Progress of Superconducting ECR Ion Sources at IMP


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Outline

• Review of SECRAL works
• Recent work with SECRAL source
  ▪ Intense metal beam production
  ▪ Operation status report
• SECRAL II project
• Summary
Main Features

- Frequency: 18-24 GHz
- Magnet: Reverse configuration
- 3 axial solenoids providing mirror fields: 3.7 T, 0.8 T, 2.2 T
- Mirror length: 420 mm
- Sextupole field at chamber inner wall: 2.0 T
- Warm bore size: Ø140 mm
- Plasma chamber: Max. Ø126 mm ID
- Plasma volume: 5.2 L/4.8 L
- Max. extraction HV: 25 kV
- LHe: external recondensation system

Microwave:

- 18 GHz: 3.0 kW Max. available
- 24 GHz: 7.0 kW Max. available

Available in 2005 and used for operation in 2007
Gaseous Beam Production (Xe)


- Better confinement
- Large plasma volume
- Frequency effect

L Sun, ICIS’13, Chiba, 8-13, Sept. 2013, Slide 4
Needs of Metallic Beams

- High accuracy exotic isotopes’ mass measurement
- Nuclei synthesis
- $^{48}\text{Ca}$, $^{58,60}\text{Ni}$, $^{92}\text{Mo}$, $^{76}\text{Ge}$, $^{82}\text{Se}$, $^{112}\text{Sn}$...
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**Pie Chart:**
- Metallic ion beams: 54.66%
- Gaseous ion beams: 45.34%

**Legend:**
- SSC
- SFC

**SECERAL Beam Time**
Metallic Beam Techniques

• Micro-oven
  ■ Resistor Oven
    » Be, Ca, Sn...
  ■ Low Temperature Oven
    » Se, Pb, Bi...
  ■ High Temperature Oven
    » Ti, Ge, U...

• MIVOC

• Sputtering
  » U, Ta, Mo...
Beams with Resistor Oven

$^{112}\text{Sn MP}$: $232 \, ^\circ\text{C} (505\text{K})$

Main production temp.: $1100 \, ^\circ\text{C}$

- Average 50 eµA $^{112}\text{Sn}^{26+}$, 61 days continuous operation $\rightarrow$ 450-500 euA beam accumulation in CSRm;
- Average material consumption rate 1.4 mg/hr.
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Low Temp. Oven (LTO)

- Al₂O₃ crucible
- Watt-Flex Cartridge Heater
- Vapor

Based on LBNL Cartridge Oven Concept

- Temp.: 800°C Max., continuous control
- Capacity: Ø 7mmX12 mm crucible → >2 g Max. for Bi grains
- No liquid metal spilling
Intense Bi Beams

SECRAL: 3.7 kW/24 GHz + 1.3 kW/18 GHz

<table>
<thead>
<tr>
<th>Q</th>
<th>SECRAL-24GHz (euA)</th>
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<tbody>
<tr>
<td>30</td>
<td>422</td>
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<tr>
<td>31</td>
<td>396</td>
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<td>32</td>
<td>346</td>
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<td>33</td>
<td>270</td>
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<tr>
<td>34</td>
<td>200</td>
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</tbody>
</table>

- Sufficient metal vapor delivered
- High 24 + 18 GHz rf power heating

330 eμA Bi\(^{31+}\)
H: 0.15 π.mm.mrad
V: 0.21 π.mm.mrad
Intense Bi Beams

Bismuth Beam Records with SECRAL

- More metal vapor
- Higher RF power

1.6 kW Max. of 18+14.5 GHz
Intense Bi Beam

115 eμA Bi^{31+}

0.14 μm

330 eμA Bi^{31+}

0.15 μm

0.16 μm

0.21 μm
Intense Bi Beam

Start point: $^{209}\text{Bi}^{31+} = 329 \text{euA}$
$\text{Io} = 10 \text{mA}, 4.0 \times 10^{-7}, 7.4 \times 10^{-8}$

End point: $^{209}\text{Bi}^{31+} = 331 \text{euA}$
$\text{Io} = 9.5 \text{mA}, 4.3 \times 10^{-7}, 8.2 \times 10^{-8}$

3 hours continuous test

rf: 24GHz + 18GHz
Pw = 3.4kW + 0.3kW, HV = 23kV, Slits = 20mm
OVEN: 10.9V * 6.5A, 11.0V * 6.0A
LTO Limits

Limits:
- Higher temperature oven → more intense Bi\(^{30+}\)...
- Copper holder cannot work in high temperature for long time without cooling
- Biased disk needs better cooling at high µW power

