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DISCLAIMER

DEVELOPMENT OF STRIPPER OPTIONS FOR FRIB*

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Abstract

The US Department of Energy Facility for Rare Isotope Beams (FRIB) at Michigan State University includes a heavy ion superconducting linac capable of accelerating all ions up to uranium with energies higher than 200 MeV/u and beam power up to 400 kW. To achieve these goals with present ion source performance it is necessary to accelerate simultaneously two charge states of uranium from the ion source in the first section of the linac. At an energy of approximately 16.5 MeV/u it is planned to strip the uranium beam to reduce the voltage needed in the rest of the linac to achieve the final energy. Up to five different charge states are planned to be accelerated simultaneously after the stripper. The design of the stripper is a challenging problem due to the high power deposited (approximately 0.7 kW) in the stripper media by the beam in a small spot. To assure success of the project we have established a research and development program that includes several options: carbon or diamond foils, liquid lithium films, gas strippers and plasma strippers. We present in this paper the status of the different options.

INTRODUCTION

The general layout of the FRIB facility [1] is shown in Figure 1, where the stripper location at the first bend is indicated. No stripper is planned at the second bend because of the limited benefit obtained from it.

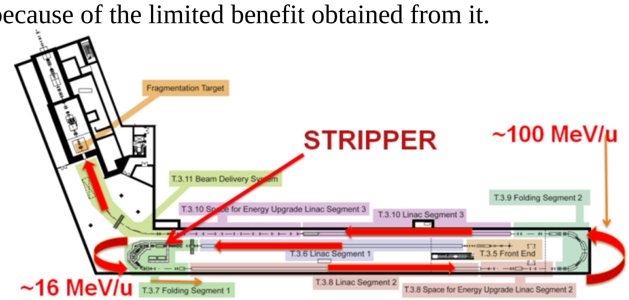

Figure 1 General layout of the FRIB driver linac. The red arrows indicate the beam direction.

SOLID STRIPPER

A research program to study the feasibility of solid strippers was established at MSU. The purpose was to gain confidence in the understanding of the thermal and mechanical issues associated with the high power deposition. It was demonstrated that we could accurately estimate the temperatures and sublimation rates of the solid foils, but the radiation damage tests showed that due to the high energy loss rate for the heavy ions (U at 16.5MeV/u dE/dx ~ 25 keV/nm) the thickness of the foil was changing extremely fast, unacceptable because of the losses in the following linac accelerating segments. Scanning Electron Microscope photos of the unexposed and irradiated foils are shown in Figure 2. More details on this work are discussed in another paper at this conference [2].

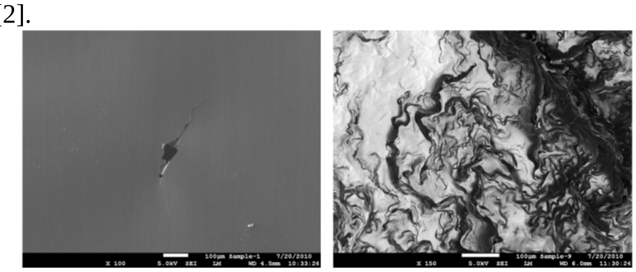

Figure 2 SEM photographs of an unused carbon foil (left, showing a pinhole) and of a foil irradiated with a Pb beam at 8.1 MeV/u. Significant structural changes and thinning was produced.

LIQUID LITHIUM STRIPPER

One of the most promising options is a liquid lithium stripper being developed at Argonne National Laboratory (ANL). ANL previously demonstrated that a thick liquid lithium target streaming at a few m/s can dissipate power of 20 kW at very high power density (up to 2 MW/cm^3) and the liquid lithium system operated well in a typical accelerator environment [3]. Also previously a high-speed (> 50 m/s), thin (~10 μm) liquid lithium film was demonstrated in a vacuum environment [4], see Figure 3**Error! Reference source not found.**.

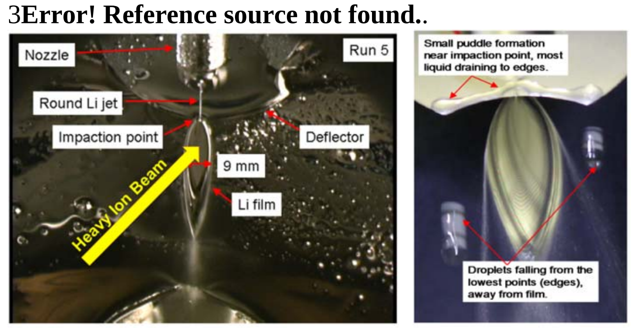

Figure 3 Liquid lithium flow producing a thin film in the original ANL experiment (left). Improved deflector shape being tested with water (right).

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ANL is now working to improve the film stability and reproducibility, necessary for reliable linac operation, and to measure the exact film thickness to match the required film thickness (~0.5 mg/cm^2). Many modifications have been made to the existing liquid lithium system, including

(1) new nozzle,
(2) new deflector and its support system,
(3) new thermal sensing, liquid metal level probe for future fully-automatic operation,
(4) addition of an e-beam thickness measurement system (EMS) [5],
(5) new vacuum chamber to accommodate above changes.

