RECENT PROGRESS OF RIKEN 18 GHz ECRIS

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Abstract

We successfully produced intense beams of highly charged ions from various kind of gaseous elements, organic metallic compounds (by MIVOC method), and solid materials from RIKEN 18 GHz ECRIS. (e. g. 160eμA of Ar^{11+}, 5eμA of Ar^{16+}, 80 eμA of Fe^{13+}). The ion confinement time of highly charged ions was also determined under the pulsed mode operation.

1. INTRODUCTION

The intense beams of medium mass heavy ions, mainly metallic ions, has become one of the major requests of users in RIKEN Accelerator Research Facility. For satisfying such requests, a new ECRIS is demanded as an external ion source of the RILAC(Riken heavy Ion Linear ACcelerator)-Ring cyclotron accelerator complex[1]. This ECRIS is also required for the Radioactive Ion Beam Factory (RIBF) project, in which it is aimed to supply the various unstable nuclei beams to the experiments in various fields.[2] According to the scaling low proposed by R. Geller, the beam intensity increases with the micro wave frequency and magnetic field strength of ECRIS.[3] Therefore, we have chosen the micro wave frequency of 18 GHz for the new RIKEN ECRIS In this paper, we present the description of the 18 GHz ECRIS and its performance in producing multi-charged heavy ions

2. DESCRIPTION OF RIKEN 18 GHz ECRIS

The detailed design of the ECRIS was described in ref. 4. 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 in order 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.

3 PERFORMANCE FOR GASEOUS ELEMENTS

It was observed that the intensities of highly charged ions were dramatically enhanced by coating the surface of the plasma chamber with aluminum oxide or using an aluminum plasma chamber[5-7]. It is due to the increase of the electron number emitted secondary by the electron impact. In stead of using these methods, we use an aluminum tube to cover the inner wall of plasma chamber. It is much easier than to construct a whole plasma chamber with aluminum. Figure 1 shows the obtained beam intensities of O, Ar and Kr ions. The extraction voltage was 10 kV. Open and closed circles show the beam intensities with using a tantalum tube and an aluminum tube, respectively.

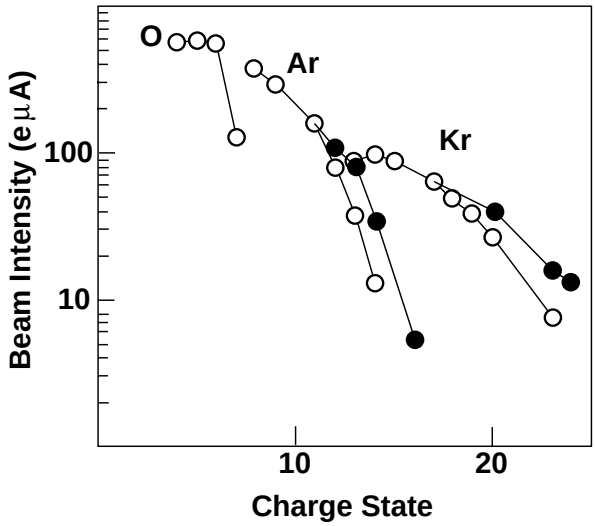

Fig. 1 Charge State distribution of Ar and Kr ions. Open and closed circles represent the results obtained using the Ta and Al tube, respectively

4. METALLIC IONS

4.1. MIVOC method

A MIVOC-method at an ECR ion source enables production of highly charged metal ion beams at room temperature conditions. In the MIVOC vapors of volatile compounds having metal atoms in their molecular structure are used to release metallic elements.[8-10] In the present experiments the MIVOC chamber was connected to the RIKEN 18 GHz ECRIS. The chamber(~300 cm^3 in volume) was attached to the gas feed tube via a rough, large conductance regulation valve to control flow rate of the compound vapor. In order to minimize contamination,

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the plasma chamber wall was covered with a thin aluminum tube (thickness 1 mm) which could be easily replaced if necessary. Furthermore, the aluminum surface emits several secondary electrons per electron impact, which helps to increase plasma density.

