STATUS OF THE RIKEN ECRIS

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ABSTRACT

An ECR ion source for an AVF-ring cyclotron complex has been constructed at RIKEN. The source is used to produce highly-charged ions for relatively light heavy elements (up to Ca). The first beam from the source was obtained in April, 1988. The source has been operated with mainly gaseous elements for one year. A fully stripped ^{13}C beam was obtained with the intensity of 2 eμA and has been used for experiments in Atomic Physics. A $^{14}N^{5+}$ beam was successfully injected into the AVF cyclotron in April, 1989. The design and the construction of the ion source and the beam line are described includind preliminary results.

1. INTRODUCTION

At RIKEN Accelerator Research Facility (RARF), beams from a K540 four-sector ring cyclotron (RRC) have been delivered to experiments since May, 1987. A detailed description of RARF is given at this conference.[1] Up to now, a frequency tunable heavy-ion linac (RILAC) with a PIG source has been used as an injector for RRC. The construction of another injector, a K70 AVF cyclotron, was just completed in March, 1989. The AVF cyclotron is equipped with a duoplasmatron source for protons and deuterons and the ECR source for heavier ions. The first beam from the ECRIS was obtained in April, 1988. The source has been operated with mainly gaseous elements from ^{12}C to Xe in order to make experiments in Atomic Physics as well as to improve the performance of the source itself. For example, the fully stripped ^{13}C ions were used to study the double charge exchange collision in He gas. $^{14}N^{5+}$ ions from the ECRIS were injected into the AVF cyclotron, accelerated up to 7 MeV/u, and successfully extracted in April, 1989. In this first test, the transmission efficiency from the source to a spiral inflector installed at the center of the cyclotron was about 50 %. A detailed report on the AVF cyclotron is presented at this conference.[2]

2.DESCRIPTION OF THE SOURCE

The detailed design of the RIKEN ECRIS was discussed elsewhere.[3] Main parameters of the source are listed in Table 1, and its cutaway view is shown in Fig. 1. The source consists of two stages: the first stage, 6 cm in diameter and 25 cm long, is used for plasma filamentation and the second stage, 10 cm in diameter and 52 cm long, for production of highly charged ions. It is provided with three gas feeding lines: two at the first stage and one at the second stage for gas mixing. Figure 2 shows the fully assembled RIKEN ECRIS.

The axial magnetic field is produced by solenoid coils which are devided into eight sections. Each section can be independently excited to optimize the axial magmetic field

Table 1. Main parameters of the RIKEN ECRIS.

<u>1st stage</u>	
Magnetic confinement	solenoidal field
Chamber diameter	60 mm ($D/\lambda = 2$) 20 mm (quartz tube)
Chamber length	250 mm
RF	10 GHz, CW, 1 kW max. Radial injection
Evacuating pump	520 l/sec TMP
<u>2nd stage</u>	
Magnetic confinement	Mirror + hexapole field
Mirror ratio	1.4 to 1.8 (variable)
Hexapole	6 $SmCo_5$ bars $40^W \times 50^H \times 450^L$ Stronger than 3.8 kG at chamber
Chamber diameter	100 mm ($D/\lambda = 3.3$)
Chamber length	520 mm
RF	10 GHz, CW, 2.5 kW max. Axial injection
Evacuating pump	1500 l/sec TMP
<u>Extraction</u>	
Extraction voltage	3 to 25 kV
Suppression voltage	0 to -10 kV
Extraction gap	5 to 45 mm (variable)
Evacuating pump	1500 l/sec TMP

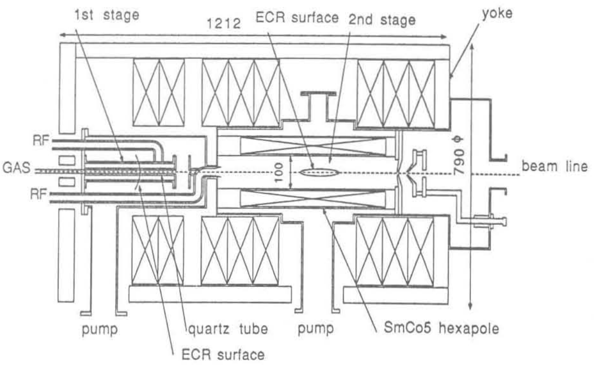

Fig. 1. Schematic drawing of the RIKEN ECRIS.

