A New Possibility of Low-Z Gas Stripper for High-Power Uranium Beam Acceleration as Alternative to C Foil

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Preview of the Talk

Introduction to RIBF

Upgrade programs to increase beam intensity of U ion

R&D works for charge stripper problem (C-foil on rotating cylinder and Gas (N₂))

Low-Z gas stripper
Introduction RIKEN RI Beam Factory (RIBF)

The Old Facility (1975~1990)

RIBF (1997~2012)

BigRIPS (Fragment Separator)
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The Old Facility (1975~1990)

RIBF (1997~2012)

The Chair of HB2010 with SRC
History of RIBF

1997: Construction started.

2003 March: The building for the accelerator was completed. Installation was started.

2005 Nov.: Successful Excitation of the superconducting sector magnets for SRC

2006 28th Dec: The first beam from SRC


Beam Intensities achieved so far (Goal 1 pμA)

- pol-d(250 MeV/u): 120 pnA: May2009 Mode 3
- \(^4\)He(320 MeV/u): 1000 pnA: Oct2009 Mode 1
- \(^{14}\)N(250 MeV/u): 80 pnA: May2009 Mode 3
- \(^{18}\)O(345 MeV/u): 1000 pnA: June2010 Mode 1
- \(^{48}\)Ca(345 MeV/u): 230 pnA: May 2010 Mode 1
- \(^{86}\)Kr(345 MeV/u): 30 pnA(<1min): Nov2007 Mode 1
- \(^{238}\)U(345 MeV/u): 0.8 pnA: Dec2009 Mode 2
Key issues to increase the intensity of U beam

- **Increase the beam intensity from the ion source**
  - New 28 GHz Superconducting ECR ion source
  - Goal intensity of U\(^{35+}\) >15 \(\mu A\) (1\(\mu A\) @ SRC)
  - Developments for U beam are in progress.

- **Improve transmission efficiency**
  - New injector (Efficient acceleration in the low energy region)
  - Avoid the emittance growth due to the space charge.

- **Make charge strippers with long lifetimes**
  - The 1\(^{st}\) stripper is critical.
  - Max. lifetime \(~12\) hrs @1000enA after RRC
  - R&D programs : Rotating, Gas
New 28 GHz Superconducting ECR ion source (Nakagawa et. al.)

Design:
- Flat $B_{\text{min}}$ configuration
- Large plasma volume: $1100 \text{ cm}^3$

Construction:
- Started in Oct. 2007
- Successfully excited to the designed field in October 2008.

Developments for U beam (18 GHz mode):
- Dec. 2008 : Installation
- April 2009-- : Start
- Nov. 2009 : U$^{35+}$ 10 euA (~5 times)

Move to the upstream of the New Injector:
- Finished (Summer 2010)

Upgrade to 28 GHz
- In progress (Autumn 2010).
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New Injector for RRC
$M/q=7,\ 680\ keV/u$

Fabrication of the main components was completed in FY2009.
New Injector (RILAC2) in the AVF room

Beam commissioning will start from Dec. 2010!
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Charge strippers in Uranium Acceleration

The 1\textsuperscript{st} stripper: Commercially available C-foils are usually used.

\begin{itemize}
  \item \textbf{Lifetime:} 12 hours (1.4 e\mu A)
\end{itemize}

The present intensity: No problem

The present intensity x 100: Serious Problem! \rightarrow much stronger strippers
R&D programs for the 1\textsuperscript{st} stripper (2008-)

**Carbon foil:**
Large Carbon foils on a rotating cylinder. 60 times longer lifetimes than that of the fixed foil.

**Gas stripper (N\textsubscript{2}):**
1. Free from lifetime related problems.
2. Lower equilibrium charge state $Q_e$. (density effect)
The first test of a rotating stripper (May 2008)

A foil on the rotating cylinder was tested in May 2008 => Broke shortly, 15 min
Rotation speed ~ 100 rpm
Slowly rotating (0.05 rpm) foil (Mar. 2010)

Before irradiation

38 hours @ 1.7 eμA => Survived!

However,..

- Intensity before the stripper (A01)
- Intensity after the stripper (D15)
Test of the gas stripper (Feb./March 2009)

- U beam: The average charge state with the gas stripper was far below the acceptable state for the fRC.
What can we do to get higher charge state in gas?

- Higher stripping energy
  - $Q_e$ measurements at (11), 14 and 15 MeV/u.
  - 22 MeV/u is necessary to get 69+ as $Q_e$.
    (cf. The present stripping energy is 11 MeV/u)
  - Huge remodel of the accelerators before and after the stripper.
    Such remodel will cost more than $10M.$
- Different material
  - Low-Z gas (H$_2$ and He)
Examples of charge state of U in He or N$_2$ (50 MeV/u)

Effective charge

Equilibrium charge state

NIMB 107 (1996) 9

NIM B 245 (2006) 32
Mechanism to get higher charge state

1: Equilibrium charge state $Q_e$ is determined by competition between e-loss and e-capture.