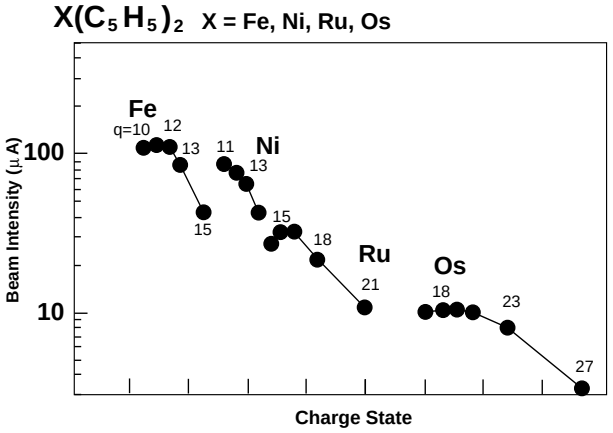

Fig. 2. Charge distribution of Fe, Ni, Ru and Os

Figure 2 shows the beam intensities of the highly charged Fe, Ni and Ru and Os ions. The ion beams were produced at room temperature from compounds of $Fe(C_5H_5)_2$, $Ni(C_5H_5)_2$, $Ru(C_5H_5)_2$, and $Os(C_5H_5)_2$. The extraction voltage was 10 kV. Typical gas pressure in the plasma chamber was 2×10^{-6} mbar and in the extraction stage 7×10^{-7} mbar. To produce these ions, we only need RF power of 150~500 w

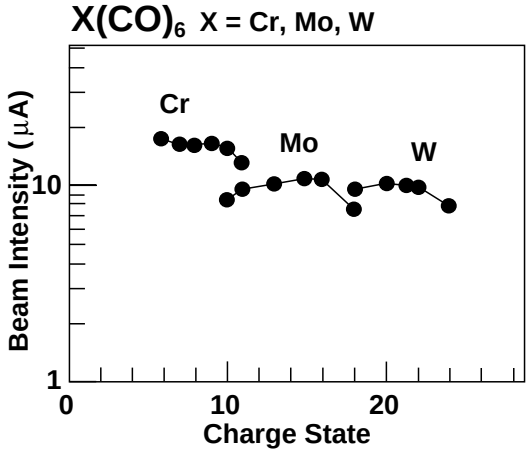

Fig. 3 Charge state distribution of Cr, Mo, W

The Cr, Mo, and W ion beams were produced from their hexacarbonyl compounds: $Cr(CO)_6$, $Mo(CO)_6$, and $W(CO)_6$. A typical operation pressure was ~3×10^{-6} mbar. Fig. 3 shows the beam intensity as a function of charge state of Cr, Mo, and W ions. The maximum beam intensities were around 10 μA. The beam intensities of the highly charged ions produced from these compounds are remarkably smaller than those from the metalocenes. In the case of the hexacarbonyls, the metal ions are bound with six CO molecules. To produce Cr, Mo and W ions, all the bounds have to be cut by electron impacts. As a result, the number of metallic ions may be insufficient to produce intense beams of highly charged ions.

4-2 Ta ions

In order to produce highly charged Ta ions, we insert a Ta-rod (the diameter is 2 mm) to the plasma directly. Figure 4 shows the best results of Ta ions at the extraction voltage of 14 kV.

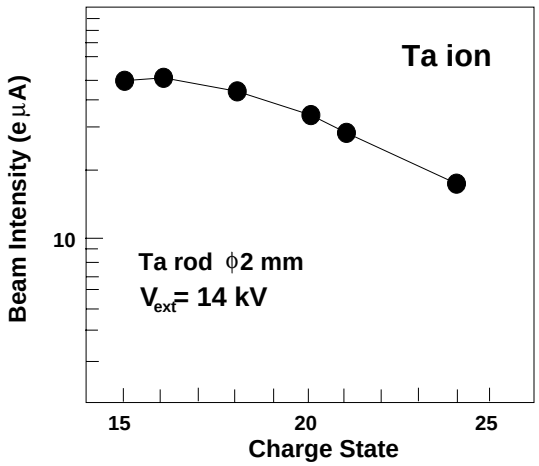

Fig. 4 Charge state distribution of Ta ions

5. Determination of Ion Confinement Time

To produce highly charged ions in a ECRIS, good ionization and confinement are necessary. To determine t_{ic} (ion confinement time) and t_{ion} (ionization time), it is crucial to measure the ion production rate as a function of time. The afterglow current is a good tool for observing the condition of a plasma directly.[11] The duration of existence of a plasma can be controlled using pulsed mode operation. Figure 5 shows the $I_{afterglow}$ obtained for Ar^{11+} ions as a function of the RF duration (Δt). We define the saturation time ($t_{saturation}$) as the point of the intersection of the curves obtained, as shown in Fig. 5. The RF power was varied between 200 and 800 W.