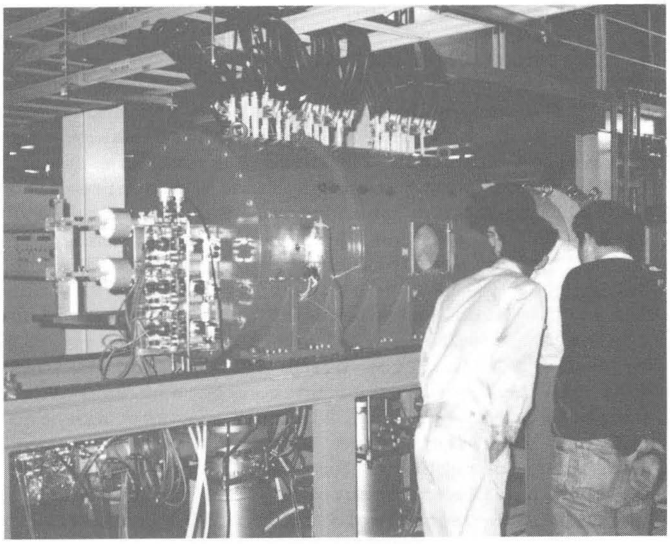

Fig. 2. Photograph of the RIKEN ECRIS.

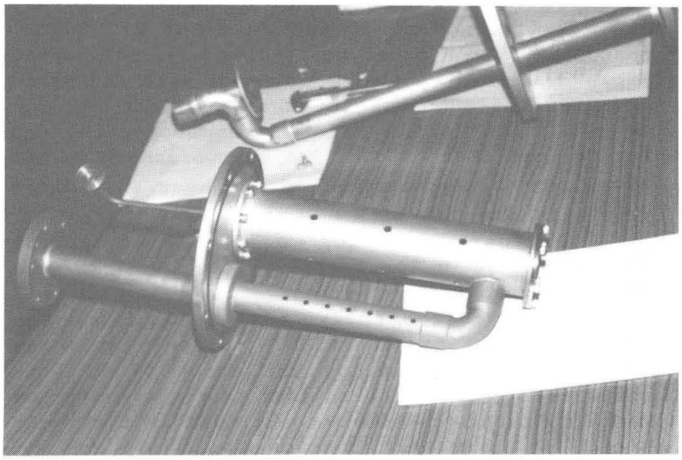

Fig. 3. The first stage chamber and circular wavegides.

profile. A return yoke of 5 cm thickness reduces the power consumption by coils, and shields X-rays from the plasma chamber. An ECR surface is not closed in the first stage. The position of the surface near the gas inlet is easily changed by varying currents of the first two coils. The field at the exit of the first stage is well above the resonance value for 10 GHz. This field profile gives a better second stage confinement. The axial field in the second stage has the usual minimum B configuration. The mirror ratio and the minimum field value are easily controlled by varying currents for six axial coils. In the second stage, an open $SmCo_5$ (B_{res} = 10 kG) hexapole magnet consisting of six poles is installed to produce the radial magnetic field. The inner diameter of the hexapole is 11 cm. Each pole is 4 cm wide, 5 cm high and 45 cm long. The strength of the magnetic field was measured to be about 4 kG at the surface of each pole. The hexapole is placed inside the vacuum chamber and each pole is enclosed in a jacket and cooled by a non-dielectric coolant, ethylene-glycol. The radial magnetic field was measured to be stronger than 3.8 kG at the surface of the plasma chamber of 10 cm in diameter, and the azimuthal component of the field was stronger than 3.5 kG at the middle of two poles and at the radius of 5 cm.

