ECR ION SOURCE FOR THE INJECTOR AVF CYCLOTRON AT RIKEN

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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 relatively light heavy ions (up to Ar). The first beam from the source was obtained on 13rd April 1988. Through further one-year development, the beam from this source will be axially injected-into the AVF cyclotron. The design of the ion source and the beam injection line and the preliminary results are described.

1. INTRODUCTION

At RIKEN Accelerator Research Facility (RARF), a K540 four-sector ring cyclotron (RRC) was completed in November 1986, and has delivered beams to the experiments since May 1987. At present, a heavy-ion linac (RILAC) with a PIG source is used as an injector for RRC.[1] The construction of another injector, a K70 AVF cyclotron, has been started and will be completed at the end of 1988 FY.[2] The AVF cyclotron is equipped with three kinds of external ion sources: a duoplasmatron source for protons and deuterons, an ECR source for heavier ions and a polarized ^{3}He source. Ions from these sources are axially injected into the AVF cyclotron and led into the median plane with a spiral inflector. The M/Q value of ions which the AVF cyclotron can accept is less than 4. In the case of Ar ions, for example, the charge state must be higher than 10. If an $^{40}Ar^{11+}$ ion is accelerated with this cyclotron, the final beam energy from RRC reaches up to 95 MeV/u.

2. ION SOURCE DESIGN

Principal design of our ECR source is based on the LBL ECR source.[3] Higher frequency (10 GHz) microwave is used for both the first and second stages, and stronger magnetic confinement is adopted in plasma stages.

Main parameters of the source are listed in Table 1; its schematic view is shown in Fig. 1 . The source consists of two stages: the first stage is used for plasma filamentation and the second stage for production of highly charged ions. It is provided with three gas feeding lines: two lines at the first stage and another line at the second stage for gas mixing.

Table 1 Main parameters of the ECR source

1st stage	
magnetic confinement	solenoidal field
chamber diameter	60 mm (D/l=2)
	20 mm (quartz tube)
chamber length	250 mm
RF	10 GHz CW 1 kW max
pump	520 l/s TMP
2nd stage	
magnetic confinement	mirror+hexapole field
mirror ratio	1.4 to 1.8 (variable)
chamber diameter	100 mm (D/l=3.3)
chamber length	520 mm
RF	10 GHz CW 2.5 kW max
pump	1500 l/s TMP
extraction	
acceleration voltage	3 to 25 kV
suppression voltage	0 to -10 kV
extraction gap	5 to 45 mm (variable)

2.1 Magnetic field

Axial field is produced by solenoid coils which are devided into eight sections. The currents in all eight axial field coils can be independently varied to optimize an axial magnetic field profile. A return yoke reduces the power consumption of coils, and shields X-rays from the plasma chamber.

In the second stage, an open $SmCo_5$ (B_{res} = 10 kG) sextupole magnet is set to produce the radial magnetic field. The inner diameter of the sextupole is 11 cm. Each pole is 4 cm wide, 5 cm high and 45 cm long. The sextupole is placed inside the vacuum chamber and each pole is enclosed in a jacket and cooled by a non-dielectric coolant. The magnetic field was measured to be stronger than 3.8 kG at the surface of the plasma chamber.

The magnetic field at the exit of the first stage is well above the resonance field for 10 GHz. This field profile gives better second stage confinement. A surface position of the ECR zone near the gas feed is easily changed by varying currents of the first two axial coils. The second stage works in the usual minimum B mode. The mirror ratio and the minimum value of the magnetic field are easily controlled by varying currents for six axial coils. The minimum field can be high enough to test the tangential field effect.[4] The second stage plasma chamber is 10 cm in diameter and 52 cm in length. The long plasma region can reduce the magnetic field gradient at an ECR surface to about 100 G/cm, which is better for the electron accelaration by the ECR and increases the electron temperature.[3]

2.2 RF system

10 GHz microwaves are fed into both first and second stages through circular wave guides of 27 mm in inner diameter. In the first stage, an RF power is injected radially from the high magnetic field region. By the beach effect, an RF reflection will 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 must be a multimode cavity. It is pointed out that the chamber diameter D is more than twice as large as the RF wavelength λ.[6,7] In our case, D/λ is 2 in the first stage and 3.3 in the second stage.

The RF signal is generated by a Gunn oscillator source, amplified by a GaAs FET amplifier, divided into two lines, and amplified by two klystron amplifiers (Thomson TV851). The RF power fed to each stage can be varied independently

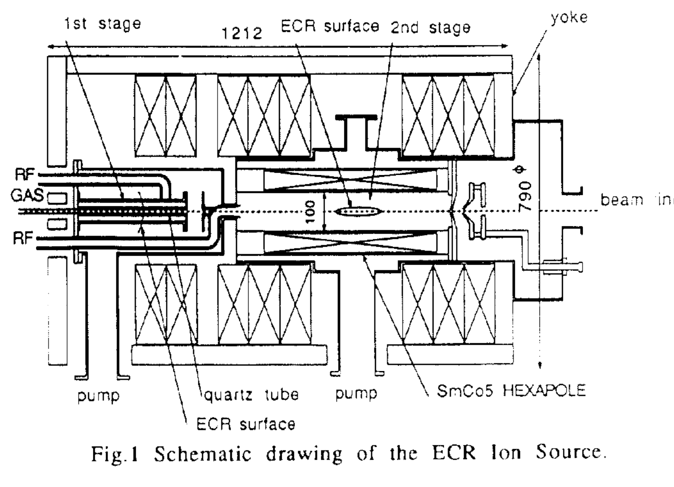

Fig.1 Schematic drawing of the ECR Ion Source.

