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Development of intense high-energy noble gas ion beams from in-terminal ion injector of tandem accelerator using an ECR ion source

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A B S T R A C T

An ECRIS-based heavy ion injector was constructed in the high-voltage terminal of JAEA-Tokai Tandem Accelerator to develop new beam species of highly charged noble gas ions. This work was associated with a lot of development to operate the ion source on the 20UR Pelletron high voltage terminal in high pressure SF_6 gas environment. Highly charged ions of N, O, Ne, Ar, Kr and Xe have been accelerated satisfactorily. Operating data integrated during many years long beam delivery service are summarized.

1. Introduction

An advantage of using a tandem accelerator to boost energy of heavy ions lies in having ions highly charged by stripping their electrons at the positively charged high voltage terminal after accelerating negatively charged ions from the ground potential. There is, however, a limit to the beam intensity we can increase, because carbon foils used for electron stripping are so thin and short-lived under penetration of heavy ion beams [1,2]. Charge states after electron stripping are dominated by a few ones around the most probable charge state, which can be empirically defined as a function of incident beam velocity and atomic number of ions, so that the amount of beam energy we can change selecting a different charge state is small [3,4]. In addition, it is impossible to accelerate positively charged noble gas ions starting from the ground potential. On the other hand, modern electron cyclotron resonance ion sources (ECRISs) have been able to produce intense beams of highly charged ions over a wide range of charge states [5], and they are very suitable for noble gas ionizations. With such an ECRIS installed on a positively charged high voltage terminal of tandem accelerator, the intensity and energy range may be increased for noble gas ion beams compared to those of nearly heavy non-noble gas ion beams normally obtained from the tandem accelerator [6,7].

In the present work, a compact 10 GHz ECRIS was chosen for the in-terminal ECRIS (T-ECRIS) injector of the vertically folded type 20UR Pelletron^{TM} tandem accelerator at Japan Atomic Energy Agency (JAEA)-Tokai is illustrated in Fig. 1 [8–11]. The T-ECRIS injector could barely be fitted at the high-voltage terminal of the tandem accelerator because of the limited space and infrastructures available. We also had to protect the T-ECRIS injector and its associated components against the severe environment of high-pressure SF_6 gas and electric surges caused by unexpected sparks along the accelerator column.

This paper describes the way to solve those problems in Sections 2 and 3, and construction work of T-ECRIS in Section 4. The result of beam acceleration from the T-ECRIS is presented in Section 5. Further developments are discussed in Section 6.

2. Principle for the T-ECRIS development

The following requirements were considered in the design of the T-ECRIS system:

(1) The system, which includes the injector and related apparatuses, should be made as small as possible, because of narrow installation space.
(2) The system should be designed to operate simply, reliably and safely.
(3) The system should have a fail-safe function, because it takes many days to open the tank and repair in case of fatal accident.

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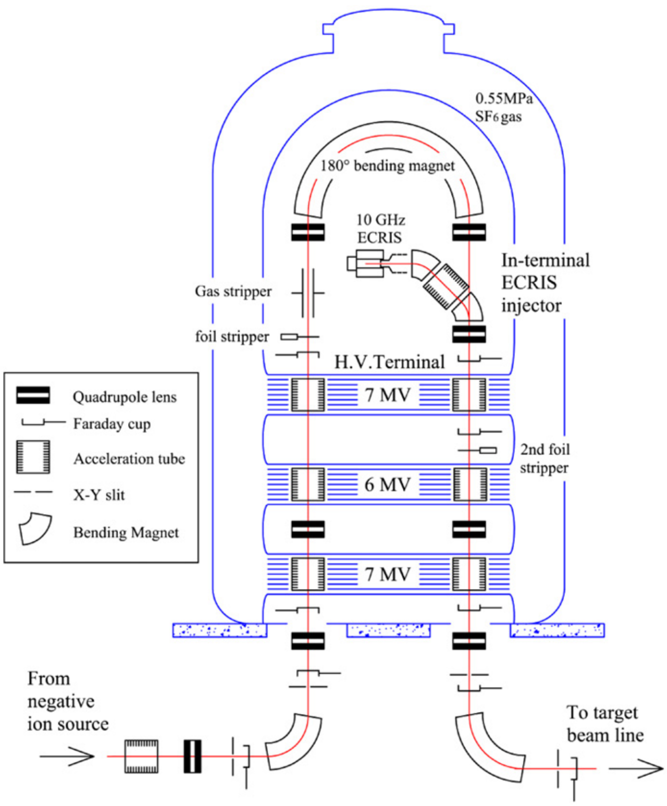

Fig. 1. Diagram of JAEA-Tokai 20 MV tandem accelerator.