The operating frequency of the source is 10 GHz for both stages. The RF signal is generated by a Gunn oscillator source, amplified by a GaAs FET amplifier, divided into two lines, and amplified by two klystrons (Thomson TV-851). The RF power fed to each stage can be varied independently with a variable attenuator. Maximum RF power is 1 kW for the first stage and 2.5 kW for the second stage. A DC cut is performed up to 25 kV with a two-fold insulation of 0.5 mm thick Teflon sheets. A vacuum window is made of BeO. The rectangular waveguides used outside the source make transition to circular waveguides at the vacuum interface. The circular waveguides of 27 mm in inner diameter enter the source from the fist stage side off axis. At the first stage, an RF power is injected radially from the high magnetic field region. By the beach effect, an RF reflection is expected to be reduced. On the other hand, a microwave is axially fed into the second stage. For the efficient absorption of an RF power in a plasma, a plasma chamber should be a multi-mode cavity. It is pointed out that the chamber diameter D is more than twice as large as the RF wavelength λ.4,5) In our case, D/l is 2 at the first stage and 3.3 at the second stage. To avoid the diffusion of the fed gas into the wave guide, a quartz tube of 20 mm in inner diameter is installed in the first stage chamber. The first stage chamber and circular waveguides to both stages are shown in Fig. 3.

The extraction voltage is varied from 3 to 25 kV according to the injection condition to the AVF cyclotron. The extraction hole is 10 mm in diameter, and the gap between the extraction hole and the extraction electrode can be changed from 5 mm to 45 mm. To reduce secondary electrons from the grounded electrode, the extraction electrode is biased at the negative suppression voltage. In the case of the low extraction voltage, the suppression voltage can be high so that the sufficient field gradient is achieved at the extraction gap.

3. BEAM INJECTION LINE TO THE AVF CYCLOTRON

The extracted beam from the ECRIS is transported to the cyclotron vault and axially injected into the AVF cyclotron. A beam emittance from the source is assumed to be 200π mmmrad, which is about the same as the acceptance of the AVF cyclotron with a spiral inflector.

The system consists of two main parts: the first one is devoted to analyze a charge and a mass of the extracted ion, the second to transfer the analyzed ion to the cyclotron. A schematic drawing of the beam injection line is shown in Fig. 4. A beam extracted from the ECRIS is focused at the collimating slit, SLIT 1, by double solenoids. With a doubly focusing 90-degrees bending magnet, the charg and the mass of the ion are analysed at the slit located at the focus point, SLIT 2. The bending radius of the of the central trajectory in the magnet is 50 cm and the edge angles of the pole are 26.5 degrees at both the entrance and exit. The maximum rigidity is designed to be 1.5 kGm. The position of the field clump was adjusted such that the effective field boundary coincides with the pole edge. The inside walls of the magnet chamber are covered with 2 mm thick molybdenum plates to protect walls from being sputtered. The momentum resolving power of this system is calculated to be 20, if the beam size at the object point, SLIT 1, is 20 mm in full width. This size is estimated assuming the emittance of the beam from the source to be 200π mmmrad. The analyzed beam is bent down in the vertical plane with two 45-degrees bending magnets. The bending radius of the magnet is 25 cm, the pole gap is 6 cm, and the maximum field strength is 1.85 kG. The section consisting of these two bending magnets and three quadrupole magnets between them is an achromatic transport system. Shapes of the ellipses in the transverse phase spaces are controlled by suceeding quadrupole quartet to be matched with the acceptance of the AVF cyclotron. A sawtooth single gap buncher is installed 2 m upstream the inflector to bunch the beam. The space charge effect in the longitudinal space is estimated to be negligible as long as the beam intensity is about 10 eμA.

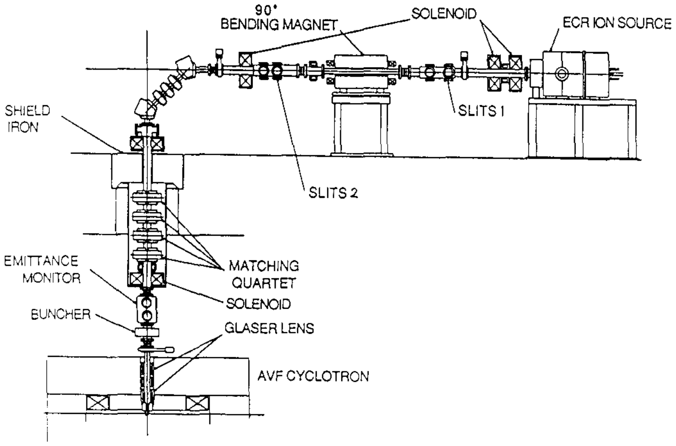

Fig. 4. Schematic drawing of the beam injection line.

