CHARGE STRIPPING OF URANIUM-238 ION BEAM WITH HELIUM GAS STRIPPER

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Abstract

Development of the undestructive and efficient electric charge stripping method is one of the key issues in next-generation high-intensity heavy ion accelerators like the RIKEN RI-beam facility, RIBF. Conventional carbon-foil charge strippers are not applicable to very heavy ion beams like uranium beams generated in such accelerators primary because of the radiation damage. A charge stripper using low-Z gas is an important candidate applicable for high-intensity uranium beams in future to replace carbon foil strippers. In the present work, a high beam transmission charge stripping system using helium gas for ^{238}U beams injected at 10.8 MeV/u has been developed and demonstrated for the first time.

INTRODUCTION

A critical issue at the RIKEN RI-beam facility (RIBF) [1] is the need to improve the present intensity of ^{238}U beams (∼3.5 pnA) towards the intensity goal of 1 pμA, which is expected to provide an enormous breakthrough for exploring new domains of the nuclear chart.

A new injector, RILAC2 [2], which has a 28-GHz superconducting electron cyclotron resonance ion source (SC-ECRIS) [3], was successfully commissioned and operated in user runs [4]. The intensity of ^{238}U beams at the RIBF has steadily increased mainly because of improvements made to the 28-GHz SC-ECRIS [5].

The uranium beams outputted from RILAC2 are accelerated with four separate-sector cyclotrons; the RIKEN ring cyclotron (RRC), a fixed-frequency ring cyclotron (fRC), an intermediate-stage ring cyclotron (IRC) and a superconducting ring cyclotron (SRC). In order to realize further high-power ^{238}U beams with the powerful injector, one must resolve a number of issues including those related to beam acceleration, space charge effects, heat loading and radiation damage. In particular, the development of a reliable, efficient electric charge stripping method applicable to high-intensity uranium beams is an urgent issue.

In the present acceleration of uranium beams at the RIBF, two carbon-foil charge strippers [6] are used after the RRC and the fRC, respectively (Fig. 1). Although solid carbon-foil charge strippers provide good charge–stripping efficiency, two serious problems are emerging: (1) a short usable time and (2) non-uniform thickness. Especially for the first stripper after RRC, uranium beams having intensities as low as 10 pnA passing through the simple carbon foil becomes out of the acceptance of the subsequent cyclotrons
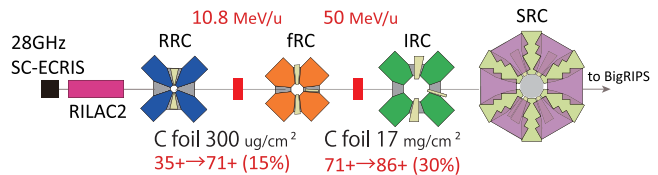

Figure 1: The acceleration scheme of the uranium beam at RIBF.

after as little as 12 hours presumably due to radiation damage [6].

A charge stripper using low-Z (Z: atomic number) gas is an important candidate to replace existing carbon foil strippers for application to high-intesity ^{238}U beams [7]. In the previous work [8], the maximum mean charge state and the charge evolution of ^{238}U beams injected at 10.8 MeV/u were investigated using thick H_2 and He gas with a 8-m gas target system. The maximum charge states obtained with the 8-m system of low-Z gas (around 65+) are superior to those of medium-Z gas strippers like N_2 around 55+ [9].

In the present work, a high beam transmission charge stripping system dedicated for the helium gas has been developed and demonstrated.

HELIUM GAS TARGET SYSTEM

Between low-Z gases, i.e., helium and hydrogen gases, helium gas is the better candidate for gas charge strippers for high-intensity uranium beam, because of the ease accumulation, larger charge-exchange cross sections, smaller energy deposition and the absence of an explosion hazard. In the previous study, in order to accumulate hydrogen gas more than 1 mg/cm^2, the 8-m low-Z gas target system was developed. However, except for hydrogen gas, one can obtain the charge equilibrium with shorter target system. For example, the target length required for accumulating the helium with the thickness up to 2-mg/cm^2 could be shortened drastically from 8 m to 0.5 m. Such short length system is favorable for improving the beam transmission efficiency. To demonstrate such high beam transmission helium gas stripper, we developed the short version (0.5 m) of the gas target system (Fig. 2).

