

Acceleration experiments of in-terminal ECR ion source of JAERI tandem accelerator

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Abstract

Modern electron cyclotron resonance ion source (ECRIS)s are able to produce intense beams of highly charged positive ions, of which charge states are higher than those obtained from electron stripping at the high voltage terminal of tandem accelerators. It is possible to increase beam intensity, beam energy and beam species by utilizing an ECRIS in a tandem accelerator. A small permanent magnet ECRIS has been installed in the high voltage terminal of the vertical and folded type 20UR Pelletron tandem accelerator at Japan Atomic Energy Research Institute at Tokai. Acceleration experiments have been successfully carried out with beams of H, N, O, Ar and Xe ions.

1. Introduction

The tandem accelerator system has been benefiting from the use of an electron stripper at the high voltage terminal. However, the most probable charge state after a foil stripper is much lower than the highest charge state of ions with an intensity of more than several μA from a high performance ECRIS. With respect to beam current increase, if beam current is increased the lifetime of stripper foils decreases. Especially for very heavy ions, it is impossible to obtain a stable and intense beam for a long time without foil exchange. Use of an ECRIS is expected to open a way for a stable acceleration of high intensity beam to higher beam energy. Compact ECRISs of which plasma confinement structures are composed of permanent magnets have been developed and commercially available also.

In Fig.1, charge states of ions of several μA expected for compact permanent magnet ECRISs are compared with the most probable charge states obtained by stripping at a terminal voltage of 16MV as a function of mass number. Concerning to ions over a mass number of 100, charge states higher than 20+ can be available from an ECRIS, compared to 13+ from the stripping at a high voltage terminal of 16MV. In addition to increases of beam energy and beam intensity, use of an ECRIS clears away many problems with stripper foils, such as short lifetimes, energy straggling, emittance growth and beam intensity reduction and makes it possible to accelerate noble gas ions and alkali-metal ions.

On the other hand, use of an ECRIS in a high voltage terminal has difficult problems due to inaccessibility and operation in high pressure SF_6 gas and under electric surges. One needs several devices to solve these problems.

We started with a small permanent magnet ECRIS,

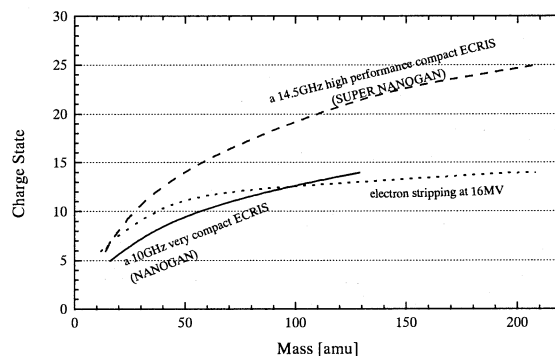


Figure 1. Charge state of the ions of several μA expected for compact ECRISs are compared with the most probable charge state obtained by stripping at a terminal voltage of 16MV.

NANOGAN [2] which works at 10GHz and with RF power of 10 to 200 W, its size and reliability are quite fitted to our plan. As a preliminary step of the in-terminal ECRIS project, in order to solve many difficulties mentioned above before going to a high performance ECRIS.

3. Optimization of Operating Conditions

The ECRIS is placed in a severe environment; i.e. in the high pressure SF_6 gas and under an attack of electric surges from occasional high voltage sparks in the accelerator. For this reason, the injection system initially needs to be simple and have minimum functions.

Ion extraction experiments at the test bench have been carried out in order to search optimum operating conditions and to minimize operating parameters[3]. As a result of the experiments, five parameters could be reduced to three, which are the gas flow, DC bias voltage and RF power. The source gases were previously mixed and flew by using a calibrated leak source instead of a variable gas valve for simplified operation and fail safety. The aim of the experiments was to obtain optimum conditions for a stable ion beam against a change in operational parameters rather than to obtain the maximum performance of the ECRIS.

4. Installation

The installation was carried out in April, 1998. The

JAERI tandem accelerator is a folded type machine with a 180 degrees bending magnet in the high voltage terminal. Electric power of 10kW+15kW is available from two power generators in the terminal. The layout of the in-terminal ECR ion injector is illustrated in Fig. 2.

An ion beam is extracted by a 30kV(at maximum) potential gap from the ECRIS, focused by an einzel lens, and then the mass and charge are roughly selected by 45 degrees pre-analyzing magnet. The magnet is used to reduce the load to the pre-acceleration tube high voltage power supply, since the beams from the ion source amount to 2mA. An electrostatic steerer is placed just after the pre-analyzing magnet to correct the horizontal beam direction. An aperture for rough beam selection is placed just before the pre-acceleration tube. After an acceleration through the 80kV pre-acceleration tube, a desired ion beam is selected by a 45 degrees injection magnet with a radius of curvature of about 0.3m, an electrostatic quadrupole triplet and an aperture of 6.0mm in diameter placed at about 0.4m above the accelerator tube together with a Faraday cup. Magnetic field probes are set to both bending magnets for ion beam selection.