Figure 6 shows $t_{saturation}$ as a function of the RF power. In this figure, we classify two regions, Region I and Region II,. In Region II, t_{ion} is shorter than t_{ic}. Usually $t_{saturation}$ is strongly dependent on t_{ion} , which is proportional to $1/n_e$. The density and temperature of electrons in the ECRIS increase with increasing the RF power.[9] Then $t_{saturation}$ decreases as RF power increases. In Region I, however, t_{ic} is shorter than t_{ion}.

In this case, $t_{saturation}$ is determined by t_{ic}. The staying time of the ions is too short to achieve equilibration. $t_{saturation}$ is influenced only slightly by the density and temperature of electrons in this case.

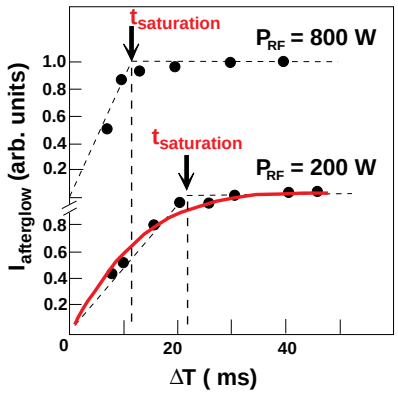

Fig. 5. The measured $I_{afterglow}$ as a function of the RF pulse duration (Δt).

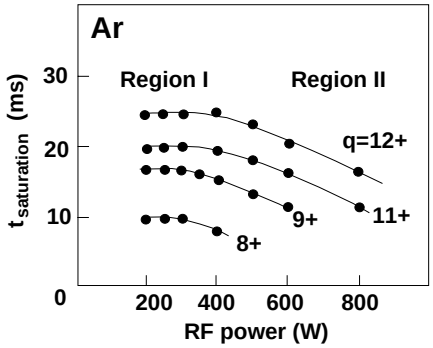

Fig. 6 The obtained $t_{saturation}$ as a function of RF power for argon ion charge state from 8+ to 12+

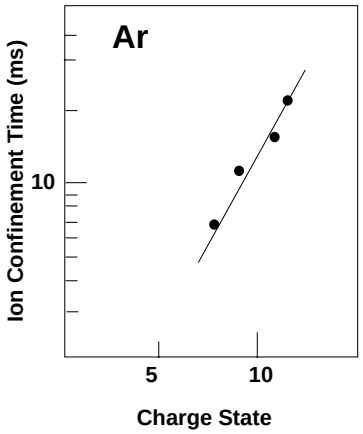

Fig. 7. The obtained ion confinement time as a function of the charge state of argon ion

When we assume $t_{ic} \ll t_{ion}$, the rate equation [12]can be written as

$$dn_i/dt \approx -(1/t_{ic})n_i \quad (1)$$

where n_i is defined as the density of i-th charge state ions. When this equation integrated from t = 0 to t, then

$$n_i = n_{i\infty}(1- \exp(-t/t_{ic})) \quad (2)$$

Using eq. (2), we fitted $I_{afterglow}$ for the lowest RF power in Region I to determine t_{ic}. Figure 7 shows the obtained t_{ic} as a function of the charge state of Ar ions. t_{ic} increases exponentially as a function of the charge state of the ions. Figure 8 shows the ion confinement time of highly charged Ar ions as a function of current to solenoid coils.

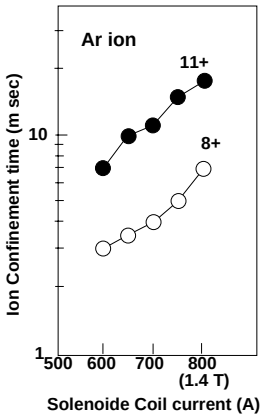

Fig.8 Ion confinement time as a function of current of solenoid coils

6. CONCLUSION

We have tested the RIKEN 18 GHz ECRIS to extract various ions. We successfully obtained the intense beams of highly charged ions from various kind of gaseous elements, organic metallic compounds (by MIVOC method), and solid materials. The ion confinement time of highly charged ions was also determined under the pulsed mode operation.

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