CHARGE STRIPPING PLAN OF THE RIKEN RI-BEAM FACTORY

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Abstract

In the RIKEN RI-beam factory, four stripper sections are under investigation. Typical charge stripping schemes and an overview of the strippers are described. Charge state distributions of ^{136}Xe stripped by carbon foils or polymer films were measured at 11 MeV/nucleon and 39 MeV/nucleon.

INTRODUCTION

The RIKEN RI-beam factory (RIBF) is an accelerator complex that consists of four cyclotrons (and an AVF cyclotron for lighter ion injection) and linacs together with four stripper sections. Ions from hydrogen to uranium are designed to be accelerated in order to observe wide range of new isotopes. Figure 1 shows the schematic of the RIBF. Accelerators of the RIBF are, 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) [1]. Four strippers are placed between, the accelerator and the decelerator of the CSM, the RRC and the fRC, the fRC and the IRC, and the RRC and the IRC, respectively. A typical objective of the beam on target is 1 pμA uranium at 350 MeV/nucleon.

CHARGE STRIPPING SCHEME

In the RIBF, four stripper sections are under investigation. The purpose of the first stripper section is to obtain sufficiently high charge state to be accelerated by the RRC. In the uranium beam case, the first stripper is planned to be used only in the commissioning stage of the RIBF, when the ion source provides an insufficient intensity of $^{238}U^{35+}$ beam. The second stripper is utilized for obtaining sufficiently high charge state to be accelerated by the fRC. The third stripper is the last stripper when the ions are accelerated with the fRC, which is used for obtaining sufficiently high charge states to be accelerated by the IRC and the SRC. When a beam extracted from the RRC is directly injected into the IRC without being accelerated by the fRC, the fourth stripper is employed in order to obtain sufficiently high charge states to be accelerated by the IRC and the SRC.

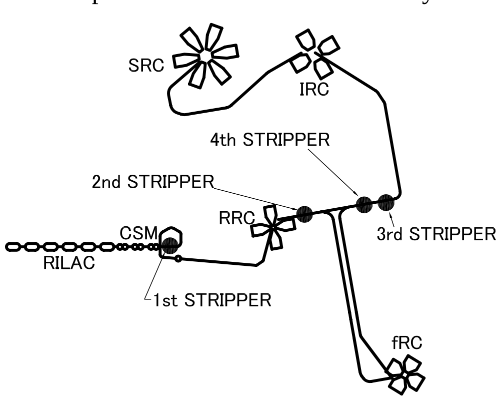

Figure 1: Schematic of the RIBF.

Two cases of typical charge stripping schemes, that ^{238}U, ^{136}Xe and ^{86}Kr ions are accelerated to 350 MeV/nucleon, are discussed here. The first case is that the injection radius of the IRC is fixed. The second case is that the injection radius of the IRC is upgraded to be adjustable to the beam energy.

Case1: IRC Has Fixed Injection Radius

Table 1 shows the parameters of the strippers for the RIBF when the injection radius of the IRC is fixed. In the commissioning stage when a sufficient intensity of $^{238}U^{35+}$ beam is not supplied from ion source, uranium beam is planned to be stripped to 36+ by the first stripper. The first stripper is planned to be a 0.025 mg/cm^2 thick carbon foil [2]. The charge state fraction is estimated to be 17% [3]. The $^{238}U^{35+}$ beam is accelerated by the RRC, and stripped to 72+ by the second stripper, a 0.5 mg/cm^2 thick carbon foil. The charge state fraction of $^{238}U^{72+}$ at 11 MeV/nucleon is expected to be 19%, which is assumed to be the same value as the charge state fraction of $^{238}U^{73+}$ at 11.4 MeV/nucleon stripped by a 0.49 mg/cm^2 thick carbon foil in Ref. [4]. The $^{238}U^{72+}$ beam is accelerated by the fRC to 51 MeV/nucleon, and injected into the third stripper, a 14 mg/cm^2 thick carbon plate. The third stripper is expected to strip the uranium ions to 88+ receiving 8% of kinetic energy. The charge state fraction of $^{238}U^{88+}$ is estimated to be 34% by a calculation code GLOBAL [4]. The extraction energy of the fRC was determined as the energy of the uranium beam behind the third stripper to be 46 MeV/nucleon, the injection energy of the IRC. The $^{238}U^{88+}$ beam is accelerated by the IRC, and then by the SRC to 350 MeV/nucleon.

