OPERATION OF ION SOURCES AND BEAM TRANSPORT TO JAERI AVF CYCLOTRON

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ABSTRACT

Two ion sources, a multi-cusp ion source for light ions and an ECR ion source for heavy ions, were installed for the JAERI AVF cyclotron. Operation of the sources at JAERI started in February 1991. The ability of ion generation required for beam injection into the cyclotron has been attained. Some characteristics, test generation of metal ions and results of beam transport to the cyclotron are described.

1. INTRODUCTION

A multi-cusp and an ECR (OCTOPUS) ion source manufactured at Ion Beam Applications s.a. in Belgium were tested and connected with the computer control system at the Niihama Works of Sumitomo Heavy Industries, Ltd. in 1990.

The sources and the cyclotron were installed at JAERI in early 1991. The beam generation tests of the sources, acceleration by the cyclotron and transport of beams to the end of beam lines have been conducted. In these days, the sources supply ion beams mainly for beam study of the cyclotron and some experiments at beam course ends.[1,2] Improvements and developments have also been carried out mainly for higher beam transmission to the cyclotron and metal ion generation. Emittance of Ar beam from an ECR ion source was measured in detail.

2. ECR ION SOURCE OPERATION

The ion generation test at JAERI has been made for O^{6+}, Ar^{8+}, Ar^{13+} and Kr^{20+} to ensure that beam currents more than 1 eμA were generated, and the test was successful for every ion species.

The beams except for O^{6+} were injected into the cyclotron, and acceleration and beam extraction tests have been carried out. The currents measured at beam course ends also satisfied those expected. The He^{2+} beam was also produced by the JAERI ECR source and was supplied for the cyclotron. The results were reported for ion beam generation from gaseous materials by the JAERI ECR source elsewhere.[3]

2.1. Metal Ion Generation

We tried to generate metal ions of Al, Mo and B by direct insertion of a rod into plasma. Rods of Al_2O_3, Mo_2C and BN were inserted radially into the 2nd stage plasma by remotely controlled motor drive and could be positioned by 50 μm steps. Though the insertion depth has not been optimized, we observed these ion beam currents as listed in Table 1 enough for acceleration by the cyclotron. Beam currents of Al ions were stable and the maximum currents were easily attained. The Mo ion beam currents were less stable and the total currents of all the isotopes were similar to the Al ion beam currents. Ion beam of B was unstable and small compared with the other two metal ions in spite of low charge state. The averaged beam currents are listed in Table 1. The performance on metal ion generation and beam stability appear to depend on physical and chemical characteristics of rod materials.

2.2. Charge State Distribution and Main Gas Feeding

The JAERI ECR source had been operated by feeding main and support gases into the 1st stage chamber. We examined the difference of charge state distribution of Ar ions by feeding Ar gas into the 1st and the 2nd stage. We used O_2 as the support gas and fed it into the 1st stage in all cases. When feeding into the 2nd stage, the beam current sensitively depended on the operating parameters, such as mirror coil current, microwave power, etc., and the plasma fired in narrower range of mirror coil current at the 2nd stage. The gas flow range of Ar reduced down to one tenth. These indicate that the plasma condition is different between the fed chambers of the 1st and the 2nd stage. Further experiments and data are necessary to assign the cause of the difference. However, it may come from the change of pressure distribution of Ar gas with feeding position, for example. The difference of the plasma condition clearly appeared in

Table 1. Maximum beam currents of metal ions.

material	support gas	ion	current(eμA)
Al_2O_3	O_2	Al^{8+}	5
		Al^{6+}	17
		Al^{4+}	43
		Al^{3+}	62
Mo_2C	N_2	$^{98}Mo^{17+*}$	5
		$^{98}Mo^{15+}$	6
		$^{98}Mo^{13+}$	7
		$^{98}Mo^{11+}$	2
		$^{98}Mo^{10+}$	4
		$^{98}Mo^{9+}$	4
BN	N_2	$^{11}B^{3+}$	5
		$^{11}B^{2+}$	5

* natural abundance of ^{98}Mo is 24%.