![Photo of Inj. Baffle]

![Graph: Bi\(^{30+}\) beam intensity evolution vs. RF power]

- >600 eµA
Off-line test reached 2000°C with heating current of ~200 A
First On-line Test with HTO

Troubleshooting:
- Insufficient heat shielding
- Lawrence force

- W lead was bent
- Ta cap was melt

Over-heating on Inj. Baffle

Breakdown point

 Electric power (W)

 temperature (°C)
Lawrence Forces

24 GHz WG

Contribution of $B_r$, $B_\theta$ and $B_z$

Bent

Twisted
U beams with Sputtering

Isotope effect - $^{238}\text{U}^{33+}$ beam current

- 16O gas
- 18O-gas

$7.5 \text{ mg/h, ionization ratio } \sim 6.9\%$

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Frequency Effect

Beam intensity vs. mW power

80 euA @18 GHz \rightarrow 142@24 GHz (extrapolated)/140 eμA, Matched!!
Mo beams with Sputtering

Ø10 mm Natural Mo rod

Sputtering: @18 GHz/1.5 kW, 30 eμA Mo beam, Q: 21+~22+
Micro-oven with MoO₃ material is probably better solution: G. Machicoane, WedP16
Operation Status-2013

- **SECRAL**: intense highly charged heavy ion beams
- **LECR3**: medium charge state ion beams (< Kr)
- **LAPECR1**: intense light ion beams
Operation Data - 2013

Total operation time: ~13,230 hours

<table>
<thead>
<tr>
<th>Year</th>
<th>SECRAL</th>
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<tbody>
<tr>
<td>2007</td>
<td>759</td>
</tr>
<tr>
<td>2008</td>
<td>960</td>
</tr>
<tr>
<td>2009</td>
<td>1641</td>
</tr>
<tr>
<td>2010</td>
<td>1947.5</td>
</tr>
<tr>
<td>2011</td>
<td>2848.5</td>
</tr>
<tr>
<td>2012</td>
<td>3616.5</td>
</tr>
<tr>
<td>2013</td>
<td>1454.5*</td>
</tr>
</tbody>
</table>
HIRFL Operation Scheme

- ECRIS + SFC
- ECRIS + SFC + SSC
- ECRIS + SFC + CSRm (CSRe)
- ECRIS + SFC + SSC + CSRm
- SCECR + LINAC + CSRm
CSR-LINAC Project

SECERAL II

RFQ

KONUS-DTL

HEBT

→CSRm

4 keV/u

300 keV/u

108.48 MHz

7/14 MeV/u

108.48/216.96/

325.44 MHz

<table>
<thead>
<tr>
<th>A/q</th>
<th>3~7 ((^{238})U(^{34+}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>108.48/216.96/(325.44 ) MHz</td>
</tr>
<tr>
<td>Kinetic energy</td>
<td>7(14) MeV/u</td>
</tr>
<tr>
<td>Pulsed Beam current</td>
<td>&gt;1puA → ECR &gt;2 puA</td>
</tr>
<tr>
<td>Beam repetition rate</td>
<td>1~30 Hz</td>
</tr>
<tr>
<td>Beam pulse duration</td>
<td>0.1~3 ms</td>
</tr>
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</table>
SECRAL II

Parameters | Value
--- | ---
$\omega_{rf}$ (GHz) | 18-28
Axial Field Peaks (T) | 3.7 (Inj.), 2.2 (Ext.)
Mirror Length (mm) | 420 mm
No. of Axial SNs | 3
$B_r$ at Chamber Inner Wall (T) | 2.0
Coldmass Length (mm) | ~810
SC-material | NbTi
Magnet Cooling | LHe bathing
Warmbore ID (mm) | ~142
Chamber ID (mm) | ~126
Dynamic cooling power (W) | ~5
SC-wire

- WST Inc. SC-wire: rectangular
- Monolith type NbTi/Cu
- Insulated size 1.28 mm × 0.83 mm
- Cu/Sc ratio: 1.3:1
- No. of Filament: 630

Loading factor

INJ. 91.1%
EXT. 82.4%
SEXT. 87.8%

Factor similar to SECRAL
Coil Winding

SECRAL II Coldmass

- 3 of 6 sextupole coils are available
- Axial solenoids are available, and tested to 115% design current (limited by current power supply)

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Summary

- Metallic ion beams are more attractive beams for modern heavy ion accelerators, but the main limitation is the technique to produce sufficient vapor;
- Resistor HTO if desired to support long term continuous operation, Lawrence force problem must be solved;
- 3rd generation ECRIS is powerful, but we still know little about it.
Thanks !!