Status of ECR Ion Source at JAERI

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Abstract

An ECR ion source has been in operation for two years and a half at JAERI. The source generates multiply charged ions mainly with gaseous element and supplied to the AVF cyclotron. Generation tests of metallic ions were carried out using direct insertion of a ceramic rod into the plasma and were successful for several elements. The paper describes the operational experience, test generation of metallic ions, results of beam transport to the cyclotron and some ion beam characteristics.

I. INTRODUCTION

The JAERI ECR ion source is of OCTOPUS type and the RF frequencies are 14.3 GHz for the 1st stage and 6.4 GHz for the 2nd stage. It was manufactured at Ion Beam Applications s.a. in Belgium and installed at JAERI in 1991. After tuning for ten months, the routine operation began and ion beams are supplied to the cyclotron, accelerated and transport to the beam course end for research experiment[1].

A multi-cusp ion source is installed for hydrogen ion generation. While hydrogen ion beam is supplied to the cyclotron, the ECR ion source is in maintenance or in operation for metallic ion generation and measurement of beam characteristics.

II. OPERATIONAL EXPERIENCE

Ion generation has been made for He^{2+},C^{5+}, Ne^{6+}, Ne^{7+}, $^{36}Ar^{8+}$, $^{36}Ar^{10+}$, $^{40}Ar^{8+}$, $^{40}Ar^{11+}$, $^{40}Ar^{13+}$ and Kr^{20+} by the ECR source from gases (as listed in Table 1). The total operating time for 1992 fiscal year is 1831 hours and 250 hours are allocated for metallic ion generation and beam characteristic measurement (see Fig.2).

Two troubles occurred in the klystron power amplifier. One was burst in a rubber tube in which forced air flowed to cool the klystron tube for 2nd stage. The rubber deteriorated by high temperature. The other was failure of the 14.3GHz klystron tube. A body current of the tube suddenly increased beyond the limitation on turning on and RF power output could not be obtained. The total operating time of the tube was about two thousand hours. The tube was replaced with a stored one. During both failure, the source was operated without 1st stage RF power and ion beams were generated sufficiently for research experiments.

Table 1. Beam currents and transmission between the source and the cyclotron entrance.

ion	extraction voltage (kv)	beam current ($e\mu A$) at ion source	beam current ($e\mu A$) at cyclotron entrance	transmission (%)
$^{4}He^{2+}$	10.2	160	130	81
	8.5	240	206	86
	3.4	38	25	67
$^{12}C^{5+}$	14.3	3.0	2.4	80
$^{20}Ne^{6+}$	9.1	17	12.8	75
$^{20}Ne^{7+}$	11.7	4	3.3	82
$^{36}Ar^{8+}$	10.2	18.0	15.7	87
$^{36}Ar^{10+}$	8.2	9.0	7.7	86
$^{40}Ar^{8+}$	10.1	58	54.5	94
$^{40}Ar^{11+}$	9.4	3.0	2.8	93
$^{40}Ar^{13+}$	11.7	0.5	0.39	77
$^{84}Kr^{20+}$	8.8	0.4	0.33	83

III. METALLIC ION GENERATION

We tried to generate metallic ions of Aluminum (Al), Molybdenum (Mo), and Boron (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 2 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 metallic ions in spite of low charge state. The beam currents are listed in Table 2.

Vapor pressures of possible products from the examined materials are different by factor to some orders at high temperature. It was found that facility of ion generation and beam stability appeared closely dependent on the vapor pressure difference. Since vapor pressure can be estimated by thermodynamic calculation and we will be able to choose proper material without ion generation test from now on.

Additionally we tried to generate B ion from LaB_6 whose vapor pressure was quite proper, and the obtained ion beam was very stable. Vapor pressures for BN are not proper and this lead instability of B ion beams.

Table 2. Maximum beam current of metallic ions.

material	support gas	ion	current(e μ A)
Al_2O_3	O_2	$^{27}Al^{8+}$	5
		$^{27}Al^{6+}$	17
		$^{27}Al^{4+}$	43
		$^{27}Al^{3+}$	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%

Ⅳ. CHARGE STATE DISTRIBUTION AND MAIN GAS FEEDING

The JAERI ECR ion 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 Ar gas 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 rate 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 the charge state distribution of Ar. Fig. 1 shows that beam currents 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.