In the same way as the uranium case except for the first stripper, a $^{136}Xe^{20+}$ beam is accelerated by the RRC, stripped to 44+ by the second stripper, a 0.15 mg/cm^2 thick carbon foil, and injected into the fRC. The charge state fraction of $^{136}Xe^{44+}$ at 11 MeV/nucleon was measured to be approximately 30% as described below. 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

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Table 1: Parameters of the strippers for the RIBF when the injection radius of the IRC is fixed.

	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 [2]	0.5 [4]	14 [4]	0.15	20 [4]	0.04	0.3
Expecting charge-state	36+	72+	88+	44+	52+	26+	33+
Fraction	17% [3]	19% [4]	34% [4]	30%	44% [4]	31%	41%

MeV/nucleon, the injection energy of the IRC. The charge state fraction of ^{136}Xe^{72+} stripped by a 20 mg/cm^2 thick stripper is also estimated by the GLOBAL calculation to be 44%.

The stripping scheme for a krypton beam is somewhat different from the uranium and xenon cases. It is rather advantageous not to employ the fRC in the krypton case. If the fRC was employed, the thickness of the third stripper would be 27 mg/cm^2 in order to degrade the energy to the injection energy of the IRC, that would superfluously deteriorate the emittance and the energy straggling. Krypton ions are 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, losing smaller amount of energy than the third stripper in order not to mismatch the injection energy of the IRC. The charge state fractions of ^{86}Kr^{26+} at 2.7 MeV/nucleon and ^{86}Kr^{33+} at 46 MeV/nucleon are measured values [5].

Case2: Injection Radius of the IRC Is Adjustable to the Beam Energy

Table 2 shows the parameters of the strippers for the RIBF when the injection radius of the IRC is upgraded to be adjustable to the beam energy. The stripping scheme for the uranium beam is the same as the first case. The stripping scheme for the xenon beam is also the same as the first case except for the third stripper. The thickness of the third stripper for the xenon beam was assumed to be the same as that for the uranium beam. The charge state fractions were estimated by the same bases as the first case.

In this case, a krypton beam is accelerated with the fRC, stripped only by the second stripper. According to a calculation code ETACHA [6], 38% of ^{86}Kr^{33+} ions are expected to be obtained by a 0.15 mg/cm^2 thick stripper.

STRIPPERS

Four stripper sections are mainly characterized by the energy of the beam. The beam intensity is naturally higher at the stripper section placed upstream than that placed downstream. An overview of the four strippers is presented in the following subsections.

First Stripper Section

Carbon foils in the thickness range from 0.02 mg/cm^2 to 0.1 mg/cm^2 are planned to be used as the first stripper. If the first stripper is employed to accelerate an ^{238}U beam of target intensity, approximately 90 pμA beam at 0.9 MeV/nucleon is injected into the first stripper, and the lifetime of the carbon stripper foil is expected to be approximately 1 min. [2, 7]. Therefore, for a uranium beam, the first stripper is planned to be used only in the commissioning stage, in 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 uranium beam on the first stripper is 0.65 MeV/nucleon, which makes the condition more severe. Krypton beam is also planned to be stripped by the first stripper in the first case, however the condition is rather mild because of the highness of the incident energy.

Second Stripper Section

The thickness of the second stripper is assumed to be in the range from 0.15 mg/cm^2 to 0.5 mg/cm^2. Typical beam incident on the second stripper is a 15 pμA uranium beam at 11 MeV/nucleon. When the uranium beam is stripped by a 0.5 mg/cm^2 thick carbon foil, the stripper foil receives 1 kW power, that easily evaporate the foil. A rotating carbon foil stripper is under development in order to enlarge the area from which thermal radiation is emitted.

Third Stripper Section

The third stripper receives approximately 8% of beam power. To cope with the high power deposited to the stripper, a rotating carbon disk stripper was constructed, see Ref. [5] for detail.

Fourth Stripper Section

The thickness range of the fourth stripper is almost the same as the second stripper, while the energy behind the stripper is the same as the third stripper in order to match the injection energy of the IRC. Therefore, the condition is rather moderate compared with the other stripper sections, so a still carbon foil is planned to be used. Another possible solution to the fourth stripper is a liquid film stripper [8].