The differential pumping systems are similar to the system developed for upstream differential pumping in the 8-m target system. The conductances among the vacuum chambers are limited by the diameters of the tubes, which are 6−10 mm. Stage 1 was evacuated by using a powerful mechanical booster pump backed by a rotary oil pump. A

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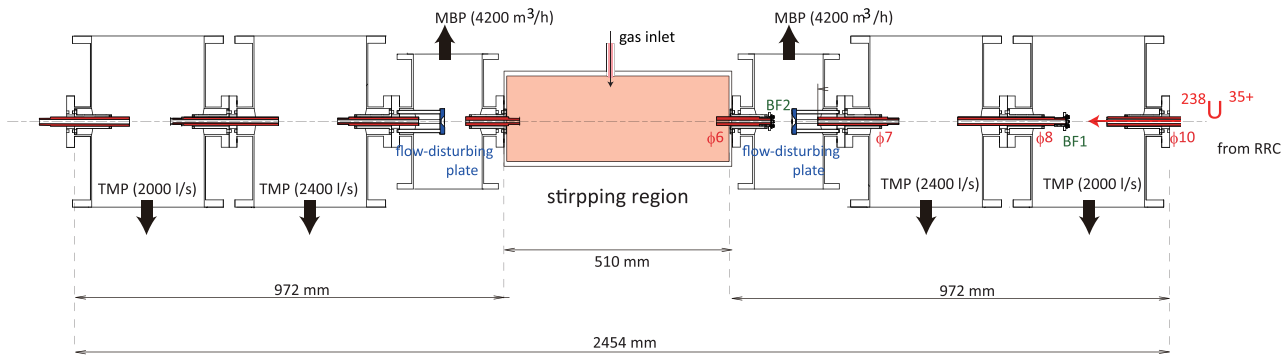04 Hadron Accelerators

A17 High Intensity Accelerators

Figure 2: Cross-sectional view of the 0.5-m charge stripping system. The 0.5-m charge stripping system consists of two three-stage differential pumping systems. The flow-disturbing plates were equipped to decouple the gas flows between stage 1 and stage 2. Four-segmented baffle beam current detectors, BF1−BF2, were attached at the beam entrance of the apertures to monitor the beam loss.

high-throughput turbomolecular pump was used in stage 2 and an ordinal one was used in stage 3. Flow-disturbing plates were placed between the first and the second stages; they were specially designed to slow the flow of the supersonic gas jet [8].

Although the length of the differential pumping system was as small as 1 m and the diameter of the beam passage was more than 6 mm, a pressure transition from 15 kPa for He to $\sim 10^{-3}$ Pa was achieved. The pressures of the upstream and downstream beamline were one order of magnitude lower than the third-stage pressure. In the 0.5-m charge stripping system, a thickness up to about 2 mg/cm^2 for He has been confined maintaining a tolerable beamline pressure.

The required helium flow rate in SLM as a function of the target thickness is shown in Fig. 3. In the present system, helium gas consumption is quite high to make thick target. We supplied helium to the target chamber from the gas handling system with a helium cylinder bundle (7 m$^3 \times$30).
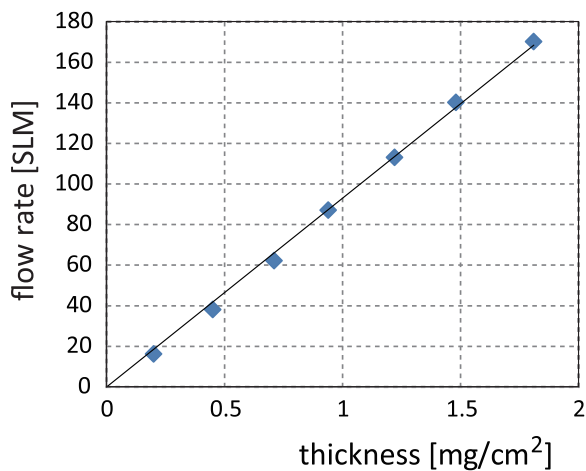

Figure 3: Required flow rate as a function of the helium thickness.

CHARGE STATE EVOLUTION AND ENERGY STRAGGLING WITH 0.5-M TARGET SYSTEM

In the experiment, the 0.5-m helium gas-charge-stripping system was placed on the beamline after the RRC at the RIBF. The 0.68 MeV/u U^{35+} beams extracted from RILAC2 were accelerated to 10.8 MeV/u using the RRC. The ^{238}U^{35+} beams outputted from RRC (100−200 enA in the present measurements) are directly injected to the 0.5-m target system via the 4 quadrupole triplets.

We transported the ^{238}U beams passing through the charge stripping section with around 80% transmission efficiency by adjustment of the magnet parameters. The beam current of a selected charge state with a 90-degree dipole magnet after the stripper was measured with the faraday cup downstream.

Because of the short length target section, transmission efficiency of the present system was drastically improved from the efficiency of the 8-m target system (Fig. 4). In these measurements, the magnet parameters of the quadrupole triplets at upstream of the stripper were fixed to the tuned values for the empty targets.