Various water experiments were performed to improve the nozzle design and the deflector design for better film stability, Figure 3. A.M. Gatti Inc. has been working closely with ANL to provide all nozzles. Based on the experiments, new nozzles and new deflectors have been fabricated. A new deflector support system was also designed to facilitate changing the deflector. The new support was fabricated and assembled and testing is now in progress. A new liquid metal level probe based on thermal sensing technique has been also developed. This will be installed on the system to test its reliability in a liquid lithium environment.

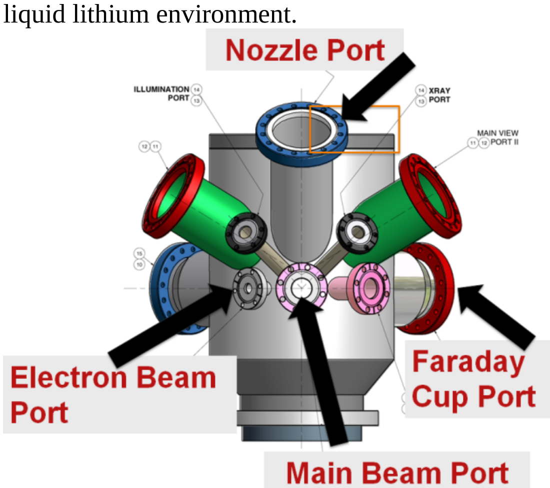

Figure 4 Vacuum chamber developed to test the liquid lithium stripper.

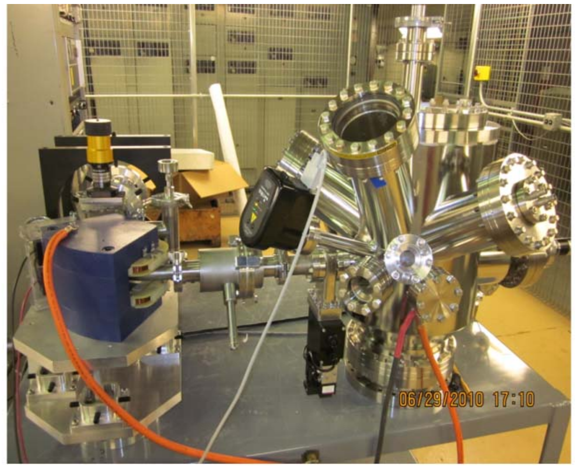

Figure 5 E-gun thickness measuring system (EMS).

Once reliable operation is shown, this level probe can be integrated into the existing control system, allowing fully-automatic operation of the Li system.

An EMS was built at ANL and its effectiveness was confirmed [5]. Note that a similar, e-beam-based, film thickness measurement system was previously built at GSI and has been successfully operated with solid thin-film targets [6]. The existing EMS of ANL has been reconfigured so that it can be mounted to the liquid lithium system. Testing the system and re-calibration of the system are now in progress.

The new vacuum chamber was fabricated and replaced the old vacuum chamber. The new chamber provides easy installation of the deflector support and has many additional ports for the EMS installation, viewing, and the future integration with an ion beam line, see Figure 4.

Assembly of the overall system is >90% complete and the first Li flow is expected soon.

As in all stripper options it is crucial to prevent contamination of the nearby superconducting cavities. No line of sight is allowed between the stripper and the cavities while traps will be setup between them.

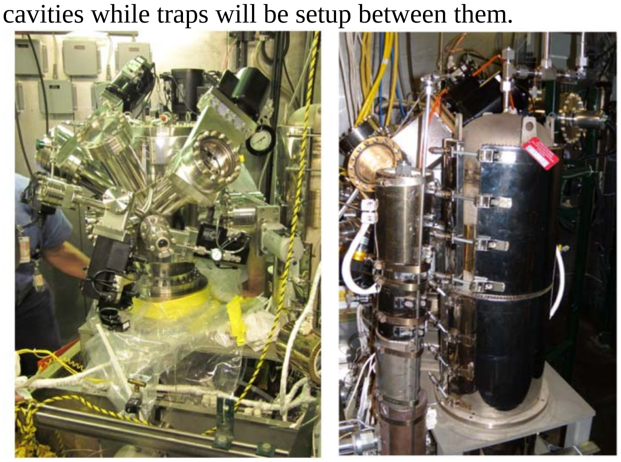

Figure 6 Vacuum chamber (left) and lithium tank (right).

GAS STRIPPING

The advantage of a gas stripper is its simplicity, but the disadvantage is the lower average charge state produced when compared to solid or liquid strippers. The most relevant work on gas strippers for heavy ions has been done at RIKEN by H. Okuno and H. Kuboki [7]. It is estimated from their experiments that at the FRIB energy (16.5 MeV/u) the average charge state expected for U stripping is 64+ well below the expected value for solids (or liquids) (78+). This lower charge state would require seven more cryomodules of the β=0.53 type to compensate the lower energy gain.