For the RF source of 10GHz, a 200W TWT airborne amplifier with a 10GHz dielectric resonance oscillator is set in a chamber to keep it at an atmospheric pressure. The amplifier, of which power consumption is 2.2kW, is cooled by water using 180 degrees bending magnet cooling system. The RF power is guided to the ECRIS by a wave-guide including RF windows, 80kV and 30kV DC-cut elements.

The main body of the ECRIS is cooled by SF₆ gas flow, which is pumped out by a diaphragm pump. A 220l/s ion pump is used for the vacuum system, because it encloses a gas flow, it is fail-safe and the ECRIS works at a very small flow rate of gas supply.

There are three shield boxes of 0kV(grounded to the high voltage terminal) Deck, 80kV Deck and 110kV Deck. Source gas control circuits and power supply for the DC bias are mounted in the 110kV Deck. Power supplies for the 30kV extraction, einzel lens, 45 degrees pre-analyzing magnet and steerer are put in the 80kV Deck. All devices in the high voltage decks are controlled through an optical link system in communication with the 0kV Deck. The electric power is provided by means of an insulating transformer. A current source for the 45 degree injection magnet, cooling pump, 80kV high voltage power supply for the pre-acceleration tube and communication circuits are installed in the 0kV Deck.

5. Result

The results of acceleration experiments for H⁺, N²⁺, O^{3+,5+}, Ar^{6+,8+,9+}, ¹²⁹Xe¹⁴⁺, ¹³²Xe^{12+,13+}, ¹³⁶Xe^{14+,15+,16+,18+} ions are presented in Table 1. In these experiments, a pre-acceleration voltage was 80kV, except for Xe ions. For Xe ions, the pre-acceleration voltage was set to 50kV, because the maximum field strength of the injection magnet was not high enough to bend the ions accelerated by 80kV(The

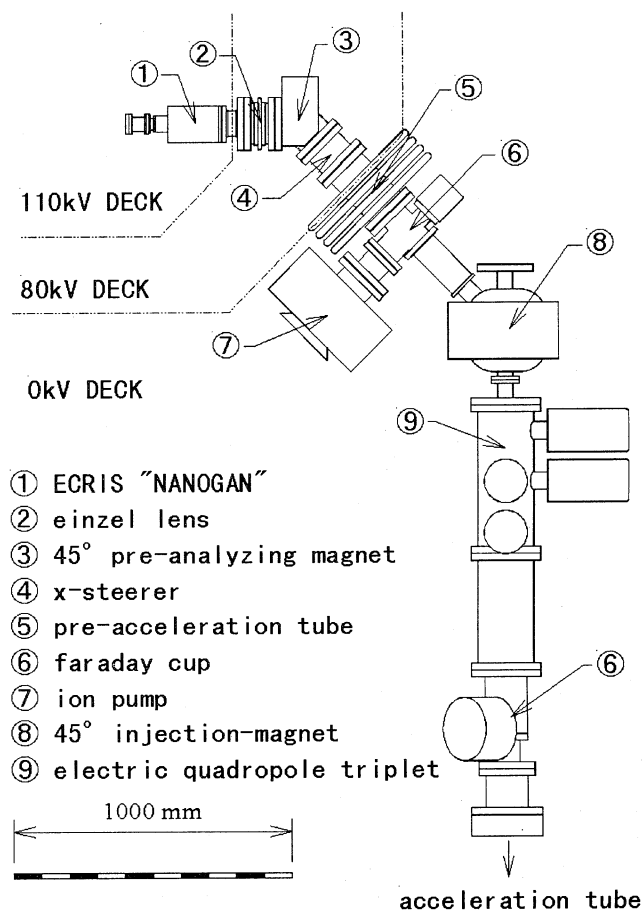


Figure 2. The layout of the in-terminal ECR ion injector.

magnet was the old one, which had been used for the old in-terminal proton/deuteron injector). The gas flow of H, O, Ar and ¹²⁹Xe were fixed by using a calibrated leak valve and that of ¹³²Xe and ¹³⁶Xe were controllable with thermo-mechanical leak valve. The beam intensities for light ions N²⁺ and O³⁺ were suppressed to a large extent to their limits allowed for this facility from the point of radiation safety.

Comparison of beam energy and intensity between conventional negative ion source with foil stripping and an in-terminal ECRIS were shown in the top and bottom of Fig. 3, respectively. Concerning to the beam energy, Xe ions from ECRIS were about twice as much as I ions (neighboring mass number) from the negative ion source with foil stripping. It was confirmed 2nd stripper foil could be able to increase beam energy up to about 300MeV for Xe beams easily. In-terminal ECRIS could produced the low energy and intense nitrogen and oxygen beams. All ions from ECRIS were about ten times as much as the beam intensity of ions nearby its mass number from negative ion source.

The beam transmission was strongly dependent on the pre-acceleration voltage. For N²⁺ ions, the beam current after the accelerator's analyzing magnet for a 60kV pre-acceleration was over twice as much as that for a 50kV pre-acceleration. This was presumably caused by the strong

Table 1. The results of acceleration experiments.