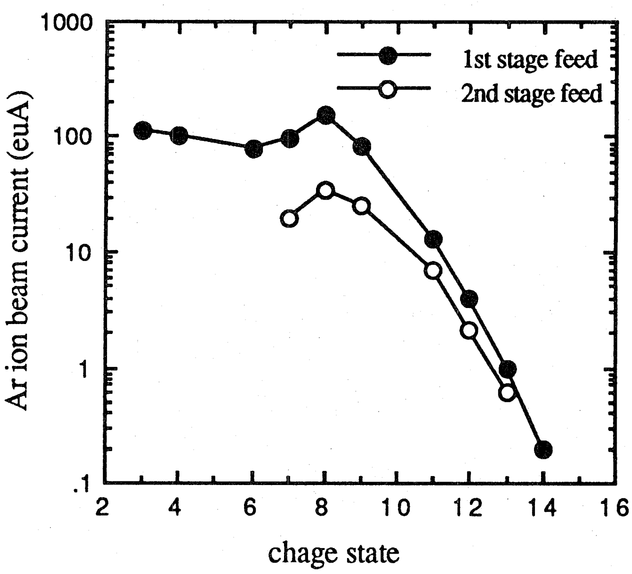

Fig. 1 Charge distribution of Ar ions, comparing 1st and 2nd stage feeding of Ar gas.

Ⅴ. BEAM EMITTANCE

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 just after analyzing magnet, 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 100π mm•mrad to 170π mm•mrad, while the vertical emittance was almost constant at 100π mm•mrad. The horizontal and the vertical emittance must be equal, since the ECR ion source and the beam extraction system are 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 100π mm•mrad, and was independent of the mirror coil current. 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.

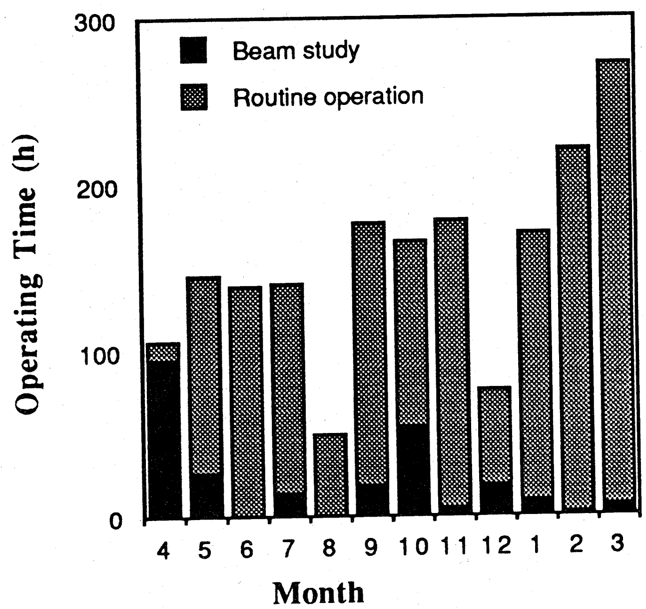

Fig. 2 Operating time at ECR ion source

Ⅵ. BEAM TRANSMISSION TO CYCLOTRON

The beam acceptance of the line is designed at 400 π mm•mrad to maximize the transmission of large emittance from the ECR source.[2]

The beam transmission to the cyclotron has been improved by careful optimization of beam transport. It was about 60 % two years ago and is above 80 % recently. An example of the transmission is listed in Table 1. As described above, emittance at 80 % beam density of the JAERI ECR source 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 at a inflector of the cyclotron is about 70 %. The beam acceptance of the inflector was only estimated at about 100 π mm•mrad by beam optical calculation. The observed transmission suggests the estimated value is roughly valid.

Ⅶ. SUMMARY

Two years and a half have passed since the ECR source started ion beam generation at JAERI. We did not experience serious trouble which leaded to shutting down the source. Beam transmission has been improved step by step for many ion species by careful optimization of transport parameters. Metallic ion has been successfully generated by direct insertion of a rod into plasma. We are planning to diversify metallic ion species and acceleration of them in next step.

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Ⅷ. REFERENCES

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