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DEVELOPMENT OF RIKEN 18GHZ ECRIS

Takahide NAKAGAWA, Yoshitoshi MIYAZAWA, Masatake HEMMI, Toshiya CHIBA, Naohito INABE, Masayuki KASE, Tadashi KAGEYAMA, Osamu KAMIGAITO, Eiji IKEZAWA, Akira GOTO, and Yasushige YANO

The Institute of Physical and Chemical Research (RIKEN), Hirosawa 2-1, Wako, Saitama 351-01, Japan

Abstract

We constructed a new ECRIS which has an operating frequency of 18 GHz. The intense beams of multi-charged ions are successfully produced. We observed that the beam intensities of highly charged and heavier ions are strongly enhanced using an afterglow mode. This ion source is connected to a new variable-frequency RFQ and used as a new injector of the RILAC(RIken heavy ion Linear ACcelerator)-Ring cyclotron complex .

1. Introduction

Electron Cyclotron Resonance Ion Source (ECRIS) technology has developed rapidly since the original pioneering work of the Grenoble group. These ion sources are capable of producing intense beams of highly charged ions.[1] These are used as an external ion source of cyclotrons and linacs, and also for atomic physics experiments. Recently, intense beams of medium mass heavy ions, mainly metallic ions, becomes one of the major requests in RIKEN Accelerator Research Facility. For satisfying such request, a new ECRIS is demanded as an external ion source of the RILAC[2]-Ring cyclotron accelerator complex. According to the scaling low proposed by R. Geller, the beam intensity increases with increasing micro wave frequency and magnetic field strength.[1] Therefore, the micro wave frequency of 18 GHz has been chosen for the RIKEN new ECRIS. It is connected to a new RFQ and used as a new injector as described in refs 3 and 4 .

In this paper, we present the description and the performance for producing multi-charged ions from gaseous elements in the 18GHz RIKEN ECRIS.

2. Description of RIKEN 18 GHz ECRIS

Figure 1 illustrates the design of RIKEN 18 GHz ECRIS. 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. The source is completely enclosed by an iron yoke in order to reduce the current of solenoid coil. The maximum power consumption is 140 kW. The mirror ratio has a nominal value of 3.0. as shown in fig.1 (B_{max} ~1.4 T, B_{min} ~ 0.47 T). To optimize the radial confinement of the plasma, we used a hexapole magnet which consists of 36 segments made of Nd-Fe-B permanent magnets.[5] The outer diameter (OD) and inner diameter (ID) are 180 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. The water cooled hexapole housing also protect the permanent magnet from the high temperature caused by the solenoid coil.

The high vacuum of the plasma chamber is very important to produce the intense beam of highly charged ions .[6] This may be due to the effect of recombination of the ions. To minimize such effect, the plasma chamber is evacuated with 500 and 150 l/s turbo-molecular pumps. The ultimate vacuum pressures of the plasma chamber and extraction stage are the middle of 10^{-8} Torrs.