Ion Species	Terminal voltage [MV]	Beam current	Beam Energy [MeV]
		After the analyzing magnet FC 04-1[μA]	
H ⁺	15	3.0*	15
N ²⁺	14	1.0*	28
O ³⁺	15	1.5*	45
O ⁵⁺	14	0.15	70
Ar ⁶⁺	14	2.1	84
Ar ⁸⁺	15	2.0	120
Ar ⁹⁺	15	1.3	135
¹²⁹ Xe ¹⁴⁺	15	0.85	210
¹³² Xe ¹²⁺	16	1.3	192
¹³² Xe ¹³⁺	16	0.47	208
¹³² Xe ^{12→23+}	16	0.067	306
¹³⁶ Xe ¹⁴⁺	15	2.3	210
¹³⁶ Xe ¹⁵⁺	15	1.1	225
¹³⁶ Xe ¹⁶⁺	15	0.77	240
¹³⁶ Xe ¹⁸⁺	15	0.17	270

*: Limited by radiation safety.

gradient at the entrance of the accelerator tube.

However, it was proven to provide beams for the machine time schedule from in-terminal ECRIS, as for light ions under an Ar ion, its beams were stabled for several days. The beam profiles were very sharp at the object and image points of the analyzing magnet, its size could be less than 1mm ϕ , since in-terminal ECRIS system is no need of a foil stripper which caused energy straggling and emittance growth.

Acceleration of very heavy metallic ions, such as Pb ions, is also considered in the project. Now, an extraction tests for metal ions are being performed in a test bench by using a MIVOC(Metal Ions from Volatile Compounds) method[4]. Preliminary obtained, extracted current of Fe⁹⁺ and Fe¹⁰⁺ were 7 μA and 2 μA , respectively.

6. Conclusions and Future Plans

A compact ECRIS was installed at the high voltage terminal of the JAERI tandem accelerator. Ions of H, N, O, Ar and Xe were successfully accelerated and noble gas ions were available from the accelerator. We can use a high intense and high energy beam without the problems with stripper foils.

A higher performance permanent magnet ECRIS will be take the place of the present ECRIS in a few years, in our in-terminal ECRIS project.

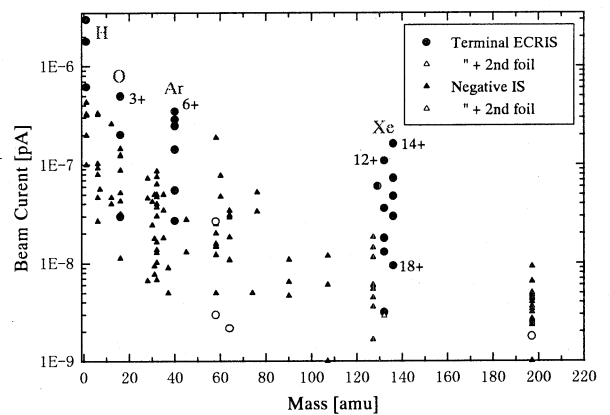
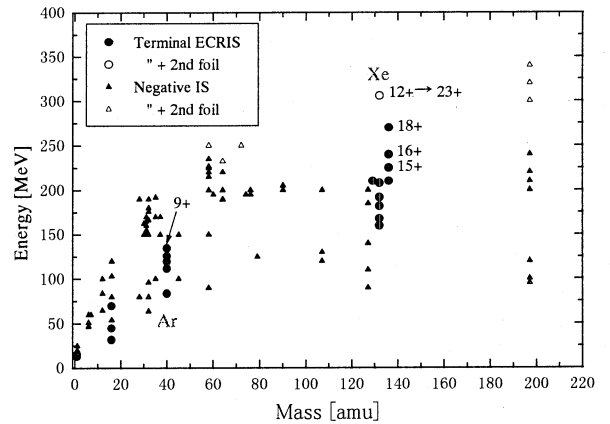


Figure 3. Comparison of beam energy(top) and beam intensity(bottom) between conventional negative ion source with foil stripping and in-terminal ECRIS.

References

- [1] D. K. Olsen, "Introduction to ECR Source in Electrostatic Machines" presented at the Symposium of Northeastern Accelerator Personnel, Oak Ridge, Tennessee, October, 1989.
- [2] P. Sortais et al., "Developments of compact permanent magnet ECRIS" in Proc. of the 12th Int. Workshop on ECR Ion Sources, RIKEN, Japan, April, 1995.
- [3] M. Matsuda et al., "Application of an ECR ion source to the JAERI tandem accelerator", Proc. of the 11th Symposium on Accelerator Science and Technology, Harima, 1997. T. Nakagawa et al., Nucl. Instrum. & Methods, A396(1997)9-12
- [4] M. Matsuda et al., "In-terminal ECR ion source of the Tandem accelerator at JAERI", Proc. of the 14th Int. Workshop on ECR ion source, CERN, Switzerland, May, 1999.