CHARGE STRIPPERS IN THE RIKEN RI-BEAM FACTORY

H. Ryuto*, N. Fukunishi, H. Hasebe, N. Inabe, S. Yokouchi,
O. Kamigaito, A. Goto, M. Kase and Y. Yano
Cyclotron Center, RIKEN, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

Abstract

In the RIKEN RI-Beam Factory, four stripper sections are under investigation to be used with four ring cyclotrons and an injector linac. The charge stripping schemes for typical ions and the selection of the charge strippers are described. The results of the measurements on charge state fractions are presented.

INTRODUCTION

Charge strippers play essential roles in a heavy-ion accelerator complex, which increase the variety of acceleration schemes and decrease the construction costs of accelerators. The RIKEN RI-beam factory (RIBF) is a heavy-ion accelerator complex under construction. The RIBF consists of four ring cyclotrons, an AVF cyclotron for light ion and light heavy-ion injection, and linacs aiming at the acceleration of ions from hydrogen to uranium [1]. A typical objective beam of the RIBF is a 1 pμA uranium beam at 350 MeV/nucleon on target. In the RIBF, four stripper sections are under investigation.

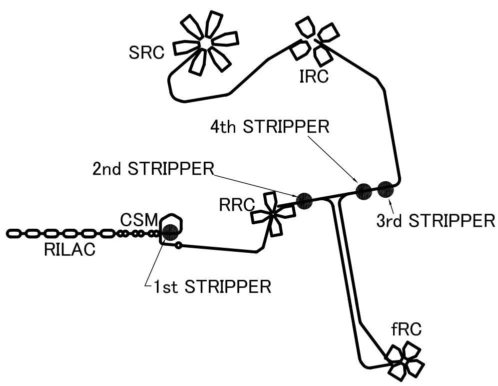

Figure 1: Schematic view of the RIBF.

Figure 1 shows a schematic view of the RIBF. The RIBF consists of, from upstream to downstream, the RIKEN heavy-ion linac (RILAC), the charge-state multiplier (CSM), the RIKEN ring cyclotron (RRC), the fixed-frequency ring cyclotron (fRC), the intermediate-stage ring cyclotron (IRC), and the superconducting ring cyclotron (SRC). Another cyclotron, an AVF cyclotron, for light ion and light heavy-ion injection is not drawn on the figure. The CSM makes possible a charge stripping at a higher energy than the injection energy of the RRC by a combination of an accelerator and a decelerator [2]. Four strippers are placed between the accelerator and decelerator of the CSM, the RRC and the fRC, the fRC and the IRC, and the RRC and the IRC, respectively.

CHARGE STRIPPING SCHEME

Table 1 shows the parameters of the strippers in the RIBF for typical ions, ^{238}U, ^{136}Xe, and ^{86}Kr. In the uranium beam case, the $^{238}U^{35+}$ ions extracted from the ion source are accelerated by the RILAC to 0.65 MeV/nucleon, and injected into the RRC. At the commissioning stage of the RIBF when a sufficient intensity of $^{238}U^{35+}$ is not obtained from the ion source, the first stripper is employed. The first stripper is planned to be a 0.025 mg/cm^2 thick carbon foil [3]. The most probable charge state of a uranium beam at 0.9 MeV/nucleon is expected to be 36+ and its fraction to be 17% [4]. The uranium beam is accelerated by the RRC to 11 MeV/nucleon, and charge stripped to 72+ by the second stripper, a 0.5 mg/cm^2 thick carbon foil. The charge state fraction of $^{238}U^{72+}$ is expected to be 19%, which is assumed from the GSI data on the charge state fraction of $^{238}U^{73+}$ stripped by a 0.49 mg/cm^2 thick carbon foil at 11.4 MeV/nucleon [5]. After being stripped by the second stripper, the beam is injected into the fRC, and accelerated to 51 MeV/nucleon. The beam extracted from the fRC is stripped to 88+ by the third stripper, whose thickness is selected to be 14 mg/cm^2 by a calculation code GLOBAL [5]. The beam loses approximately 8% of its kinetic energy while passing through the third stripper. The extraction energy of the fRC is selected as the energy of the uranium beam behind the third stripper matches the injection energy of the IRC, 46 MeV/nucleon. The charge state fraction of $^{238}U^{88+}$ is estimated to be 34% by the GLOBAL calculation.

A xenon beam is accelerated in the same way as a uranium beam except for the first stripper because a sufficient intensity of $^{136}Xe^{20+}$ beam has been already achieved obtaining from the ion source [6]. The $^{136}Xe^{20+}$ beam is accelerated by the RRC to 11 MeV/nucleon, and charge stripped to 44+ by the second stripper, a 0.15 mg/cm^2 thick carbon foil. The charge state fraction of $^{136}Xe^{44+}$ was measured to be approximately 30% as described later. The thickness of the third stripper was selected to be 20 mg/cm^2 as the energy of the xenon beam behind the stripper become 46 MeV/nucleon, the injection energy of the IRC. When an upgrade of the IRC that enables us to adjust the injection radius to the beam energy is realized, a thinner stripper will be used as the third stripper.