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-foldfoldinsulation of 2 mm thick Teflon sheets. A vacuum window is made of BeO.

2.3 Vacuum system

The pressure is expected to be about 10^{-4} Torr in the first stage cavity, and in the second stage it must be less than 10^{-6} Torr to reduce charge exchange collisions with neutral atoms. A 500 l/s TMP is installed at the first stage, and two 1500 l/s TMP's at the second stage and in the extraction region. 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.

2.4 Extraction system

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 ground 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 obtained at the extraction gap.

3. BEAM TRANSPORT LINE

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

As the beam shape from the ECR source is rotationally symmetric, solenoid focusing elements are better than quadrupole lenses for easy tuning. Downstream the ECR source, double solenoids are introduced to obtain the erect ellipses in both transverse phase spaces at the beam collimating slit, whatever the ellipses at the extraction hole are. With a doubly focusing 90-degree bending magnet, charge states of ions are analyzed at the slit located at the focus point. The vertically bending section forms an achromatic system. The beam shape is rotationally symmetric upstream the following matching section. A quadrupole quartet is placed in the vertical injection line to match the phase-space ellipses of the beam with the eigen ellipsoid of the AVF cyclotron at its entrance position. A sawtooth single gap buncher is planned to be installed 2 m upstream from the inflector in order to bunch the beam. The space charge effect in the longitudinal space is estimated to be negligible as long as the beam intensity is less than 10 eμA.

The beam pipe is made of stainless steel of 4" in inner diameter for large evacuating conductance. The pressure in the beam line should be maintained less than 10^{-7} Torr to reduce the beam loss by the charge exchange with the residual gas. To reduce the undesirable steering effect by the leakage flux from the AVF cyclotron magnet, the beam pipe is covered with 2 mm thick soft iron plates for magnetic shield.

4. PRELIMINARY PERFORMANCE OF THE SOURCE

The source was assembled and installed at the beginning of this April. The charge analyzing section, upstream the analyzing slit, was also installed to analize the charge state of ions from the source. The source has been operated since 11th April. Figure 2 shows a typical spectrum obtainde with Ar. Argon gas is fed only to the first stage and mixed with O_2 gas. Preliminary results at the extraction voltage of 13 kV are as follows: 20 eμA for Ar^{11+}, 6 eμA for Ar^{12+} and 1.2 eμA for Ar^{13+}. In this case, RF power of 50 W and 800 W was fed to the first and second stage, respectively.

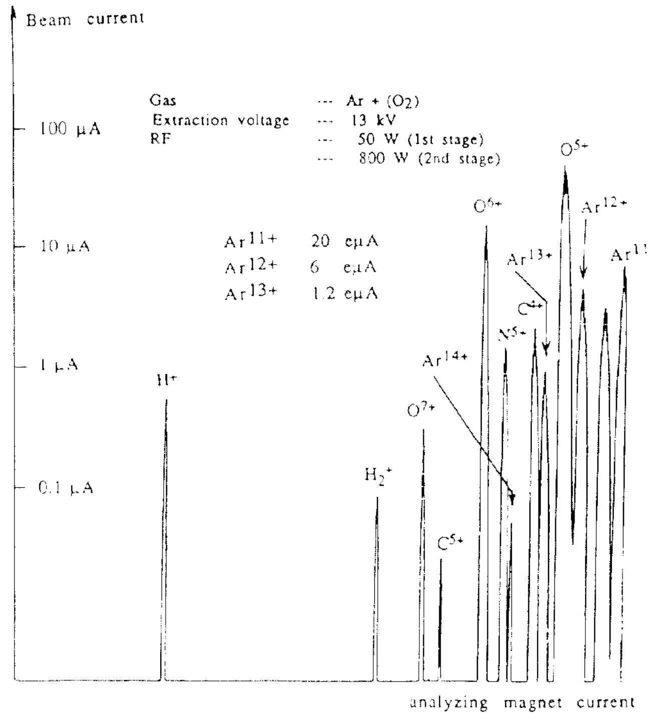

Fig. 2 Typical spectrum obtained with Ar.

REFERENCES

1. Y. Yano, contributions to this conference
2. A. Goto et al., contributions to this conference
3. C. M. Lyneis, Proc. 7th Workshop on ECR Ion Source 1(1986)
4. T. A. Antaya, Z. Q. Xie, Proc. 7th Workshop on ECR Ion Source 72(1986)
5. Y. Jongen, Proc. 6th Workshop on ECR Ion Source 238(1985)
6. R. Geller et al., Proc. 6th Workshop on ECR Ion Source 1(1985)
7. C. M. Lyneis, Private communication