Thin liquid lithium targets for high power density applications: heavy ion beam strippers and beta beam production

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Outline

- Liquid Lithium Stripper idea for FRIB
- Brief theory of film stability
- Hardware description
- Status before FRIB
- Improvements for FRIB
- E-beam thickness measuring system
- Thickness measurement results
- Next Steps
- Beta-beams
Liquid Lithium Stripper for FRIB:

Advantages

- High charge state
- High velocity flow ~60 m/s
- High heat capacity of Li
- Absorbs power deposited by the heavy ions
  - $P \sim 600 \text{ W to } \sim 1000 \text{ W}$
  - $\Delta T \sim 150 \text{ to } \sim 420 \text{ °C}$
- May have unlimited lifetime
CD-1 Conceptual Design – [2]
Concept for FRIB Thin Liquid Lithium Stripper Film

Problem:
Develop high velocity, smooth, stable lithium film-10 microns thick as a charge state stripper for intense uranium beams.

Parameters:
- Beam current: 1.5 particle microamps.
- Beam diameter: 1 mm
- Power deposited: ~500W
- Flow velocity: ~60 m/s
- Peak temperature rise: ~400 °C.
Introduction

- Development of a thin liquid lithium film is divided into three steps:

1. Experimentally develop a liquid thin film formation scheme,

2. Experimentally develop a film stability diagram for the film production scheme using water & a fluorocarbon liquid,

   This diagram will provide the range of design parameters, such as film thickness and velocity, that are potentially capable of producing a stable, smooth liquid lithium film.

3. Experimentally demonstrate formation of a thin film liquid lithium jet and confirm that the film is appropriate to be used as a stripper (thickness, film stability, size, and velocity etc).
Introduction

Approach to thin film production

- Forces on flowing Li film in vacuum:
  - Inertia (IF)
  - Surface tension (SF)
  - Viscosity (VF)
- Reynolds number (Re) ~ IF/VF
- Weber number (We) ~ IF/SF
- Empirically determine film stability in We vs Re plane

Figure 1. Schematic Representation of Stability Diagram for the Jet in Vacuum.
Introduction

Approach to thin film production

- Forces on flowing Li film in vacuum:
  - Inertia (IF)
  - Surface tension (SF)
  - Viscosity (VF)

- Reynolds number (Re) ~ IF/VF

- Weber number (We) ~ IF/SF

- Empirically determine film stability in We vs Re plane

- Use water & fluorinert to scope stable region

Demonstrate film in lithium
Thin film formation scheme & parameters

- Critical design parameters
  - Determined based on these 1st and 2nd phase experiments.

- Drive pressure > 6 MPa (for > ~150 m/s Li jet)
- Angle of incident = 30 – 45 degree
- Distance as small as possible (< ~1 cm)
- Nozzle diameter = ~0.5 mm
- Position adjustment accuracy of ~0.1 mm
- Temperature > ~ 200 °C
- Vacuum < 10^-4 Pa
Schematic of Lithium System

- Viewport for Level Check
- Nozzle Adjuster
- Vacuum Chamber
- Nozzle
- Deflector
- To Vacuum Pump
- To High Pressure Gas Supply
- Pressure Vessel
- 1/2 in. tubing
- 1 in. tubing
Old Li Stripper System
Approximate size of lithium stripper system
liquid lithium thin film
liquid lithium thin film
Record rate = 6,300 fps
Playback rate = 29.97 fps
Drive pressure = 2.8 MPa
Nozzle $\phi = 0.5$ mm
Changes for FRIB

- New nozzle assy
- New upper vessel
- Pressure Vessel
- To High Pressure Gas Supply
- Viewport for Level Check
- Nozzle Adjuster
- Vacuum Chamber
- Deflector
- Viewport
- To Vacuum Pump
- 1/2 in. tubing
- 1 in. tubing
New Li Stripper Vessel
New Upper Vessel

- Upper vessel provides many ports to study and diagnose the liquid film
- View ports for visual observation
Film formation issues

- 3 fundamental issues

1. Effects of nozzle inlet and outlet design
2. Orifice design, material, and finish
3. Deflector design and finish
Nozzle development

