LI THIN FILM THICKNESS MEASUREMENTS USING LOW ENERGY ELECTRON BEAM

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Abstract *For a heavy ion linac, employing charge strippers is often necessary to improve the performance. The most promising approach, especially for a high-power linac, is to use a liquid metal, thin film as a stripper. Some liquid metals have low vapor pressure and good thermal properties, allowing such a stripper to withstand extreme heat load from ion bombardments. Based on fluid-dynamic, thermal, and nuclear physics considerations, a liquid lithium thin film with the thickness of ~8 μm (0.4 mg/cm^2), flowing at >50 m/s may act as the best stripper for a uranium beam at 34+, 12 MeV/u. As the next-stage development, formation of such films is demonstrated at Argonne National Laboratory (ANL). From simple fluid-dynamic considerations, the film thickness and the velocity are estimated to be <~13 μm and ~58 m/s, respectively. This paper describes how to measure the Li film thickness using low energy electron beams (LEEB). When applied to the Li film, LEEB is absorbed and scattered in the film. Changing the film thickness affects characteristics of the transmitted electrons, from which the film thickness may be back-calculated. Preliminary calculations show that the electron energy of <~30 keV provides the best sensitivity for Li film thicknesses up to 20 μm.*

I. INTRODUCTION AND BACKGROUND

For an ion-beam linac, employing charge strippers is often necessary to improve the performance of the linac. Conventional strippers are typically made of various thin, solid materials. As the incoming beam power increases, the thermal stability of the stripper materials becomes important, since high power ion beam bombardments deposit considerable amount of heat in a stripper, destroying the solid stripper materials. To resolve this issue, rotating strippers have been developed to spread thermal loading. However, for next generation radioisotope beam facilities, such as Advanced Exotic Beam Facility (AEBL) proposed by ANL (Ref. 1) and Radioisotope Beam Facility (RIBF) at Riken (Ref. 2), the ion beam power becomes so intense, even rotating stripper will not be able to fully resolve this issue.

To effectively handle very large thermal loading, a windowless, liquid target/stripper concept has been proposed. Some liquid metals, including lithium, have very low vapor pressures, good thermo-physical and nuclear-physical properties. An experiment to irradiate a liquid lithium windowless target with 1 MeV electron beams, depositing up to 20 kW power within ~1 mm beam spot (resulting in ~MW/cm^3 volumetric heat deposition) was carried out at ANL (Ref. 3, 4). In the experiment, the effectiveness of the windowless concept on handling extreme thermal loading and the good compatibility of windowless, liquid lithium system with a typical beam line high vacuum environment have been successfully demonstrated.

Additional concern is the hydrodynamic instability of a liquid jet that is a windowless liquid target (Ref. 5). Liquid jets are known to be inherently unstable, because the surface tension of the liquid tends to tear off the jet. Since liquid metals tend to have high surface tensions, this instability is expected to be more intensified in the liquid metal windowless target/stripper concept than in systems using other conventional liquids with low surface tension. Currently, the range of the optimum thickness of the windowless stripper for ABEL and RIBF is expected to be ~0.3 to 1.0 mg/cm^2 that is ~6 to 20 μm thick for a Li film (Ref. 6). From thermal considerations, these Li films need to flow at >50 m/s to quickly carry deposited heat away. Creating such thin, liquid Li films flowing at such high speed, imposes not only hydrodynamic instability problems, but also some engineering problems. For a proof of principle experiment, a prototypical, liquid lithium thin film stripper system was constructed (Figure 1) at ANL and formation of liquid lithium thin film was successfully demonstrated (Figure 2) (Ref 7). From simple fluid dynamic considerations together with drive pressure, nozzle opening size, and film width, the film thickness and the velocity are estimated to be <~13 μm and ~58 m/s, respectively. Because of the lack of understanding film behaviors, appropriate instrumentation to directly measure the film thickness could not be implemented at the time of experiments. Direct and accurate measurements are yet to be performed. A method of interest should be able to measure scale of ~10-

20 μm with resolution of preferably <~1 μm range. It also must be able to work in environments where pressure is very low (<~10^{-4} Pa), temperature is high (>~200 ºC), and some Li mist and splash (hot, electrically conductive, reactive, and corrosive particulates) exist near the film (as far as ~30-50 cm).