The charge state evolution of ^{238}U beams injected at 10.8 MeV/u in 0.5-m helium gas was measured to check the reproducibility. The obtained data for charge evolution were fairly reproduced the data obtained with 8-m target system as shown in Fig. 5. The maximum mean charge state for helium is around 65$^+$.

According to the estimation with the scaled cross sections obtained in the previous measurement [8], to obtain the mean charge state 69$^+$, which is the minimum acceptable charge state for the present fRC at RIBF, a thickness around 2 mg/cm^2 and an injection energy of at least 16 MeV/u are required. In order to realize such helium stripper, we require both a larger accelerator to obtain 16 MeV/u, and a large decelerator for matching, to reach the acceptable energy levels (10.6 MeV/u) for the fRC.

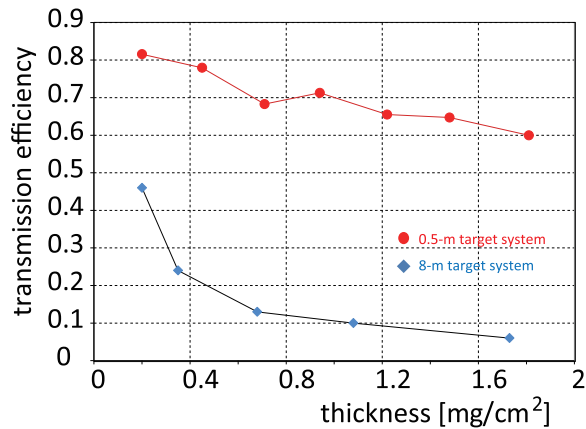A better solution is to use thinner charge strippers with

Figure 4: Transmission efficiency of a selected charge state as a function of the helium thickness. The most probable charge state for each thickness was selected and transported for the measurements
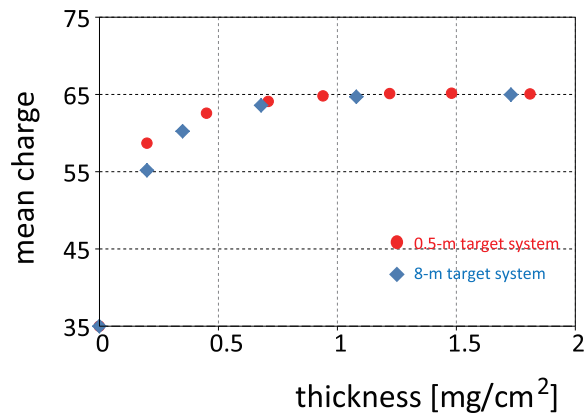

Figure 5: Comparison of the measured charge state evolution with 8-m and 0.5-m target systems. The maximum mean charge state around 65^+ are obtained in both measurements.

some modification to the fRC to match to the lower charge state ($\sim 65^+$). The charge distribution of helium with the thickness of 0.7 mg/cm^2 is shown in Fig. 6. In the present study, a 10.4 MeV/u ^{238}U^{65+} beam was obtained using the 0.7-mg/cm^2 He stripper with the 14% total efficiency involving beam transmission efficiency which is similar value to that for the current carbon-foil stripper..

CONCLUSION

The efficient charge stripping system using helium gas applicable to the charge stripping of high-intensity uranium beams has been developed and demonstrated for the first time. The obtained charge state distribution was equivalent with the data obtained with 8-m target system, while the transmission efficiency was drastically improved. The helium gas stripper with the thickness around 0.7 mg/cm^2 looks suitable for the first charge stripper of uranium beams
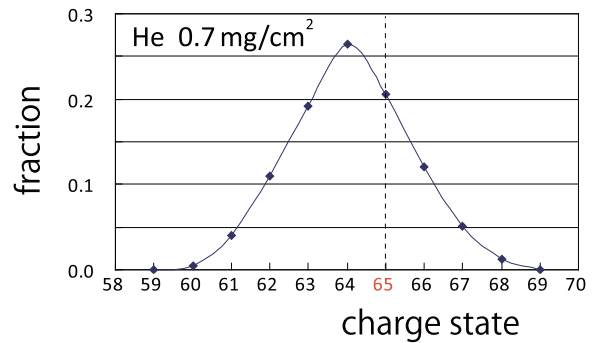

Figure 6: Charge state distribution for the helium with the thickness of 0.7 mg/cm^2. U^{65+} beams with the fractions around 20% are obtained.

at RIBF. Towards its actual use, further R&D works for the helium gas stripper to solve the problems concerning about large gas consumption and heat load on the helium gas are also undergoing.

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