Charge-state distribution measurements using gas charge stripper toward $^{238}\text{U}$ and $^{136}\text{Xe}$ acceleration at RIKEN RIBF

• Charge strippers at RIKEN RIBF
• Gas charge stripper
  - differential pumping system
  - offline pressure test
  - charge-state distribution measurements
• Results
• Summary
Collaborators


RIKEN Nishina Center
RIBF
(RI-Beam Factory)
RRC (RIKEN Ring Cyclotron)

RILAC (RIKEN Linear Accelerator)

fRC (fixed-frequency Ring Cyclotron)

IRC (Intermediate-stage Ring Cyclotron)

SRC (Superconducting Ring Cyclotron)
RIBF
(RI-Beam Factory)
Charge strippers at RIKEN RIBF

- $^{238}\text{U}$ and $^{136}\text{Xe}$ beams at 345 MeV/u

1 linear accelerator, 4 cyclotrons and 2 charge stripping sections

U beam acceleration

 Ion Source

- RILAC

1$^{\text{st}}$ charge stripper

$35^+ \rightarrow 71^+$

11 MeV/u

2$^{\text{nd}}$ charge stripper

$71^+ \rightarrow 86^+$

51 MeV/u

- Serious problems on 1$^{\text{st}}$ charge stripper (carbon foil 300 $\mu$g/cm$^2$)

**Problems**

- **short lifetime** → 12~24 hours@ U beam14 pnA (0.5 W)
- **energy spread** → $\Delta E/E = 0.55\%$ ($4\sigma$)
  
  (0.33% without charge stripper)
  
  → beyond the acceptance of rebuncher

Requirements: Toughness and uniform thickness
Gas charge stripper

- **long lifetime and uniform thickness**
- **lower charge state than solid materials**

Estimation of charge states in gas at equilibrium by empirical formulae:

All formulae are extrapolation from the data at low energy $< 1$ MeV/u

- Actual charge states are unknown
- Need to measure charge-state distributions
Gas charge stripper

- A gas charge stripper developed using a gas target system [1]


T. Kishida et al. NIM A438, 70 (1999).
Differential pumping system[1]

Gas is injected into stage 1

stage 6-2 → stage 5-2 \( P_{5-2} \)

- TMP3-2 220 L/s
- TMP2-2 550 L/s

stage 5-1 \( P_{5-1} \)

- TMP2-1 350 L/s
- TMP3-1 220 L/s

stage 4 \( P_{4} \)

stage 3 \( P_{3} \)

stage 2 \( P_{2} \)

stage 1 \( P_{1} \)

TMP1 1450 L/s

MBP2 600 m³/h

MBP1 1020 m³/h

14 cm

Cell length (stage 1) : 14cm
Gas is injected into stage 1

stage 6-2
stage 5-2 \( P_{5-2} \)

TMP3-2 220 L/s
TMP2-2 550 L/s
TMP1 1450 L/s

stage 4 \( P_4 \)
stage 3 \( P_3 \)
stage 2 \( P_2 \)
stage 1 \( P_1 \)

Orifice: 10 mm\( \phi \)
8 mm\( \phi \)
6 mm\( \phi \)
6 mm\( \phi \)

MBP2 600 m\(^3\)/h
MBP1 1020 m\(^3\)/h

stage 5-1 \( P_{5-1} \)
stage 6-1
beam

TMP2-1 350 L/s
TMP3-1 220 L/s

Cell length (stage 1): 14 cm
$N_2$ 7.7kPa ($1.3 \text{ mg/cm}^2$) was achieved under the vacuum interlock limit ($4 \times 10^{-3} \text{Pa}$) \cite{1}.
Thickness calibration\[1\]

Si detector (Canberra RF30*30–500EB)

Alpha source $^{241}$Am

Alpha particle (energy is deposited in gas)

Thickness vs $P_1$

MCA energy spectrum

<table>
<thead>
<tr>
<th>Channel</th>
<th>Counts</th>
</tr>
</thead>
<tbody>
<tr>
<td>670</td>
<td>0</td>
</tr>
<tr>
<td>680</td>
<td>10</td>
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<tr>
<td>690</td>
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<tr>
<td>780</td>
<td>110</td>
</tr>
<tr>
<td>790</td>
<td>120</td>
</tr>
</tbody>
</table>

MCA energy spectrum

(a) $N_2$

without gas (x0.5)

0.25 kPa

0.52 kPa

0.92 kPa

2.02 kPa

4.58 kPa

5.486 MeV

(b)

$N_2$

$Ar$

$CO_2$

Thickness vs $P_1$
Thickness calibration

Si detector

Alpha source $^{241}\text{Am}$

Alpha particle (energy is deposited in gas)

MCA energy spectrum

Thickness vs $P_1$
Energy at RRC exit: $U^{35+}$ or $Xe^{20+}$ 11 MeV/u

Faraday cup F41

Experimental setup


Gas charge stripper

Beam from RILAC

RRC

fRC
Setup of charge distribution measurement

Each charge state \( q \) was selected by bending magnets

\[
\text{fraction} \quad f = \frac{I_{F41}/q \text{ (pnA)}}{I_{D16}/q_{\text{ini}} \text{ (pnA)}}
\]

\( q_{\text{ini}} \): 35 for U and 20 for Xe
U\textsuperscript{56+} is not accepted by fRC acceleration. (acceptable charge state is 71+ or higher)
Xe charge state distribution[1]

![Graph showing charge state distribution for N₂, Ar, and CO₂ gases.]

- **Acceptable with fRC**
  - (lowest charge state is 41.)

- **Successful acceleration with gas stripper**

<table>
<thead>
<tr>
<th></th>
<th>Eq. charge</th>
<th>Eq. thickness (µg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>40.5</td>
<td>163</td>
</tr>
<tr>
<td>Ar</td>
<td>40.1</td>
<td>95</td>
</tr>
<tr>
<td>CO₂</td>
<td>40.3</td>
<td>139</td>
</tr>
</tbody>
</table>
Summary

- Serious problems with the carbon foil stripper at RIBF.
  1) short lifetime, 2) ununiform thickness.

- Gas stripper:
  - long lifetime
  - uniform thickness
  - low charge states

- A differential pumping system with $N_2$ gas thickness up to 1.3 mg/cm$^2$

- Charge-state distributions in the gas stripper with U and Xe beams at 11 MeV/u

<table>
<thead>
<tr>
<th></th>
<th>$N_2$</th>
<th>Ar</th>
<th>$CO_2$</th>
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</thead>
<tbody>
<tr>
<td>U</td>
<td>Eq. charge</td>
<td>56.0</td>
<td>56.6</td>
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<tr>
<td></td>
<td>Eq. thickness ($\mu g/cm^2$)</td>
<td>125</td>
<td>79</td>
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<tr>
<td>Xe</td>
<td>Eq. charge</td>
<td>40.5</td>
<td>40.1</td>
</tr>
<tr>
<td></td>
<td>Eq. thickness</td>
<td>163</td>
<td>95</td>
</tr>
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</table>

- $U^{56+}$ are not acceptable without a major remodeling of fRC.

- $Xe^{41+}$ are acceptable for acceleration by fRC.