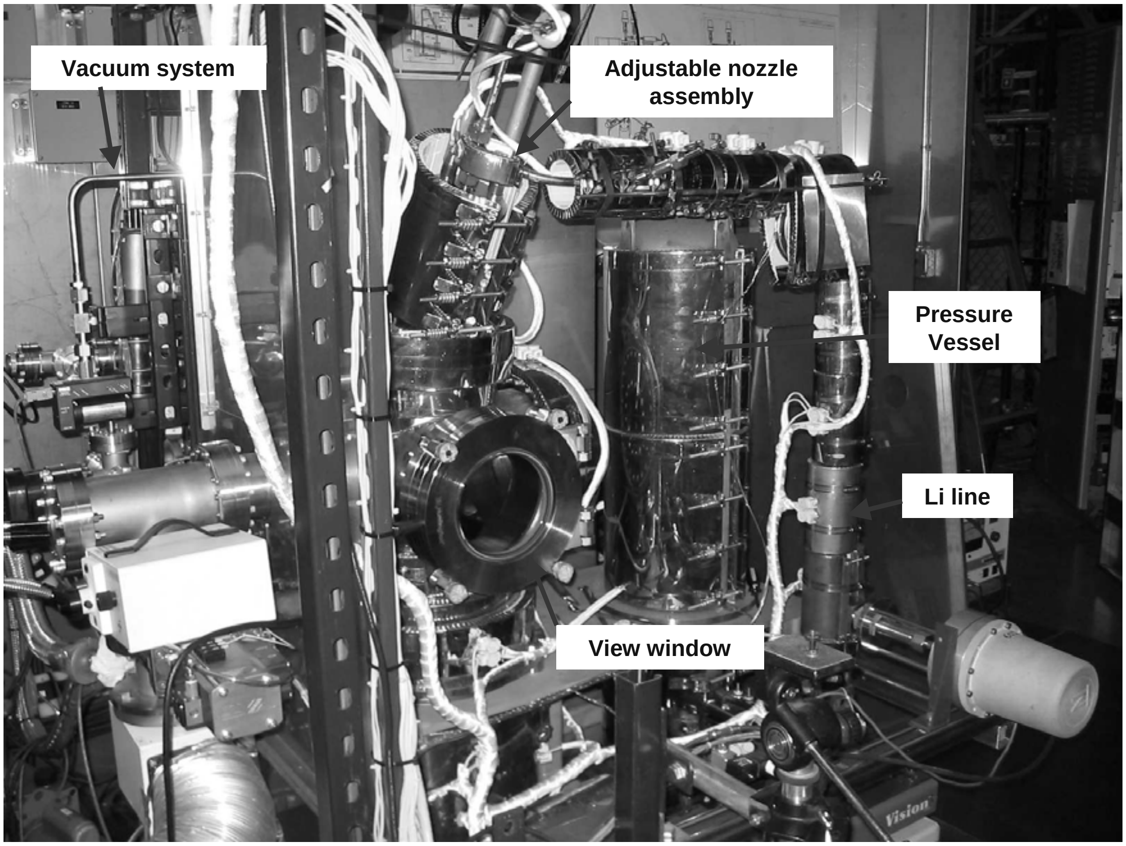

Figure 1. Liquid Lithium Thin Film Stripper Loop System.

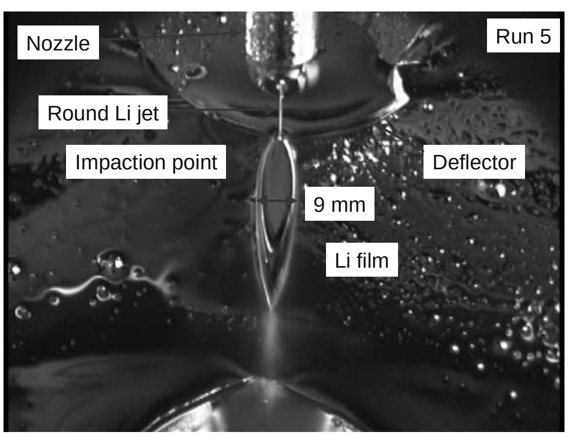

Figure 2. Liquid Lithium Thin Film.