The RIKEN gas cell is based on the windowless gas target described in [8] and based on [9]. Target thicknesses of 1 mg/cm^2 have been achieved, but the RIKEN experiments with N_2 gas show that the equilibrium is reached below 0.2 mg/cm^2. This thickness is lower than the corresponding solid carbon equilibrium thickness at this energy, but probably similar lower charge states could be achieved with carbon at this same thickness.

This chamber consists of four differential pumping stages, obtaining pressures below 6 10^{-6} Torr in the outermost vacuum chamber at a constant target gas pressure of 50 Torr.

GAS STRIPPING WITH PLASMA WINDOWS

Another significant result from the RIKEN experiments [7] is the determination that the electron pickup and electron loss cross sections for U in helium gas indicate that if equilibrium thickness could be achieved the average charge state for U stripping in He could be as high as for solid strippers.

Due to the difficulties of obtaining thick He targets we started a program with Brookhaven National Laboratory (BNL) to develop a gas cell contained by plasma windows. The plasma windows have been developed by A. Hershcovitch at BNL [10]. In this setup an improvement of a factor of ~ 230 in pressures was obtained in the low pressure side compared to differential pumping while the high pressure side was at atmosphere.

The same experiment showed that a high containment degree of helium gas can be achieved with the plasma windows, although the factor of 230 was reduced to about 80.

A demonstration setup with two plasma windows is being implemented at BNL with the purpose if establishing the stability and performing charge state experiments with the BNL Au beam, Figure 7.

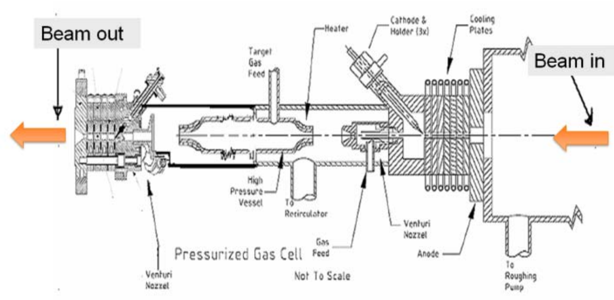

Figure 7 Sketch of the experimental setup for the BNL test with two plasma windows. A gas cell is enclosed by the plasma windows.

The plasma windows have been borrowed from D. Lanza (MIT) and from the APS (ANL). These windows have apertures of only 3mm, but if the proof of principle is successful we plan to build larger windows (6 mm diameter) at MSU to continue the development.

PLASMA STRIPPER

The use of a plasma stripper has been tested at GSI. In their experiment [11] a free electron density up to 5.5 10^{19} cm^{-3} was achieved, but with 50 MW of power in the plasma generation. This is possible in a pulsed mode, but not in the DC conditions of FRIB. The BNL team will study the generation of wall and vortex stabilized plasmas to achieve the maximum possible density of free electrons within reasonable power requirements. Although more speculative than the previous stripper alternatives, plasma strippers have the potential for very high charge states.

SUMMARY

A diverse R&D program is being carried out as part of the FRIB stripper development. It is a multi laboratory collaboration with ANL, BNL, RIKEN and MSU participating in it. Several promising approaches are being followed with the goal of selecting the technology by the end of 2011.

ACKNOWLEDGEMENTS

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REFERENCES

[1] R. C. York et al, “Status and Plans for the Facility for Rare Isotope Beams at Michigan State University “, paper at this conference.

[2] F. Marti et al., “A Carbon Foil Stripper for FRIB”, paper at this conference (TUP105).

[3] J. A. Nolen et al., Behavior of Liquid Lithium Jet Irradiated by 1 MeV Electron Beams up to 20 kW, Rev. Sci. Instrum. **76** (2005) 073501.

[4] Y. Momozaki et al., “Development of a Liquid Lithium Thin Film for Use as a Heavy Ion Beam Stripper”, JINST **4** (2009) P04005.

[5] S. Kondrashev et al., Upgrade of the FRIB Prototype Injector for Liquid Lithium Film Testing, Proc. of PAC09 (2009) TU6RFP048.
[6] R. Mann et al., “On-line target control”, GSI Scientific Report 2003, 224.
[7] H. Okuno and H. Kuboki, (RIKEN) personal communication 2010.
[8] T. Kishida et al., “A windowless gas target for secondary beam production”, Nuclear Instruments and Methods in Physics Research. A **438** (1999) 70.
[9] K. Sagara et al., “A blow-in windowless gas target”, Nuclear Instruments and Methods in Physics Research A **378** (1996) 392.
[10] A. Hershcovitch, “High-pressure arcs as vacuum-atmosphere interface and plasma lens for nonvacuum electron beam welding machines, electron beam melting, and nonvacuum ion material modification”, J. Appl. Phys. **78** (1995) 5283.
[11] A. Golubev et al., “Experimental investigation of the effective charge state of ions in beam–plasma interaction”, Nuclear Instruments and Methods in Physics Research A **464** (2001) 247.