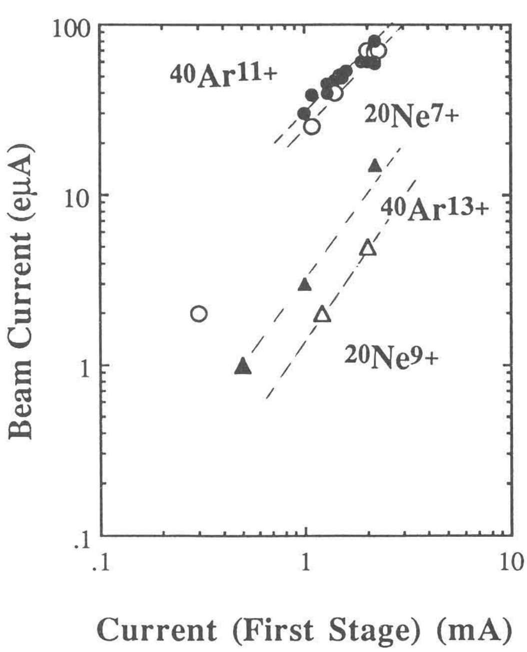

Fig.6Beam intensity measured as a function of current of the first stage

Figure 7 shows the charge state distribution of argon ions as a function of the analyzing magnet current. The source was tuned to maximize the beam intensity of $^{40}Ar^{11+}$. Usually the best beam intensity can be obtained by using the gas mixing method. To produce the Ar-ion , for example, the intensity is enhanced by using oxygen gas as a mixing gas. When we used the plasma cathode method, however, we needed no oxygen gas as a mixing to obtain the best result of 80 eμA. Another advantage of the plasma cathode method is the low consumption rate of gas. In order to obtain the best results for $^{40}Ar^{11+}$, the pressure of the first stage had to be 4-6x10^{-6} Torr using this method (Before using the plasma cathode method the optimum gas pressure was 2-3x10^{-5} Torr).

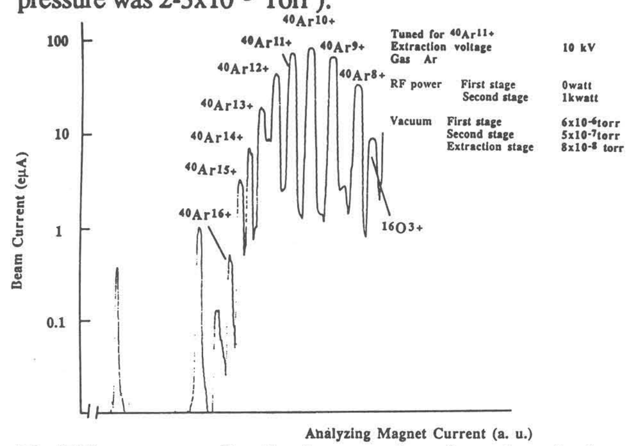

Fig.7Charge state distribution as a function of analyzing magnet current.

Figure 8 shows the beam intensities of Ar and Ne ions as a function of charge state. Open and closed circles are without and with using the plasma cathode method, respectively. It is clear that the highly charged ions are strongly enhanced by using this method.

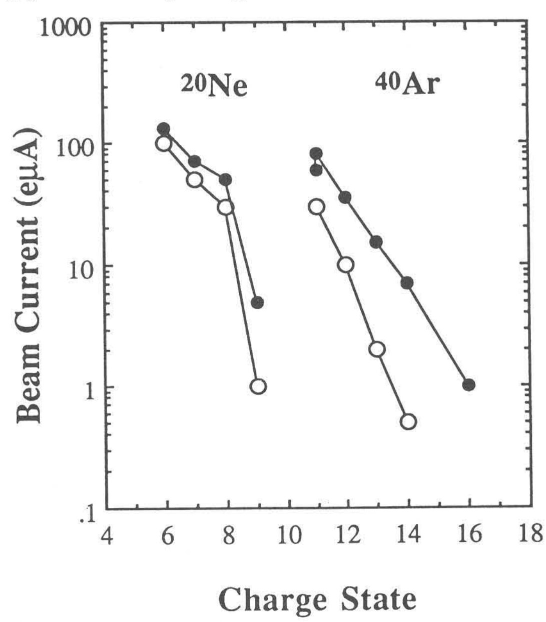

Fig. 8. Beam intensity of Ar and Ne ions as a function of charge state.

The plasma cathode method has several advantages. In principle, the plasma cathode method plays the same role as that of the biased electrode method. The first stage supply the second stage with electrons in the first stage plasma. One advantage of the plasma cathode method is its long lifetime compared to the biased electrode method. The lifetime of the electrode is about 2 months in routine operation. This is due to the sputtering of the electrode by the ion impact. In the case of the plasma cathode method, there is no such a limitation. Furthermore, as we mentioned above, plasma cathode method has other two advantages: low consumption rate of the main gas and no gas mixing. However, the reason for last two phenomena is not yet solved.

4. Conclusion

We measured the correlation of the beam intensity of highly charged ions with the electrode current, gas pressure, and bias voltage. This work led us to conclude that the beam intensity, I_b, of highly charged ions obtainable by use of the electrode is bound by the amount of electrode current I produced by the ECR discharge in the first-stage.

Based on the results of method of negatively biased electrode we change the structure of the first stage (plasma cathode method) and tested it . The tendency of beam intensity as a function of current of the electrode is the same as that by using the biased electrode. We could obtain the best result of 80 eμA for $^{40}Ar^{11+}$ ion without gas mixing method. It also has two other advantages: long lifetime and low consumption rate of gas.

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