The following sections describe how to accurately measure the Li film thickness using low energy electron beams (LEEB). When applied to the Li film, LEEB is absorbed and scattered in the film. The amount and the peak energy of the transmitted electrons are affected by the film thickness. These characteristics of LEEB interaction with the thin film may be used to accurately measure the film thickness.

II. METHODS

Several methods, including mechanical intrusion and use of light scattering/reflection, interferometry, X-ray attenuation, or electron transmission/scattering are considered for direct thickness measurements. The mechanical intrusion would tend to destroy Li films. Light scattering/reflection method would require use of complex detectors, which have to be placed very close to the film for resolution of <~µm. Interferometry would require rather complex optical setting around the film. For X-ray attenuation, an appropriate x-ray source may not be readily available and real-time measurement is considered to be difficult. Finally, use of electron transmission/scattering appears to be most compatible with lithium environments and relatively simple to implement among them. It also seems to be able to achieve good resolution (<~µm) and fast response time.

It is noted that use of LEEB to measure the thickness of liquid film stripper was previously proposed in The Sixth International Conference on Radioactive Nuclear Beams (RNB6) on Sept. 2003 (Ref. 4) and this method is also in use at GSI to measure the thickness of solid targets on a rotating wheel (Ref. 8).

To measure the film thickness using LEEB interaction with the thin film, two methods have been proposed. These methods are explained and discussed below.

II.A. Current Measurement Method

In this method, a well focused LEEB will be applied to the film. A Faraday cup will be placed behind the film to collect the transmitted electrons. Since the transmitted current is a function of the film thickness, by measuring the ratio of the incident current and the transmitted current, the film thickness can be obtained. Therefore, for accurate measurements, the large portion of the transmitted electrons needs to be captured. In order to collect majority of the transmitted electrons, the Faraday cup needs to be large and to be placed close to the film.

II.B. Energy Measurement Method

Similar to the current measurement method, a well focused LEEB will be applied to the film. In this method, however, a negatively biased Faraday cup will be placed behind the film to measure the peak energy of the transmitted electrons. As the negative bias voltage increases, the amount of current that the Faraday cup collects decreases. When the current measured at the cup becomes zero, the bias voltage at the moment is equal to the peak energy of the transmitted electrons. Since the peak energy of the transmitted electrons is a function of the film thickness, by measuring the peak energy of the transmitted electrons, the film thickness can be obtained. In this method, unlike in the current measurement method, the measurements do not depend on the amount of electrons that the Faraday cup collects. Therefore, the cup could be relatively small and does not need to be placed close to the film.

III. SIMULATIONS

Simulation using CASINO (Ref. 9) was performed to obtain relationships between the transmitted electrons through the film and the film thickness. Fluid-dynamic characteristics of the film were, therefore, ignored and a thin liquid lithium film was represented by a solid lithium film with the same thickness. The energy of the incident electron beams was varied from 10-30 keV, while the thickness of the Li film was varied between 8-22 μm. CASINO calculates the amount and the energy of the transmitted electrons, while the incident energy and the film thickness were varied.

Figure 3 shows an example of CASINO simulation, showing how an 18 keV electron beam is expected to interact with a 10 μm thick Li film. This figure shows that the electron beam is injected from the top of the figure and penetrates the Li film. Many cases while changing the incident electron energy and the Li film thickness were simulated and results were compiled to plot various different graphs to check the effectiveness of both the current measurement and energy measurement methods. The compiled results are explained next.

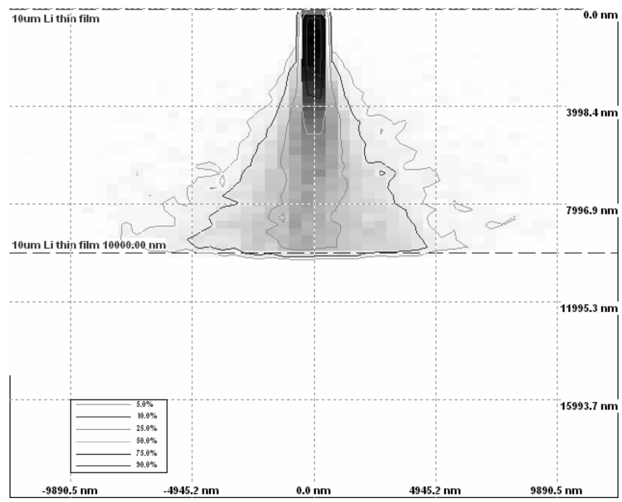

Figure 3. An Example of CASINO Simulation.