* ryuto@riken.jp

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Table 1: Parameters of the strippers for the RIBF.

	with the fRC					without the fRC	
Ion	^{238}U			^{136}Xe		^{86}Kr	
Stripper section	1st	2nd	3rd	2nd	3rd	1st	4th
Energy (MeV/nucleon)	0.9	11	51	11	51	2.7	46
Required charge-state	35+	72+	88+	42+	51+	26+	32+
Thickness (mg/cm^2)	0.025 [3]	0.5 [5]	14 [5]	0.15	20 [5]	0.04	0.3
Expecting charge-state	36+	72+	88+	44+	52+	26+	33+
Fraction	17% [4]	19% [5]	34% [5]	30%	44% [5]	31%	41%

The charge stripping scheme of the krypton beam is somewhat different from the xenon and uranium beam cases. It is advantageous not to use the fRC in the krypton beam case because the thickness of the third stripper would be too large, which superfluously deteriorate the beam quality. Krypton ions are charge stripped to 26+ by the first stripper, a 0.04 mg/cm^2 thick carbon foil, and accelerated by the RRC. The ^{86}Kr^{26+} beam at 46 MeV/nucleon extracted from the RRC is stripped to 33+ by the fourth stripper, a 0.3 mg/cm^2 thick carbon foil. The charge state fractions of ^{86}Kr^{26+} at 2.7 MeV/nucleon and ^{86}Kr^{33+} at 46 MeV/nucleon were measured to be 31% and 41%, respectively. When the injection radius of the IRC is adjustable to the beam energy, it is expected to be advantageous to employ the fRC.

CHARGE STRIPPERS

The strippers in the RIBF are mainly characterized by the energy and intensity of the beams. The beam energy and intensity are naturally lower and higher at the stripper section placed upstream than those placed downstream, respectively.

As the first stripper, carbon foils in the thickness range from 0.02 to 0.1 mg/cm^2 are planned to be used. The effect of the beam on the first stripper is expected to be severe because the highest intensity beam at the lowest energy among four stripper sections bombards the first stripper. For example, if a 0.025 mg/cm^2 thick carbon stripper foil is bombarded by a 90 pμA uranium beam at 0.9 MeV/nucleon, the lifetime of the stripper foil is expected to be approximately 1 min [3, 7]. Therefore, in the uranium beam case, the first stripper is planned to be applied only at the commissioning stage of the RIBF, at which the beam intensity is expected to be approximately 1/100 of the target intensity. If the decelerator of the CSM is not in operation, the incident energy of a uranium beam bombarding the first stripper is approximately 0.65 MeV/nucleon, which makes the condition more severe. A long-life carbon foil whose lifetime is more than 100 times longer than the foils on the market has been developed [8].

Carbon foils in the thickness range from 0.15 to 0.5 mg/cm^2 are planned to be used as the second stripper. The second stripper is expected to receive approximately 1 kW power when a 15 pμA uranium beam at 11 MeV/nucleon is bombarded. To cope with such a high power deposit, a rotating carbon foil stripper is under development now.

As the third stripper, 14 and 20 mg/cm^2 thick carbon plates are planned to be used for uranium and xenon beams, respectively. When a 3 pμA uranium beam is bombarded on the third stripper, the beam deposits approximately 3 kW power on the stripper, which corresponds to approximately 8% of its kinetic energy. A rotating carbon disk stripper was constructed in order to prevent a breakage of the stripper. Figure 2 shows a schematic drawing of the rotating carbon disk stripper. A 120 mm diameter carbon disk is rotated by an AC servo motor placed outside the vacuum chamber through a ferrofluid sealed rotary motion feedthrough. The maximum rotation frequency is 3000 rpm. An array of graphite plates is soldered to a water-cooled copper plate close to the carbon disk for absorbing the thermal radiation emitted from the carbon disk. The maximum temperature caused by a 3 pμA uranium beam was calculated by ANSYS to be 1549°C, which was sufficiently lower than the evaporating temperature of carbon. The geometrical thickness distribution of the disk was measured with a micrometer, and found that the thickness was uniform within 0.9%. Therefore, if the density of the carbon disk is uniform, the energy of the uranium beam is expected to vibrate approximately 0.07%, which is comparable to the 1σ energy straggling calculated by ATIMA in

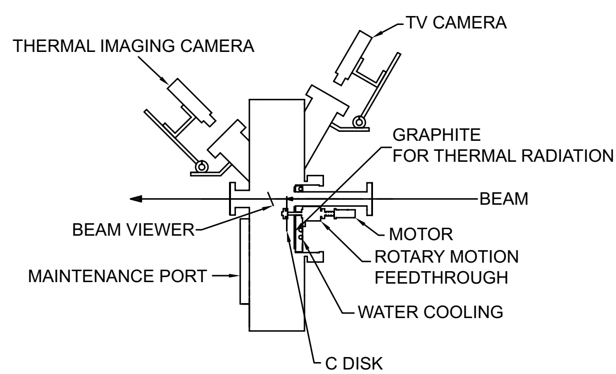

Figure 2: Schematic drawing of rotating carbon disk stripper.