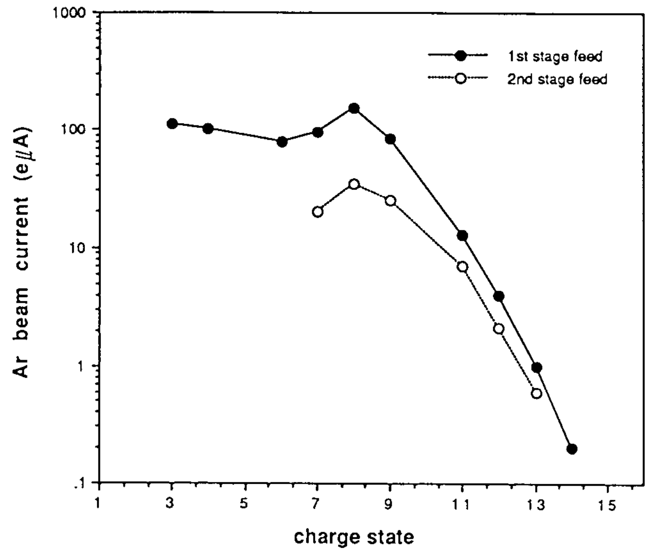

Fig. 1 Charge distribution of Ar ions, comparing 1st and 2nd stage feeding of Ar gas.

the charge state distribution of Ar. Figure 1 shows that beam currrents are lower for the 2nd stage feed than for the 1st stage one. On the other hand, decrease of currents at high charge state is smaller for the 2nd stage feed. We expect from the data that feeding into the 2nd stage provides higher performance in generation of high charge state ions. The contribution of the performance will be significant in generation of heavier ions.

2.3. Emittance of Ar Ion Beam

Measurement of emittance for 80% current density of Ar ion beam was carried out at an extraction voltage of 10 kV in a wide range of mirror coil current. It was measured by an emittance monitoring system at a diagnosis chamber (ES2, see Fig. 3), consisting of a pair of a slit and a multi-wire detector. When Ar gas was fed into the 1st stage, the horizontal emittance of Ar^{8+} beam varied from 100 πmm·mrad to 170 πmm·mrad, while the vertical emittance was almost constant at 100 πmm·mrad. The horizontal and the vertical emittance must be equal, since the ECR ion source and the beam extraction system is cylindrically symmetric. It may be only a reason for the observed phenomenon that emittance growth comes out in horizontal direction at the analyzing magnet due to momentum spread of ions. It is generally said that the momentum spread of ions from an ECR ion source is small because ion temperature is very low in ECR plasma. However, if extraction voltage flutters by hundreds of volts, growth of the horizontal emittance at the analyzing magnet is not negligible. We observed that extraction voltage fluttered by a few hundreds of volts when the plasma was very unstable. This result supports the above assumption. It is necessary to investigate the relation between fluctuation of the extraction voltage and the emittance.

When Ar gas was fed into the 2nd stage, the horizontal emittance was almost equal to the vertical one about 100 πmm·mrad, and was independent of the mirror coil currents. This also suggests that the condition of the plasma depends on the location of the inlet to feed Ar gas. The dependence of the beam emittance on charge state was not observed clearly.

It is found as a result that the emittance of beam from the JAERI ECR source depends on mirror coil currents and is a quarter to half of the beam acceptance of the injection line.

3. MULTI-CUSP ION SOURCE OPERATION

The multi-cusp ion source is of the same type as that installed at Orsay.[4] The side view of the source and specifications are shown in Fig. 2 and Table 2, respectively. The cylindrical source chamber, 15 cm in

Table 2. Specifications of Multi-cusp source.

Chamber diameter	10 cm
length	15 cm
Parmanent magnet	SmCo 46 pieces
Filament voltage	0 to 15 V
current	0 to 100 A
Arc voltage	0 to 400 V
current	0 to 15 A
Extraction voltage	3 to 20 kV
Puller voltage	0 to -3 kV
H^+ beam current	1.3 mA (maximum)
D^+ beam current	1.0 mA (maximum)