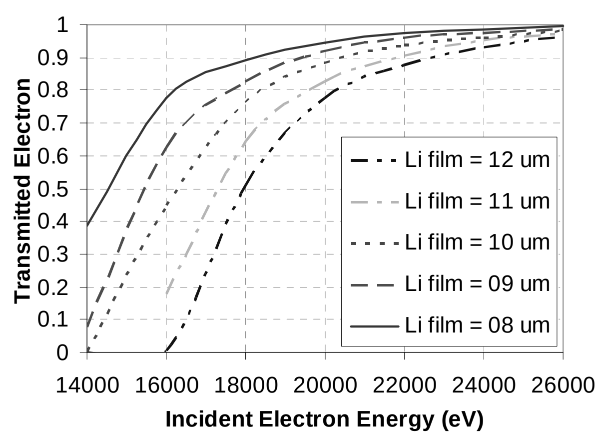

Figure 4. Ratio of Transmitted/Incident Electrons (~10μm).

Figures 4 and 5 show how the amount of the transmitted electrons changes as the incident electron energy changes for various Li film thicknesses. These graphs were used to evaluate the effectiveness of the current measurement method. For example, Figure 4 shows that when a ~16 keV electron beam is applied, the amount of the transmitted electrons changes from about 0% for a 12 μm thick Li film to about 80% for an 8 μm thick Li film. This figure shows that difference of 1 μm in film thickness corresponds to the change of as much as 15-25% in the amount of the transmitted electrons around 10 μm thick Li film thicknesses. Similarly, Figure 5 shows that when a ~23 keV electron beam is applied, the amount of the transmitted electrons changes from about 10% for a 22 μm thick Li film to about 60% for an 18 μm thick Li film, indicating that difference of 1 μm in film thickness corresponds to the change of as much as 10-15% in the amount of the transmitted electrons around 20 μm thick Li film thicknesses.

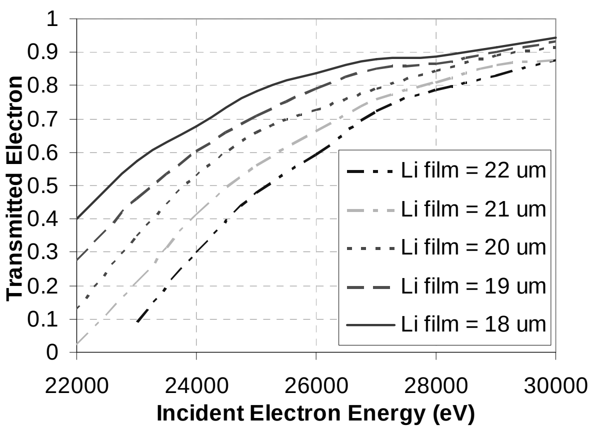

Figure 5. Ratio of Transmitted/Incident Electrons (~20μm).

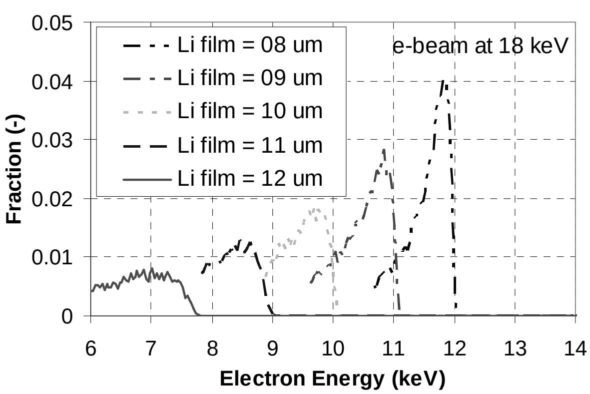

Figure 6. Energy Distribution of Transmitted Electrons (~10 μm).

