Status of an Electron Beam Ion Source for Charge Breeding for RISP

Young-Ho Park, Hyock-Jun Son, Jun-Young Moon, Seongjin Heo, Haolin Liu, Ramzi Boussaid, Jongwon Kim

RI Experimental Systems Team, Rare Isotope Science Project, Institute for Basic Science (IBS)
Contents

- Design parameter of EBIS at RAON
- Operation principle
- E-beam Simulation
- Electron Collector Design
- Electron gun Test
- Superconductor Magnet
- Vacuum system for EBIS Charge Breeder
- Works to be done this year
ECR-IS-1 (10 keV/u, 12 pμA)
LEBT1
RFQ1 (500 keV/u, 9.5 pμA)
MEBT1
SCL1 (~100 m)
• 18.5 MeV/u, 9.5 pμA

High intensity RI beams by ISOL & IF
• 35 kW ISOL: direct fission of \( ^{238}\text{U} \) by 70 MeV, 0.5 mA P
• 400 kW IF by 200 MeV/u, 8.3 pμA \( ^{238}\text{U} \)

High quality neutron-rich RI beams
• \( ^{132}\text{Sn} \) with up to ~250 MeV/u and 10^8 pps

More exotic RI beams by ISOL+IF

SCL2 (~380 m)
• 200 MeV/u, 8.3 pμA for \( ^{U^{+78}} \)
• 600 MeV, 0.66 mA for p

SCL3 (18.5 MeV/u, ~100 m)

High-E Exp. Facility (II)
- μSR
- Bio-medical Research (High-E)
- IF Target
- Fragment Separator
- Large Acceptance Spectrometer (High-E)

High-E Exp. Facility (I)
- Large Acceptance Spectrometer (High-E)
- High Resolution & Zero Degree Spectrometer

Post Accelerator
- Large Acceptance Spectrometer (Low-E)
- Recoil Spectrometer

Low-E Exp. Facility
- β-NMR
- Neutron Science Facility
- Bio-medical Research (Low-E)

Ultra-Low-E Exp. Facility
- High precision Mass Measurement
- Collinear Laser Spectroscopy

ISOL System
- ECR-IS-3
- High-E Exp. Facility (II)

Layout of RAON Facility

Driver Linac
- Charge Stripper

High-E Exp. Facility (II)
- Pre Sep
- RFQ CB
- ISOL Target
- Cyclotron (70 MeV, 0.75 mA)

IF system
- Gas Catcher
- IF Target
**EBIS: Design Parameter**

<table>
<thead>
<tr>
<th>Design parameters @ RISP</th>
<th>Electron beam current</th>
<th>Electron beam current density</th>
<th>Extraction beam energy</th>
<th>B-field in Trap region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 ~ 3 A</td>
<td>500 A/cm²</td>
<td>10 keV/u</td>
<td>6 T</td>
</tr>
<tr>
<td>A/q</td>
<td>Capacity</td>
<td>Breeding time</td>
<td>Breeding efficiency</td>
<td></td>
</tr>
<tr>
<td>&lt; 6</td>
<td>~ 10⁸ ions/bunch</td>
<td>50 ~ 100 ms</td>
<td>15 % for ¹³³Cs²⁷⁺</td>
<td></td>
</tr>
<tr>
<td>Repetition rate</td>
<td>Pulse width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>~ 10 Hz</td>
<td>10 ~ 20 µs</td>
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EBIS: Charge Breeding Process

Main parameters for charge evolution
- Electron beam energy
- Electron beam current density

\[
\frac{dN_i}{dt} = \frac{J_e}{e} \left( N_{i-1} \sigma_{i-1}^{EI} f_{e,i-1} - N_i \sigma_i^{EI} f_{e,i} \right) \\
+ \frac{J_e}{e} \left( N_{i+1} \sigma_{i+1}^{RR} f_{e,i+1} - N_i \sigma_i^{RR} f_{e,i} \right) \\
+ n_0 \left( N_{i+1} \langle \nu \sigma_{i+1}^{CX} \rangle - N_i \langle \nu \sigma_i^{CX} \rangle \right) \\
- N_i R_i^{Esc}
\]
EBIS: Charge Breeding Simulation (CBSIM)

Electron Beam Energy : 20 KeV
E-Beam Current : 3 A
E-beam Current Density : 493.5 A/cm²

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<td>$^{132}\text{Sn}$, $^{142}\text{Xe}$, $^{95}\text{Sr}$, $^{15}\text{O}$, $^{126}\text{Al}$</td>
<td>3 π mm mrad</td>
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Breeding time: 61 ms

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Breeding time: 61 ms
EBIS: Electron Beam Simulation (TRAK)

Within ion trap region
- Electron beam radius: 0.45 mm
- Electron beam current density: 500 A/cm²
- Longitudinal B-field: 6T
EBIS: Electron Collector Design