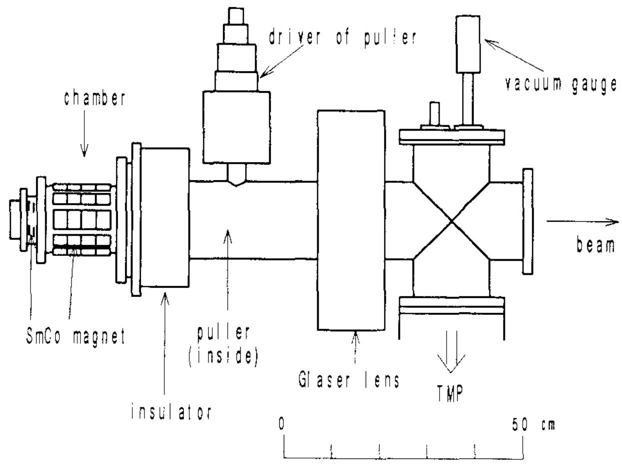

Fig. 2 Side view of the multi-cusp ion source.

length, 10 cm in diameter, is made of copper. A tungsten filament, 15 cm in length, is set along the central axis in the chamber. The arc plasma is confined by four rows of ten SmCo magnets mounted on the outer side of the chamber and six SmCo magnets at the end of the chamber. The beam extraction system consists of an extraction and movable puller electrodes, between which the gap is variable. The extracted beam is focused by a Glaser lens. The source can be simply operated mainly by arc voltage, arc current, gas flow, puller voltage and position.

The extraction voltage of the source is designed to cover a wide range of 3 kV to 20 kV to meet a wide acceleration energy range of the cyclotron. When the original extraction and puller electrodes with a single hole of 6.5 mm diameter were used, sufficient beam current was not obtained from the source at low extraction voltages. Plenty of beam current was lost around the puller electrode because of a large divergence of the extracted beam. To reduce the divergence by using a smaller aspect ratio of the diameters to the gap between the extraction and the puller electrodes, they were replaced by multi-hole type electrodes with nineteen holes of 1.8 mm diameter. This increased beam current by ten times at 3 kV extraction voltage. The maximum beam currents of H^+ (1.3 emA) and D^+ (1.0 emA) were stably extracted, in which the short term flutter was less than 5% by peak-to-peak.

However, the multi-hole puller electrode is damaged by spattering of beams. The effect of spattering turned out to be serious when high current of He^{2+} beam was extracted, and partition of holes got thin and melting also occured. Therefore we now generate He^{2+} beam usually by the JAERI ECR source.

Table 3. Beam transmission along the injection line. Beam currents are normalized by that measured at ES2. See Fig. 2.

a) JAERI ECR source

ion	Vex(kV)	ES2	IS1	IS3	IS5	I*)
Ar^{8+}	10.0	1.00	0.91	0.83	0.78	58
He^{2+}	8.5	1.00	0.94	0.92	0.84	255
He^{2+}	8.5	1.00	0.91	0.91	0.86	22

*)Beam currents at ES2 (eμA).

b) Multi-cusp source

ion	Vex(kV)	IS1	IS3	IS5	I*)	Vac**)
H^+	12.5	1.00	0.99	0.96	16	$2.8 \cdot 10^{-4}$
H^+	8.7	1.00	1.00	0.94	1.6	$6.3 \cdot 10^{-5}$
H^+	8.7	1.00	0.84	0.58	760	$6.8 \cdot 10^{-4}$
H^+	3.1	1.00	0.79	0.68	96	$2.0 \cdot 10^{-4}$
H^+	3.1	1.00	0.60	0.48	500	$9.2 \cdot 10^{-4}$

*)Beam currents at IS1 (eμA).
**)Pressure measured at a diagnosis chamber MS1 (Pa).

4. BEAM TRANSMISSION TO CYCLOTRON

A schemetic layout of the ion sources and injection line to the cyclotron is shown in Fig. 3. It consists of a 90 degree analyzing magnet (EAM) for the JAERI ECR source, an inflection magnet (IIM) as an analyzer for the multi-cusp source, a 90 degree bending magnet for vertical injection into the cyclotron and eight solenoid lenses. Eight chambers, each of which are equipped with a Faraday cup, X-Y slits and a beam profile monitor, were installed for beam diagnosis. The beam acceptance of the line is designed at 400 πmm·mrad to maximize the transmission of large emittance from the ECR source.[5)]

The beam transmission to the cyclotron has been improved by careful optimization of beam transport. An example of the transmission is listed in Table 3. As described above, emittance (80%) of the JAERI ECR source beam is a quarter to half of the acceptance and expected to be improved up to 95%, which is estimated to be a limitation by collision with residual gases in the line.