The beam pipe is made of stainless steel of 4" in inner diameter for large evacuating conductance. Three 300 l/sec turbomolecular pumps, a 320 l/sec sputter ion pump and a 700 l/sec cryo pump are eqipped along the line. The pressure in the beam line is maintained less than 1×10^{-7} Torr to reduce the beam loss by the charge exchange collision with the residual gas. To reduce the undesirable steering effect by the leakage flux from the AVF cyclotron, which was measured to be 1-2 Gauss along the line, the beam pipe is covered with 2 mm thick soft ion plates for magnetic shielding.

4. PERFORMANCE AND RESULTS

The source has been operated for about one year. The present source performance is summarized in Table 2. These currents represent the "typical best" results from the source with natural isotopic abundance. Because the AVF cyclotron is operated with the harmonic number of 2,[2] it can accelerate following ions in the Table: $^{12}C^{4+}$, $^{14}N^{5+}$, $^{16}O^{5+}$, $^{19}F^{7+}$, $^{20}Ne^{7+}$, $^{32}S^{9+}$ and $^{40}Ar^{11+}$. When accelerated by the AVF-ring cyclotron complex, the maximum energy of 135 MeV/u is attained for beams ^{12}C-^{20}Ne, and ^{32}S and ^{40}Ar can be accelerated up to 110 and 95 MeV/u, respectively. For all elements, gases are fed only to the first stage. Gas flow rates are not measured directly, but are controlled by monitoring the pressure of the first stage. Usually, the pressure is 4×10^{-5}, 3×10^{-6} and 2×10^{-7} Torr at the first, second and extraction stage, respectively. Typical RF power of 50 W and 800 W is fed to the first and second stage, respectively. The extraction voltage is 13 kV except for Xe (10 kV). Openings of slits are 20 mm in full width for lighter elements up to Ar. They are reduced to 10 and 2 mm for Kr and Xe, respectively, in order to resolve adjacent peaks. Table 3 summarizes the performance with different combinations of gases for C and Ne ions. it can be seen that helium is a better supporting gas for Ne ions than oxigen. For carbon ions, CO_2 gas gives better performance than CH_4 gas. A similar result is obtained with PIG source.

An operational test of the AVF cyclotron was performed in April, 1989. Ions of $^{14}N^{5+}$ were injected into the cyclotron, accelerated up to 7 MeV/u and successfully extracted from the cyclotron. The transmission efficiency from the source to the inflector was about 50 %. This worse value may be due to fact that the emittance matching procedure was not employed in the test. The first beam test through the whole system, ECRIS, AVF and ring cyclotron, will start in May, 1989.

Table 2. Ion currents of RIKEN ECRIS.

element	^{12}C	^{14}N	^{16}O	^{19}F	^{20}Ne	^{32}S	^{40}Ar	^{84}Kr	^{129}Xe
gas	CO_2+He	N_2+He	O_2+He	CHF_3+He	Ne+He	SF_6+O_2	$Ar+O_2$	$Kr+O_2$	$Xe+O_2$
charge state									
2	85	300	180						
3	*	230	225	45	110				
4	56	155	*	46	115				
5	12	110	120	33	*	11			
6	2	24	125	*	95	*	52		
7	(cf. $^{13}C^{6+}$)		20	18	50	24	72		
8				*	35	*	95		
9				0.05	1.1	16	87		
10						*	*	20	
11						2.4	30	23	
12						*	10	*	
13						0.025	2.2	27	4.8
14							0.5	25	5.0
15								15	5.0
16								5.3	*
17								2.5	5.0
18								*	5.5
19								1.6	5.5
20								0.6	5.2
21								*	
22								0.1	

All currents in eμA at 13 kV extraction voltage except for Xe at 10 kV.
* indicates not measured because a mixture of two ions with identical charge to mass ratios was present.

Table 3. Gas mixing effect.

element	^{12}C			^{20}Ne	
gas	CH_4+O_2	CO_2+O_2	CO_2+He	$Ne+O_2$	Ne+He
charge state					
2	41	85	85		
3	*	*	*	110	110
4	6.3	37	56	115	115
5	0.3	2.3	12	*	*
6				63	95
7				24	50
8				14	35
9				0.3	1.1

All currents in eμA at 13 kV extraction voltage.

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