Table 2: Parameters of the strippers for the RIBF when the injection radius of the IRC is adjustable to the beam energy. The fRC is employed in all cases.

Ion	^{238}U			^{136}Xe		^{86}Kr
Stripper section	1st	2nd	3rd	2nd	3rd	2nd
Energy (MeV/nucleon)	0.9	11	51	11	51	11
Required charge-state	35+	72+	88+	42+	51+	32+
Thickness (mg/cm^2)	0.025 [2]	0.5 [4]	14 [4]	0.15	14 [4]	0.15 [6]
Expecting charge-state	36+	72+	88+	44+	52+	33+
Fraction	17% [3]	19% [4]	34% [4]	30%	48% [4]	38% [6]

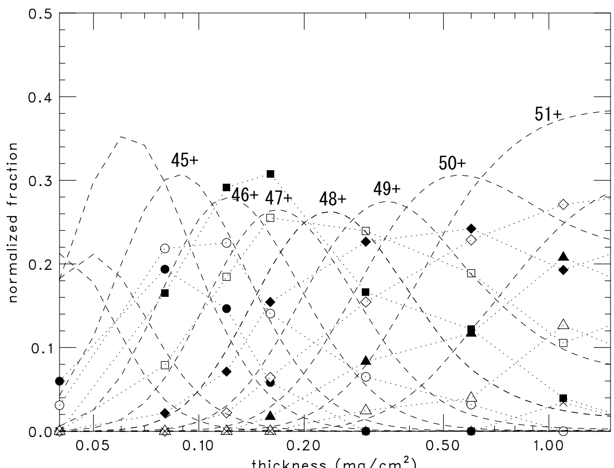

Figure 2: Charge state fractions of ^{136}Xe at 11 MeV/nucleon. Horizontal and vertical axes indicate the thickness of the strippers and the charge-state fractions, respectively. Solid circles, blank circles, solid squares, blank squares, solid diamonds, blank diamonds, solid triangles, blank triangles, and crosses indicate the measured charge-state fractions from 42+ to 50+, 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.

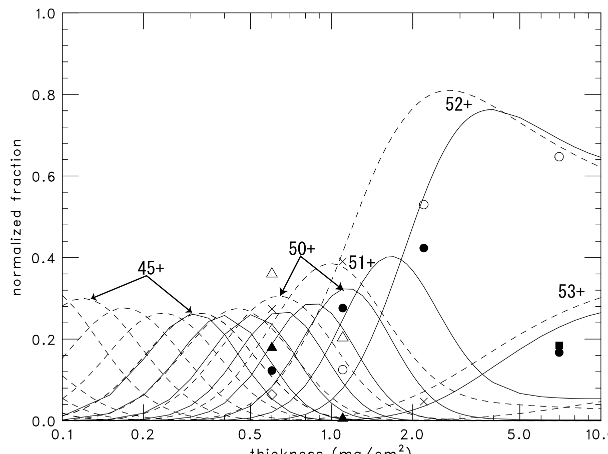

Figure 3: Charge state fractions of ^{136}Xe at 39 MeV/nucleon. Axes are the same as Fig. 2. Blank diamonds, solid triangles, blank triangles, crosses, solid circles, blank circles, and a solid square indicate the measured charge-state fractions from 47+ to 53+, respectively. The charge-state fractions are normalized by the area of the Gaussian fitted to the measured charge-state distribution. Solid and dashed lines indicate the calculations by GLOBAL and ETACHA, respectively.

CHARGE STATE FRACTIONS

Figure 2 and 3 show the charge state fractions of ^{136}Xe at 11 MeV/nucleon and 39 MeV/nucleon, respectively. A carbon foil, an aramid film or a polyimide film was used as a stripping medium. The thickness of the second stripper for the xenon beam is determined to be 0.15 mg/cm^2 by the data on Fig. 2. ETACHA and GLOBAL calculations are also drawn on the figures. The GLOBAL calculations well reproduced the higher-charge state data at 39 MeV/nucleon.

SUMMARY

Charge stripping schemes of the RIKEN RI-beam factory were investigated. Rotating strippers for the second and third stripper sections are indispensable in order to accelerate 1 pμA uranium beam to 350 MeV/nucleon. Charge state distributions of ^{136}Xe were measured at 11 MeV/nucleon and 39 MeV/nucleon.

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