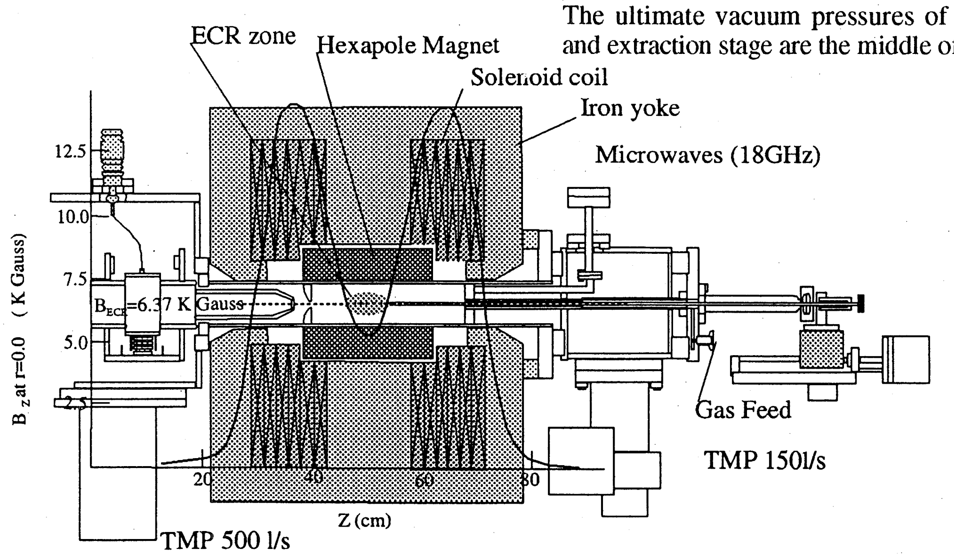

Fig. 1. Cross sectional view of RIKEN 18 GHz ECRIS

3. Performance of 18 GHz ECRIS

3.1. CW mode operation.

Figure 2 shows the beam intensities of highly charged ions produced from gaseous element. These results were obtained by using the gas mixing method.[1] The typical gas pressures of plasma chamber and extraction stage were 1.0×10^{-6}, and 9×10^{-7} Torrs, respectively. The extraction voltage was 15 kV. For example, beam intensities of Ar^{11+} and O^{7+} were 160 and 130 eμA, respectively. Figure 3 shows the beam intensities of Ar^{11+} as a function of the extraction voltage. As shown in fig.3, the beam intensity is proportional to $V^{1.5}$ below 10kV, which follows the Child-Langmuir law, where V is the extraction voltage. Above 10 kV, it is deviated form it and increases linearly with increasing the extraction voltage.

The distance between the orifice (ϕ= 10 mm) and the extraction electrode (ϕ= 13 mm) is also one of the important parameters to optimize the performance of ECRIS. It strongly depend on the condition of plasma, shape of extraction electrode, and charge state of extracted ions. [7] For RIKEN 18 GHz ECRIS, the best results of medium charge states of heavy ions (i.e., $O^{5+,6+}$, $Ar^{8+\sim 11+}$) could be obtained at the distance of about 30 mm

Figure 4 shows the beam intensities of Ar^{11+} ions for 18 GHz ECRIS, CAPRICE (14.5 and 10 GHz) developed in Grenoble [8] and ECRIS 4 (GANIL)[9] as a function of RF power. At the same RF power, the beam intensity increases with increasing the frequency of micro wave and magnetic field strength. In the figure the B_{max} indicates the maximum field strength of the mirror magnetic field.

