In-terminal ECR Ion Source of the Tandem Accelerator at JAERI

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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 tests have been successfully carried out with beams of H^+, N^{2+}, $O^{3+,5+}$, $Ar^{6+,8+,9+}$ and $^{132}Xe^{12+,13+}$ ions.

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 eμA 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. ECRISs were, in the past, too large and too heavy to utilize in tandem accelerators. It was possible only for large vertically standing folded tandem accelerator like 25UR Pelletron tandem accelerator at Oak Ridge National Laboratory where an installation project of an ECRIS in its terminal was once considered [1]. In recent years, 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 eμA 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 a 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.

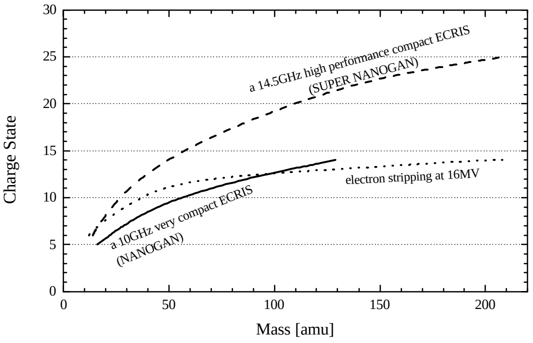
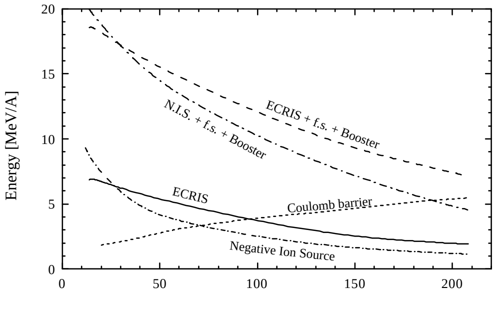


Figure 1. Charge state of the ions of several eμA expected for compact ECRISs are compared with the most probable charge state obtained by stripping at a terminal voltage of 16MV.

We started with a small permanent magnet ECRIS, NANOGAN [2] which works at 10GHz and with RF power of 10 to 200 W, 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.

We are also aiming at increasing injection velocities of very heavy ions to the super-conducting booster linac [3], of which lowest acceptance velocity is 5% of the light velocity, with this in-terminal ECRIS project. Comparison of expected energy between conventional negative ion source with foil stripping and an in-terminal ECR ion source is shown in Fig.2.

Figure 2. Comparison of expected energy between



conventional negative ion source with foil stripping and an in-terminal 14.5GHz compact ECR ion source.

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 have been carried out in order to search optimum operating conditions and to minimize operating parameters. 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 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.

The support gas could be previously mixed for simplified operation. The currents of different charge states of Ar ions are seen in Fig.4 as a function of mixing ratio of oxygen gas to argon gas. The currents of highly charged ions(8+, 9+) do not depend on the mixing ratio very much, while the currents of low charge state ions decrease with increasing mixing ratio. So that, the ratio of Ar:O_2=1:10 was chosen, because we wanted to use an ion pump(see the next section) and to restrain the load to the pump(The total gas flow rate is fixed in the measurement for Fig.4. The flow of argon gas into the ion pump can be reduced very much.) because the pumping speed for argon gas is only about 10% compared with that for air. With an ion pump of 200l/s, the ECRIS ran stably for several months for noble gases with a flow of less than 2×10^{-5}torr l/s. The high mixing ratio reduces unwanted low charge state Ar beams as well. The results with krypton and xenon gases were similar to argon.

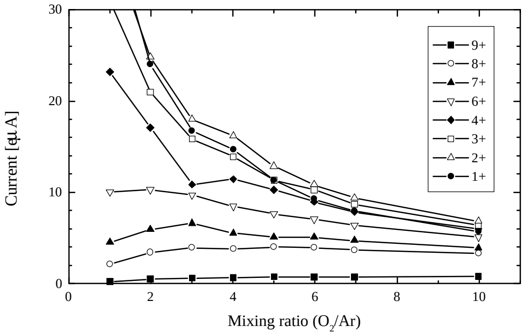


Figure 3. The currents of different charge states of Ar ions as a function of mixing ratio of oxygen gas to argon gas with the total gas flow ratio was fixed.

The gas flow, or the pressure in the plasma chamber, was a critical parameter for the condition of a stable and intense beam. It was optimum at 1.6×10^{-4}(±20%)torr l/s for Ar^{8+}. A calibrated leak source was employed instead of a variable gas valve, because a complicated and troublesome feedback control could be eliminated. This method was quite effective to make the ion source operation easy. A DC bias to the bias electrode was necessary to produce an intense beam. With a DC bias of -40 to -200 V, a beam was extracted with an intensity of at least ten times as intense as that without DC bias.

Installation

The JAERI tandem accelerator is a folded type machine with a 180°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.4. 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°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°injection magnet with a radius of curvature of about 0.3m, an electrostatic quadrupole triplet and an aperture of 4.8mm 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°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 SF_6 gas flow which is pumped out by a diaphragm pump. A 200l/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 as is described in the previous section.