LISE++ [9]. The 1σ angular straggling is expected to be 0.9 mrad [10]. A beam test was performed by a 0.1 pμA krypton beam at 46 MeV/nucleon, and no visible damage of the carbon disk was observed.

The thickness range of the fourth stripper is approximately the same as the second stripper, while the energy behind the fourth stripper is the same as the third stripper, the injection energy of the IRC. Therefore, the condition is rather moderate compared with the other strippers, so an ordinary carbon foil stripper is planned to be used. Another possible solution to the fourth stripper is a liquid film stripper [11].

CHARGE STATE FRACTIONS

Charge state fractions of ^{136}Xe and ^{86}Kr were measured at several energies changing the thickness of the stripping medium, a carbon foil, an aramid film, a polyimide film, or a rotating carbon disk of the rotating carbon disk stripper. Figures 3 and 4 show the charge state fractions of ^{136}Xe

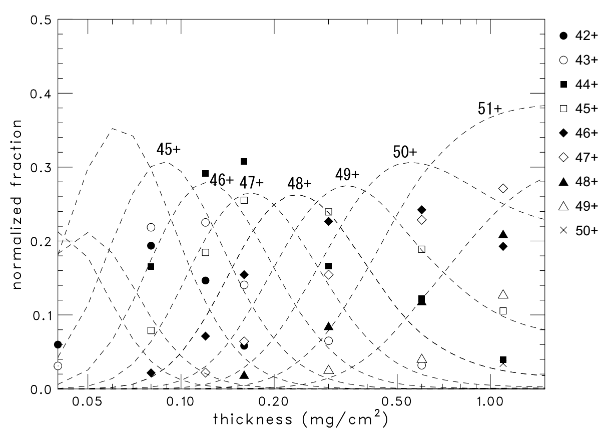

Figure 3: Charge state fractions of ^{136}Xe at 11 MeV/nucleon. Horizontal and vertical axes indicate the thickness of the strippers and the charge-state fractions, respectively. The charge-state fractions are normalized by the area of the Gaussian fitted to the measured charge state distribution. Dashed lines indicate the calculations by ETACHA [12].

at 11 MeV/nucleon and ^{86}Kr at 46 MeV/nucleon, respectively. The thicknesses of the second stripper for ^{136}Xe ions and the first and fourth strippers for ^{86}Kr ions were selected by the measured data. The charge state fractions were estimated also by the data. The GLOBAL calculations well reproduced the higher-charge state data in Fig. 4.

CONCLUSION

Charge stripping schemes of the RIKEN RI-beam factory were investigated. It is indispensable to use rotating strippers for the second and third strippers to achieve the objective intensity of the uranium beam, 1 pμA at 350 MeV/nucleon, so a rotating carbon foil stripper is under

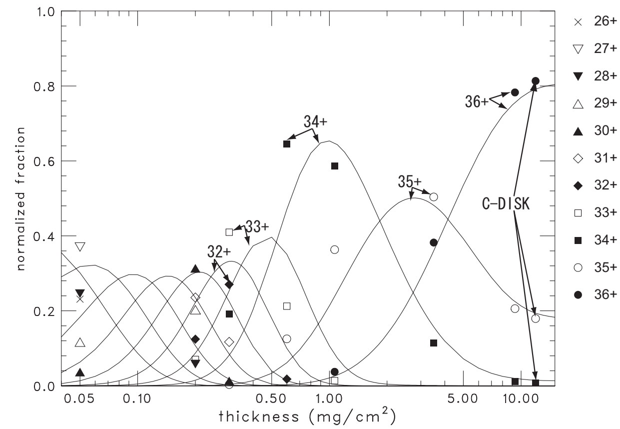

Figure 4: Charge state fractions of ^{86}Kr at 46 MeV/nucleon. Axes are the same as Fig. 3. The charge state fractions are normalized by the sum of the measured charge state fractions. Solid lines indicate the calculations by GLOBAL.

development as the second stripper, and a rotating carbon disk stripper was constructed as the third stripper. Charge state fractions of xenon and krypton ions were measured.

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