2: Capture cross sections strongly depend on the $V_p$ (ion velocity) compared with that of the target electrons.

3: e-Capture is highly suppressed due to bad kinematical matching when $V_p >> V_{1s}$ (the fastest target electron).

4: Suppression of e-capture is expected in the case of low Z region or higher ion velocity because $V_{1s} \sim Z/137$.

5: $Q_e$ will be higher in low-Z region.

<table>
<thead>
<tr>
<th>Case</th>
<th>Ion @ Energy (MeV/u)</th>
<th>Target</th>
<th>$V_p/V_{1s}$</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U @ 22</td>
<td>He</td>
<td>14.9</td>
<td>$Q_e$ (He) = $Q_e$ (Ar) + 16</td>
</tr>
<tr>
<td>2</td>
<td>U @ 55.5</td>
<td>$N_2$</td>
<td>6.8</td>
<td>$Q_e$ ($N_2$) = $Q_e$ (C) - 2</td>
</tr>
<tr>
<td>3</td>
<td>U @ 11</td>
<td>He</td>
<td>10.4</td>
<td>Similar to Case 1,2?</td>
</tr>
<tr>
<td>4</td>
<td>U @ 11</td>
<td>$N_2$</td>
<td>3.0</td>
<td>Not similar to Case 1,2?</td>
</tr>
</tbody>
</table>
A simple estimation of cross section for 1e-loss and 1e-capture

Loss: M. Gryzinski, Phys. Rev. 138 (1965) A305. (Binary Encounter Model)
Experimental Method

Beam from RILAC
U beam
11 MeV/u 35+
14 MeV/u 41+
15 MeV/u 41+

C foil

Qi+ selection
(60+ < Qi+ < 75)

\[ \sigma_{\text{capture}} = \frac{1}{t} \times \frac{I(Q_i - 1)}{\sum I(Q_j)} \]

\[ \sigma_{\text{loss}} = \frac{1}{t} \times \frac{I(Q_i + 1)}{\sum I(Q_j)} \]

\( t \) : thickness of gas cell

\( I(Q_i) \) : Current at F41
Electron capture and loss cross sections of U in He-gas were measured to estimate the equilibrium charge state.

Measured Results

Eq. Charge state in N$_2$: 56+ @ 11 MeV/u

Acceptable with fRC: 69+

66+ @ 11 MeV/u

73+ @ 14 MeV/u

75+ @ 15 MeV/u
Difficulty in accumulation of low-Z gas

The existing gas stripper: He $\sim 15 \mu g/cm^2$ (0.7 kPa)
(cf. $N_2$ 1.3 mg/cm$^2$)

$\sim 1$ mg/cm$^2$ of low-Z gas is necessary to be accumulated to get higher charge state.

$\rightarrow$ A new device to make it possible ...

Plasma Window (1995-)
Inventor: Ady Hershcovitch (BNL)
Plasma Window (Wall Stabilization Theory)

- **Cathode Holder**: (3x)
- **Anode**:
- **Insulator**:
- **3/8" Valve to Atmosphere**:
- **Gas Feed**:
- **Cathode**: (3x)
- **COOLING PLATES**:
- **TEFLON**:
- **To Roughing Pump**:
- **Valve**:
- **Box Pumped by Two Diffusion Pumps**:
- **VACUUM**:
- **Plasma by arc**: (15000K)
- **Atomosphere**:

**Diagram Description**:
- Plasma formation through an arc at 15000K within a vacuum chamber.
- Connections and components for gas feed, cathode, and insulator are highlighted.
- Valve connections to atmosphere and vacuum pump are also indicated.
Schematic sketch of the low-Z gas stripper using two plasma windows
R&D 1: Plasma Window (-March 2011)

R&D 2: Ar $\rightarrow$ He ($H_2$), $d = 2$ mm $\rightarrow$ 6 mm (2011)

R&D 3: gas cell with the two plasma windows for offline test (2012)
Review of the Talk

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Sextupole
Summary

- The operation of RIBF after the first beam was very successful from 2007 to 2010.
- The new 28 GHz superconducting ECR ion source and the new injector are now ready to increase intensity of uranium beam.
- Stripper problem is still open:
  - large foil on rotation cylinder, \( \text{N}_2 \) gas stripper.
- Low-Z gas stripper is one of the candidates.
- We believe that the plasma window may solve difficulty in accumulation of low-Z gas.
Measurements of Equilibrium Charge State in Low-Z Gas using a Long Gas Stripper (9/24-9/26)

\[ Q_e = 65^+ \] (He and H\(_2\))

\( 238\text{U}^{35+} \rightarrow \) \( \text{H}_2/\text{He} (7\text{m}, 10\text{torr}) \rightarrow \) \( 238\text{U}^{??+} \)

\[ \text{mean charge} \]

\[ \text{thickness [mg/cm}^2\text{]} \]

H. Imao et al. to be published