The transmission of the beam from the multi-cusp source is strongly dependent on the extraction voltage and beam current. The transmission is quite satisfactory for low beam current and at high extraction voltage. The transmission is very low along all the injection line when extraction voltage is low and/or beam current is high. This is attributed to large beam divergence beyond the beam acceptance of the line. Space charge in the extraction region also may have considerable effect on beam divergence. In addition, contribution of gas pressure after extraction may not negligible. When we extract high

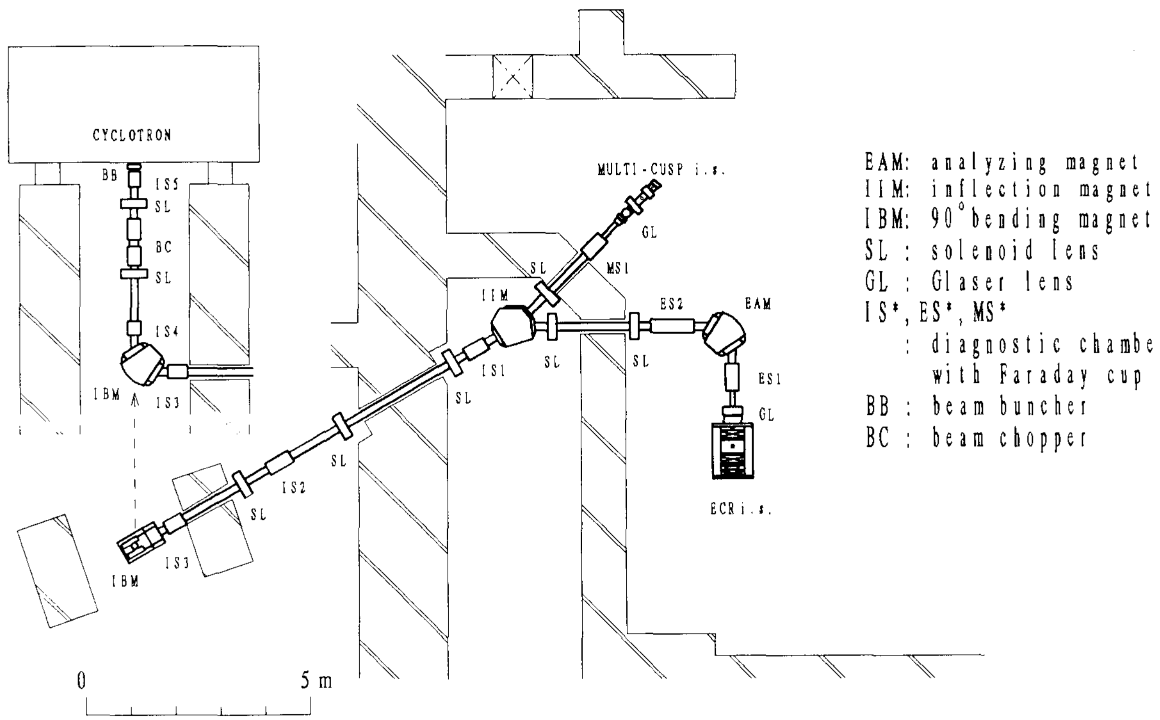

Fig. 3 Schematic layout of the ion sources and the injection line.

current beam from the source, gas is fed into the source at high flow rate, and gas pressure around the extract region increases; it is assumed to be much larger than monitored value measured at a diagnosis chamber MS1 (see Fig. 3). This contributes to growth of beam divergence through collision with the gases. In the case of the JAERI ECR source, gas pressure at extraction is about $5{\cdot}10^{-5}$ Pa, and at high current of He^{2+}, lowering of transmission was not observed at all as shown in Table 3.

5. SUMMARY

Three years have passed since the JAERI ECR and the multi-cusp sources started ion beam generation. The performance of the sources has been improved by several minor changes. Beam transmission also has been improved step by step for many ion species. For the ECR ion source, metal ion has been successfully generated by direct insertion of a rod into the plasma. We are planning to diversify metal ion species. For the multi-cusp source, further improvement will be necessary for transmission at low extraction voltage and high beam current.

Further data collection and investigation should be continued to improve performance and solve remaining problems of the sources and the injection line.

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