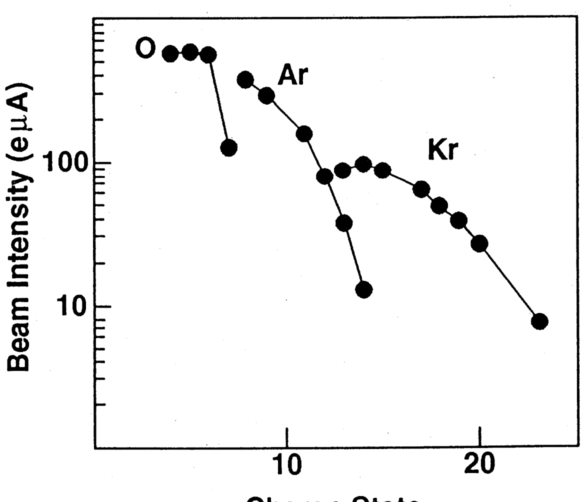

Fig.2. Charge state distributions of O, Ar and Kr ions

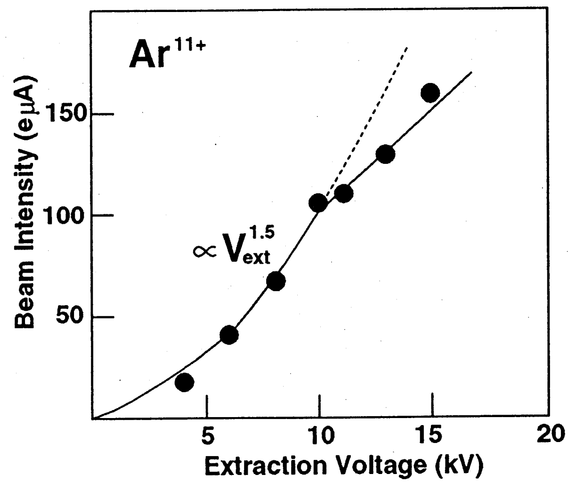

Fig.3. The beam intensity of Ar^{11+} as a function of extraction voltage

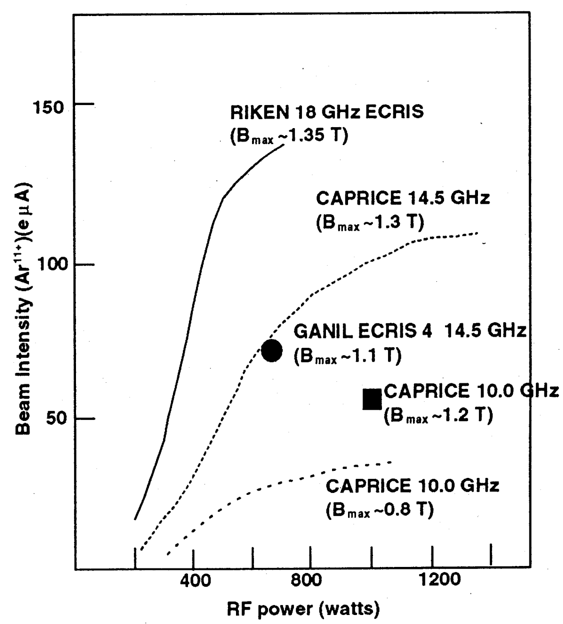

Fig.4. Beam intensity of Ar^{11+} for various ion sources as a function of RF power. The extraction voltage of RIKEN ECRIS is 13 kV. The extraction voltage of the other sources is 20 kV.

3.2. Pulsed mode operation

It is well known that at the turnoff of the RF power of an ECRIS, the extracted current for highly charged heavy ions dramatically increases. As described in Ref. 10. if the central plasma shows a depressed negative potential Δϕ, the ratio between the beam currents of a steady sate and the afterglow 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 negative potential, and ion temperature, respectively. Figure 5 shows the typical result of $I_{afterglow}/I_{steady}$ as a function of charge state in the case of Kr and O ions. In this figure, we observe the exponential dependence of this ratio as described in eq. (1).

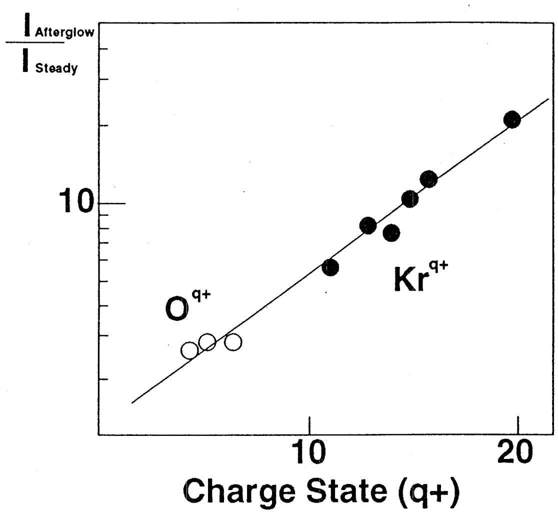

Fig. 5. $I_{afterglow}/I_{steady}$ for Kr and O ions

The maximum current can be produced only if the duration of the RF pulse is long enough to achieve the maximum ionization of the considered ions. In our case the duration was fixed to 15 ms to produce the Kr, and Ar ions. Figure 6 shows the comparison between the best results of CW mode operation (open circles) and afterglow mode (closed circles) at the extraction voltage of 10 kV. The RF power was kept at the same value for both operations. It is clearly seen that the beam intensity of highly charged and heavier ions strongly enhanced by pulsed mode operation.

4. Conclusion

The RIKEN 18 GHz ECRIS has been constructed and tested in CW and pulsed mode operation. The intense beam of multi-charged ions can be produced at the relatively lower micro wave power (for example, 160 eμA of Ar^{11+}, 130 eμA of O^{7+} at 600 W). In the case of pulsed mode operation, we observed that the beam intensities of highly charged and heavier ions were strongly enhanced. In the next step, we will try to produce the highly charged ions from solid materials.

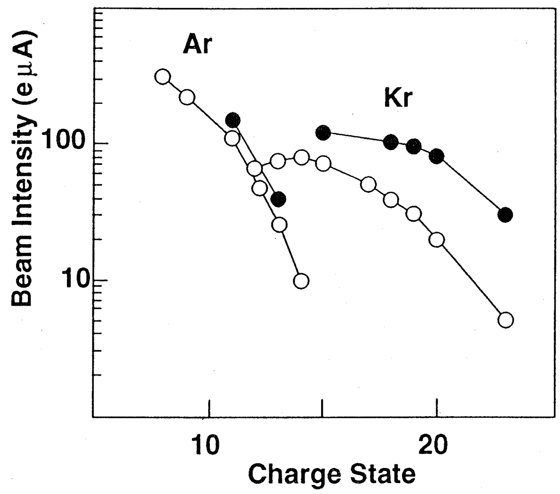

Fig.6. Charge state distributions of Ar and Kr ions. Open and closed circles are the results of CW and pulsed mode operation, respectively

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