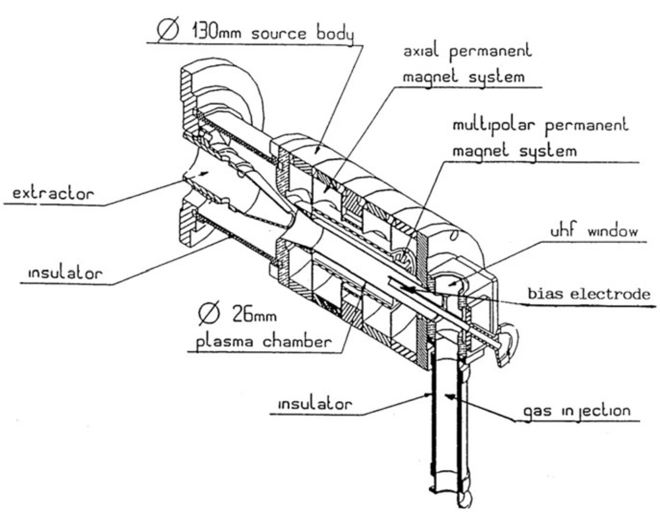

Fig. 2. Cutaway drawing of all-permanent-magnet type 10 GHz ECRIS (Nanogan^{TM}).

(4) The system should allow the tandem accelerator to run in the normal tandem mode, while turned off.

From requirements (1) and (2), a compact all-permanent-magnet type ECRIS (Nanogan^{TM} [12–14]) shown in Fig. 2 was employed, because the structure without mirror coils saves electric power, cooling system and space. The ECRIS runs reliably and performs well by injecting typically 80 W of 10 GHz RF power for plasma heating, in spite of the fact that the body has a diameter of 130 mm, a length of 220 mm and a weight of approximately 25 kg. The T-ECRIS could be installed at the position of a previously used hydrogen ion injector in the high-voltage terminal [9].

3. Experiments for the optimization and simplification of control parameters

Before installation, beam generation experiments with the ECRIS were carried out on a test bench in order to obtain the optimum operating conditions and to minimize operating parameters for simple operation rather than maximum performance.

The ECRIS can be controlled by only adjusting the RF power and DC bias probe voltage provided that enough source gas is injected for stable operation. If the flow rate of source gas is fixed near the optimum point, troublesome gas flow adjustment can be excluded. Experiments were then carried out with different mixing ratios of main gas and support gas. Gas flow controls, different plasma apertures and other items were also studied.

3.1. Optimum gas mixing ratio

The gas mixing method is useful to enhance the ionization of highly charged ion beams [5]. The source gas bottles were filled up with a mixture of main gas and support gas. Beam currents obtained for different charge states of argon and xenon ions are shown in Fig. 3 as a function of mixing volume ratio of main gas to support gas. The ion source parameter was optimized with respect to Ar^{8+} or Xe^{15+} ion current. In both cases of argon and xenon ions, higher charge state ions are intense at a low mixing ratio, while lower charge state ions are intense at higher mixing ratios.

From the point of view of the high-voltage stability or radiation safety for the tandem accelerator, the maximum acceptable beam current into the acceleration tube is limited to several eμA. Such beam currents are available for many multiple charges at mixing ratios of 10% for argon and 2% for xenon, as is seen in Fig. 3. In addition, the beam lines in the high voltage terminal are mainly evacuated by ion pumps. The noble gas load to them should be as small as possible to prevent noble gas instability.

The optimum mixing ratios for the different gas combinations were chosen as follows: $Ne+H_2$ (1:2), $Ar+O_2$ (1:10), $Kr+O_2$ (1:20) and $Xe+O_2$ (1:50). Support gas is selected in consideration of the charge-to-mass ratio of desired ion.

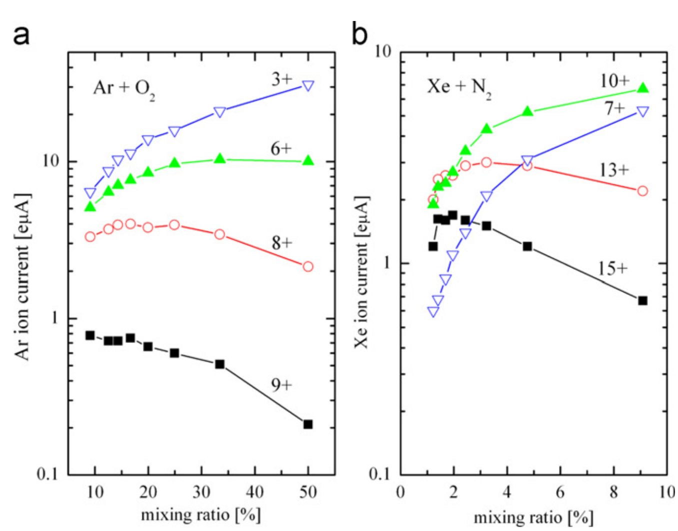

Fig. 3. (a) Beam current of different charge states of argon ions as a function of mixing ratio of argon gas to oxygen gas and (b) those of xenon ions as a function of mixing ratio of xenon gas to nitrogen gas. The data were obtained at a fixed total gas flow.