There are three shield boxes of 0kV(grounded to the high voltage terminal)Deck, 80kV Deck and 110kV Deck. Source gas control circuits and a power supply for the DC bias are mounted in the 110kV Deck. Power supplies for the 30kV extraction, einzel lens, 45°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°injection magnet, cooling pump, 80kV high voltage power supply for the pre-acceleration tube and communication circuits are installed in the 0kV Deck.

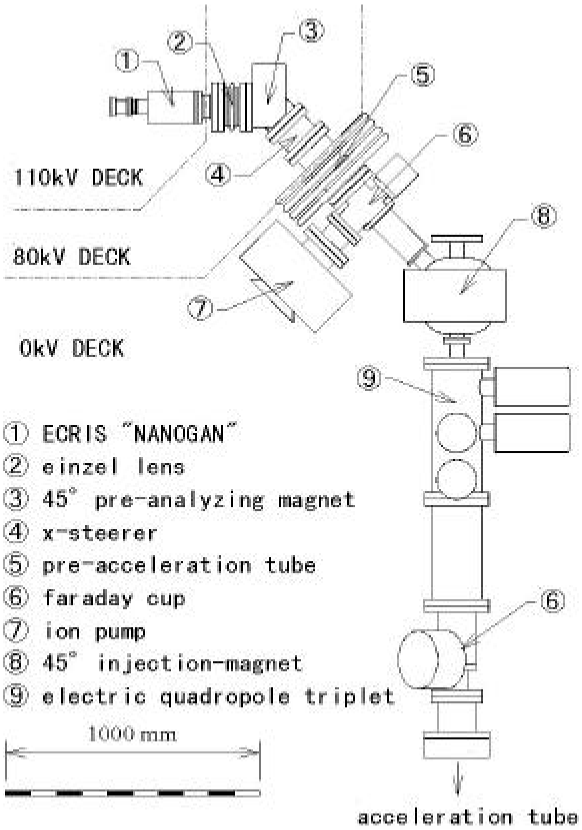


Figure 4. The layout of the in-terminal ECR ion injector.

The installation was carried out in April, 1998. In the first two acceleration tests, some troubles were found in power supplies, some of which were caused by high voltage sparks in the accelerator and a few of which were due to pressurized insulating gas. Even with these troubles, we obtained good feasibility from accelerating H^+ and Ar^{8+} ion beams. During a tank opening in August, the power supplies and their AC power lines were fixed and two gas sources were installed, which were Ar+10 O_2 and ^{132}Xe(enriched 60%)+10 N_2 gases. The gas flow of Ar+10 O_2 was fixed by using a calibrated leak valve and that of Xe+10 N_2 was controllable with a thermo-mechanical leak valve. We obtained, in the third acceleration test, a result as below.

Result

The results of acceleration experiments for H^+, N^{2+}, $O^{3+,5+}$, $Ar^{6+,8+,9+}$ and $^{132}Xe^{12+,\ 13+}$ ions are presented in Table 1. In these experiments, the extraction, pre-acceleration and terminal voltages were 15kV, 80kV and 14MV, respectively, 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 magnet was the old one which had been used for the old in-terminal proton/deuteron injector). The beam intensities for light ions N^{2+} and O^{3+} were suppressed to a large extent to their limits allowed for this facility from the point of radiation safety. The beam transmission was strongly dependent on the pre-acceleration voltage. For N^{2+} 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 gradient at the entrance of the accelerator tube. The beam profiles were very sharp at the object and image points of the analyzing magnet. The beam width of $^{132}Xe^{12+}$, for example, was between 1 and 2mm(FWHM) in the bending plane. One can expect a very high quality energy beam from the ECR in-terminal injector plus electrostatic accelerator system as we know about beams from a single ended Van de Graaff.

Table 1. The results of acceleration experiments.

	Energy	Current	
		Before the acceleration tube.	After the analyzing magnet.
	[MeV]	[eμA]	[eμA]
H^+	14	3.1	2.3
N^{2+}	28	3.4	1.0*
O^{3+}	42	1.6	1.5*
O^{5+}	70	---	0.15
Ar^{6+}	84	---	2.1
Ar^{8+}	112	---	2.3
Ar^{9+}	126	0.26	0.24
$^{132}Xe^{12+}$	168	0.31	0.22
$^{132}Xe^{13+}$	182	0.26	0.17

*:limited by radiation safety.

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. Now, noble gas ions are available from the accelerator, in addition to the ions normally available from the negative ion injector. We can use a high intense and high energy beam without the problems with stripper foils.

The charge states of medium mass ions, such as Xe^{12+} ions, from the very compact ECRIS are comparable to those obtained by electron stripping. A higher performance permanent magnet ECRIS is to take the place of the present ECRIS in a few years, in our in-terminal ECRIS project. Acceleration of very heavy metallic ions, such as Pb ions, are also considered in the project.

References

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[3] S. Takeuchi, et al., Nucl. Inst. and Meth., 1996, A382, pp.153-160.