- Effects of nozzle inlet and outlet design

Orifice=20 mil, Outlet=55 mil

Orifice=20 mil, Outlet=20 mil

20 mil Al2O3
File:100-265

20 mil SS
File:100-275

10 psi
Nozzle development

- Orifice design, material, and finish

1. Well defined orifice
2. Stainless steel, orifice
3. Three-piece design

![Clean sharp edge](image1)
![Rough edge](image2)

40-40 mil SS X
40-40 mil SS (2)

40-40 mil SS X
File:100-452

40-40 mil SS (2)
File:100-528

20 psi
Deflector Issues

Old deflector

- Liquid flows down to the lowest point (impaction point) and drips.
- Impaction point

Puddle formation around impaction point.

Droplets falling from the lowest point, interfering film.

New deflector

- Liquid flows down to the lowest point (edges) and drips, while film forms at impaction point.
- Impaction point

Small puddle formation near impaction point, most liquid draining to edges.

Droplets falling from the lowest points (edges), away from film.

Li Film
4-Profile Deflector With Wicks

1 µ diamond polish on face and both sides of knife edge

Stainless steel mesh wicking to “pull” Li from deflector face and reduce puddling

Stainless steel wire to guide Li droplets down and away from film
EMS system and operation

- System layout

<table>
<thead>
<tr>
<th>Instruments</th>
<th>e-gun power supply</th>
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<tbody>
<tr>
<td>(Bias HV supply)</td>
<td></td>
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</tbody>
</table>

- Faraday cup
- Nozzle
- Deflector
- Focusing coil
- Li film
- Bending magnet
- Vacum chamber

Existing Li system

Kimball Physics Inc.
- EMG-4212/EGPS-4212
- 1 keV to 30 keV
E-GUN SYSTEM INSTALLED ON LI VESSEL
FARADAY CUP
CUSTOM LASER ALIGNMENT DEVICE HELPS POSITION DEFLECTOR

Deflector

Wick Structures

Alignment Laser Beam Spot
Electron Beam Alignment

- The electron beam gun is aligned at the position of the lithium film with the temporary installation of a phosphor screen.
E-BEAM ON PHOSPHOR SCREEN (looking through ion beam port)
REAL TIME REMOTE S-VIDEO SCREEN IMAGES
4 MULTI-MEGAPIXEL DV CAMERAS
REAL TIME REMOTE S-VIDEO SCREEN IMAGES
4 MULTI-MEGAPIXEL DV CAMERAS
Stripper Chamber Vacuum Level

![Graph showing Chamber pressure and Valve position (1=open) over time. The x-axis represents time in minutes (10, 19, 29), and the y-axis represents vacuum in Torr (1.0E-07 to 1.0E-05).]
Operating conditions, experimental parameters

- Orifice opening diameter = 0.5 mm
- Angle of incidence = 52 degree
- Distance as small as possible
- Temperature > ~ 200 °C
- Vacuum < 10⁻⁴ Pa (10⁻⁶ Torr)
- Runtime <~30 min

Drive pressure ~1000 (690-1380) kPa

<table>
<thead>
<tr>
<th>Operation parameters</th>
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<tr>
<td>Li temperature</td>
<td>220 °C</td>
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<tr>
<td>Drive pressure</td>
<td>550 - 1380 kPa</td>
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<tr>
<td>Estimated Li velocity</td>
<td>46 - 73 m/s</td>
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<tr>
<td>Angle of incidence</td>
<td>52±0.2 °</td>
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<tr>
<td>Nozzle size</td>
<td>14.3 mm</td>
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<tr>
<td>Orifice opening size</td>
<td>0.5 mm</td>
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<tr>
<td>Deflector type</td>
<td>Type 1 &amp; 2</td>
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</tbody>
</table>
Thicknness Measurement Result

- $632 \pm 35 \, \mu g/cm^2$
- $\pm 5.5\%$ for 1 mm spot diameter
- Physical thickness $12.3 \pm 0.7 \, \mu m$
Next Steps

1. Ion beam on Li film
2. dc ~110 mA ion source from LANL
3. 75 keV
4. ~1kW to be deposited in Li film
Beta-beams

Very preliminary discussions with beta-beam collaboration