Electron dump simulation

Collector cut view

<table>
<thead>
<tr>
<th>Dissipated Power</th>
<th>Flow Rate (kg/s)</th>
<th>Flow Rate (liter/min)</th>
<th>Temperature Rise (℃)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 kW</td>
<td>1.0</td>
<td>60</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>48</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>36</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>0.4</td>
<td>24</td>
<td>9.0</td>
</tr>
</tbody>
</table>

- E-beam simulation was performed with TRAK code.
- Collector design was verified based on the simulation.
- Distribution of the power deposit on the inner surface of collector was calculated.
- Collector dimension, the repeller position, and the repeller voltage were tuned to achieve as small power density on the surface as possible.
EBIS: Electron Dump (Collector) Water line
EBIS: Electron Dump (Collector) Magnetic shield

- Materials: OFHC, Stainless Steel *(STS 316L)*, Soft iron
- Connection method: All vacuum brazing
- Cooling Power: >15 kW
- Flow rate: ~ 25 L/min
- Parallel four water lines at the cylinder surface
- One water line at the front
- Cross section of water line: 6X12 mm²
- Material: OFHC
Electron Gun

E-Gun Cathode Diameter: 5.6 mm
Cathode Material: IrCe
E-Beam Current: 3 A
Current Density at Cathode: 12 A/cm²
Magnetic Field at Cathode Surface: 0.2 T

Manufacturer: BINP (Russia)
EBIS: Electron Gun Test

- **E-Gun Solenoid**
- **Collector Solenoid**
- **E-Gun**
- **Drift Tube**
- **Collector**
EBIS: Electron Gun Test
EBIS: Electron Gun Test

<table>
<thead>
<tr>
<th></th>
<th>$I_{\text{emission}}$</th>
<th>$I_{\text{collection}}$</th>
<th>Pulse width</th>
<th>Duty cycle</th>
<th>$V_{\text{anode}}$</th>
<th>$I_{\text{anode}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6 mm cathode</td>
<td>2 A</td>
<td>2 A</td>
<td>40 ms</td>
<td>40 %</td>
<td>12.5 kV</td>
<td>15~60 mA</td>
</tr>
<tr>
<td>4.2 mm cathode</td>
<td>3 A</td>
<td>3 A</td>
<td>Sawtooth mode</td>
<td>25 %</td>
<td>14 kV</td>
<td>2 mA</td>
</tr>
<tr>
<td></td>
<td>2.3 A</td>
<td>2.3 A</td>
<td>50 ms</td>
<td></td>
<td>13 kV</td>
<td>&lt; 2 mA</td>
</tr>
</tbody>
</table>
EBIS Charge Breeder

- Electron Gun
- SC Solenoid System
- Diagnostic System
- Switchyard
- Drift Tube Section
- Electron Collector
- Ion Injection/Extraction Chamber
Superconductor Magnet

- Magnetic Field: 6T
- Warm Bore: 8"
- Cyrocooler: 1.5W
- Current: 96.3 A
- Homogeneity: 0.4%
Superconductor Magnet: Inhomogeneity

Field along centre axis of Magnet: $r = 0.0 \text{ mm}, 0^\circ$

- Magnetic Field (T)
- Distance from centre of magnet (mm)
- Cold Head End, Service End

Graph showing the magnetic field along the center axis of the magnet at $r = 0.0 \text{ mm}$ and $0^\circ$. The field is plotted against the distance from the center of the magnet, with specific lines indicating the ±4% and ±0.4% tolerances.
Superconductor Magnet Control Program

Switch Heater
- SC Switch Voltage: -0.001 V

Temperature Monitor
- (C) 41.34 K
- (D) 4.23 K
- (G) 51.82 K
- (E) 57.18 K
- (F) 55.04 K

Helium Level Monitor
- Output Power: 1.052 W
- LHe Level: 100%

Power Supply
- Current Output
- Measured Voltage: 0.007 V
- Voltage Setting: 0 V
- Measured Current: 0 A
- Current Setting: 0 A

Hall Probe IC
- Magnetic Field: 0.0000 T
- Solenoid Current: 0.000 A
- Hall IC Voltage: 2.4742 V

Magnet Auto Control
- Target Current: 0.00 A
- SC Switch Voltage: 1.70 V
- Time left: 00:00:00

Location of sensors and operational temperature
- (A) Bottom of magnet (4-5 K): 0.00 K
- (A) Shield end-plate (Service turret 50-65 K): 57.18 K
- (B) Top of magnet (4-5 K): 4.25 K
- (F) Shield end-plate (cold head 50-65 K): 55.04 K
- (C) Cold head 1st stage (40-60 K): 41.34 K
- (G) Thermal link (40-60 K): 51.82 K
- (D) Cold head 2nd stage (4-5 K): 4.23 K
- (H) Inside superconducting switch (4-12 K): 4.18 K
Superconductor Magnet : Energizing

1. PS output voltage
2. Actual solenoid current
3. Voltage across the SC switch

1. Temperature inside switch heater
2. Pressure stabilizer power
3. Pressure inside LHe vessel

1. Top of the solenoid
2. Cold head 1st stage
3. Cold head 2nd stage

1. Shield end (Service turret)
2. Shield end (Cold head)
3. Thermal link
Superconductor Magnet : Energizing

1. **Ramping Time [h]** vs. **SC Switch Voltage (V)**
   - Ramp Down
   - Ramp Up
   - Graph shows the relationship between ramping time and switch voltage.