Figures 6 and 7 show how the energy distribution of the transmitted electrons changes as the Li film thickness changes for different incident electron energy. These graphs were used to evaluate the effectiveness of the energy measurement method. For example, Figure 6 shows that when an 18 keV electron beam is applied, the peak energy of the transmitted electrons changes from about 7.7 keV for a 12 μm thick Li film to about 12 keV for an 8 μm thick Li film. This figure shows that difference of 1 μm in film thickness corresponds to the change of ~1 keV in the peak energy of the transmitted electrons around 10 μm thick Li film thicknesses. Figure 7 shows that when a 25 keV electron beam is applied, the peak energy of the transmitted electrons changes from about 10.5 keV for a 22 μm thick Li film to about 14.2 keV for an 18 μm thick Li film, indicating that difference of 1 μm in film thickness again corresponds to the change of ~1 keV in the peak energy of the transmitted electrons around 20 μm thick Li film thicknesses.

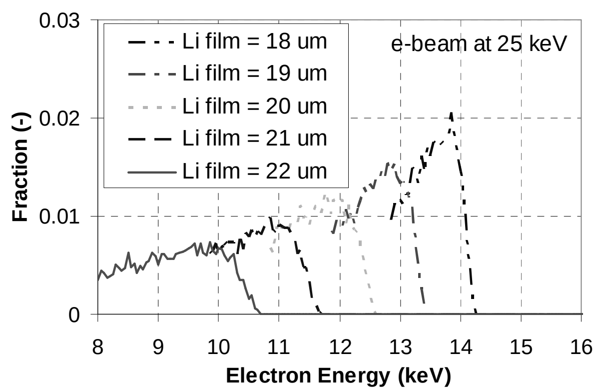

Figure 7. Energy Distribution of Transmitted Electrons (~20 μm).

These results show the effectiveness of both the current measurement and energy measurement methods on measuring the Li film thicknesses of ~10-20 μm with an accuracy <~1 μm.

IV. SETUP

In order to implement the methods discussed above, an electron gun instrumentation system will be additionally installed to the existing liquid lithium thin film loop system. The instrumentation system will consist of the electron gun, bending magnet, focusing/steering coils, Faraday cup, e-gun power supply, high voltage bias power supply, and current meter (Figure 8). The e-gun power supply drives the e-gun at desired voltage and current. The electron beam is then bent at the bending magnet, whose purpose is to protect the e-gun from harsh Li environments. Sufficiently bending the beam line prevents Li vapor, mist, and splash from reaching the e-gun. The e-beam is then steered to and focused on the Li film. The transmitted electrons are then collected by the Faraday cup located behind the film. The collected current is measured by the current meter. For the energy measurement method, the high voltage bias power supply may be connected to the Faraday cup. The e-gun and associated power supply capable to produce e-beams at up to 30 keV (EMG-4212/EGPS-4212) have been purchased from Kimball Physics Inc. We are planning to build this setup without coupling with the Li system first for testing.

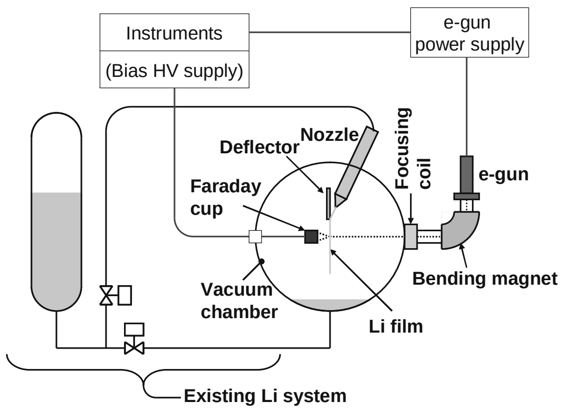

Figure 8. Schematic of LEEB Instrumentation and Li Loop.

V. SUMMARY

Approximately 10 μm thick Li thin films flowing at ~50 m/s in high vacuum environments are produced at ANL, but currently no means to directly measure their thickness is available. To measure the film thickness in Li environments, measuring transmission of low energy electron beam appears to be a simple method for both absolute and time-dependent measurements. Simulations using CASINO indicate two possible methods, 1) measuring transmission current as a function of thickness, or 2) monitoring peak energy of the transmitted electrons as a function of thickness. Simulations also suggested that the resolution better than <1 μm may be easily achievable. A layout of the setup was developed and obtaining hardware is in progress. Preliminary dry-runs are planned prior to coupling with the Li system. Modification of the existing system is also in progress.

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