2. **Pressure after run-up against solenoid voltage**
   - Graph illustrates the pressure response to different solenoid voltages.

3. **Self-heating operation**
   - Graph depicting temperature vs. switch voltage.
   - Meam value = 280.5

4. **Inductance (H)** vs. **SC Switch Voltage (V)**
   - Graph showing inductance changes with voltage.

- Alignment, High vacuum, High voltage
Ion Trap Section: Chamber Baking
Vacuum System

E-Gun

SC Solenoid

NEG ZAO disk

NEG pump

Cryo-Pump #1

Cryo-Pump #2

Cryo-Pump #3

TMP #1

TMP #2

TMP #3

Control Unit

He compressor

Cryopump

1st Baking Pump (TMP)

Compression Ratio (Mg): 2x10^4

2nd Baking Pump (Dry Pump)

Ultimate vacuum: 8x10^-11 Torr
<table>
<thead>
<tr>
<th>Staged vacuum test</th>
<th>Final pressure (Gauge 01 / 02)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1st stage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMP only</td>
<td>1.42E-09 / 1.84E-09 torr</td>
<td>150°C, 72hBaking</td>
</tr>
<tr>
<td>Tandem TMP system &amp; Cryopump</td>
<td>1.21E-09 / 9.96E-10 torr</td>
<td></td>
</tr>
<tr>
<td>Chamber Baking</td>
<td>3.66E-10 / 6.72E-10 torr</td>
<td>150°C, 72h Baking</td>
</tr>
<tr>
<td><strong>2nd stage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After 1st Baking (450°C)</td>
<td>8.89E-11 / 1.45E-10 torr</td>
<td>450°C, 78h Baking</td>
</tr>
<tr>
<td>After 2nd Baking (550°C)</td>
<td><strong>3.60E-11 / 2.08E-11 torr</strong></td>
<td>550°C, 143h Baking</td>
</tr>
</tbody>
</table>
Ion Injection/Extraction Line

Acceleration Tube

Einzel Lens & Steerer

Switchard

Collector

Extraction Electrode

Einzel Lens & Steerer
EBIS Floor plan at Korea University

- E-gun/Collector section
- DT section
- Clean booth
- Test ion source
- Isolation Transformers
- Chiller
- Door
- 5 Gauss 영역
Cooling Water

Chiller (20RT)
- W x L x H: 1000 x 2070 x 1752
- Cooling Power: 65.11 kW
- Flow Rate: ~200 LPM

Collector Coil
열량: 20 kW
유량: 28 L/min

Steering Coil
열량: No data
유량: No data

Gun Coil
열량: 3.8 kW
유량: 7.5 L/min

Cry.P. He Comp #1
열량: 6 kW
유량: 7 L/min

Cry.P. He Comp #2
열량: 6 kW
유량: 7 L/min

Cry.P. He Comp #3
열량: 2.6 kW
유량: 3.8 L/min

SC He Comp
열량: No data
유량: 5.7 L/min

Collect or Power Supply
열량: No data
유량: 8 L/min
Power Supply System

- Power Supplies #1
  - E-gun & Collector section
  - DT section

Voltage Distribution

- Anode, 15
- DT#1, 14
- DT#2, 12
- DT#3, 10
- DT#4
- DT#5
- DT#6
- DT#7
- DT#8, 10
- DT#9, 6
- DT#10, 4
- Collector, 0
- Cathode, -6
- Repeller, -12
Test Ion Source

- Test ion source
  - Cs+1 이온 소스
  - 제작 완료

- Power Supplies - Test ion beam line part #1

- Emittance (RMS)
  - $8.5 \, \text{mrad} \cdot \text{mm}$

- Emittance (Normalized)
  - $XX' : 0.00876 \, \text{mrad} \cdot \text{mm}$

- Average Energy : 26.84 [keV]
Test Ion Source
Beam Diagnostics

**CCD Camera**
- CCD Size: 2/3”
- Resolution: 2448X2048
- Pixel Size: 3.45X3.45um²

**Zoom Lens (1X)**

**Mask**
- Aperture size: 40 mm
- Hole sep/size: 1 mm / 20 um
- Tantalum

**MCP Active Area**: 40 mm
**Mask-MCP Sep**: 17-60 mm

**Faraday Cup**
- Aperture size: 47mm
Detailed design of EBIS CB was finished.
Superconductor Magnet was procured.
Test ion source is being built.
Beam diagnostics (pepperpot, FC) were manufactured.
Vacuum conditioning of DT chamber was performed.
Electron beam extraction test was performed. The anode structure will be improved.
Injection/extraction beam line and ToF charge state analyzer will be manufactured soon.
Hope we will be able to perform the 1st charge breeding experiment at the end of this year.
Thank You!