A Negative Surface Ionization Source for Generation of Halogen Radioactive Ion Beams

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A simple and efficient negative surface ionization source has been designed, fabricated and initially tested for on-line generation of radioactive ion beams of the halogens (Cl, Br, I, and At) for use in the nuclear-structure and nuclear-astrophysics research programs at the Holifield Radioactive Ion Beam Facility. The source utilizes a solid, spherical geometry LaB_6 surface ionizer for forming highly electronegative atoms and molecules. Despite its widely publicized propensity for being easily poisoned, no evidences of this effect were experienced during testing of the source. Nominal efficiencies of 15% for Br^- beam generation were obtained during off-line evaluation of the source with $AlBr_3$ feed material when account is taken of the fractional dissociation of the molecule. Principles of operation, design features, operational parameter data, initial performance results, and beam quality data (emittance) are presented in this article.

I. INTRODUCTION

The Holifield Radioactive Ion Beam Facility (HRIBF) utilizes negative ion beams for post acceleration to research energies [1]. Because of the restricted number of elements with high electron affinities, this type of surface ionization source is highly selective and can be used to great advantage for radioactive ion beam (RIB) applications to eliminate isobaric contaminants that may compromise experimental results. For these reasons, a negative surface ionization source was designed and characterized for on-line use in generating radioactive ion beams (RIBs) of the halogen elements for the nuclear-structure and nuclear-astrophysics experimental programs at the HRIBF. These sources are characterized by high beam purity (chemical selectivity), low thermal energy spreads (~2 kT<<1 eV), and limited range of species capability. Since the electron affinity E_A, of each atomic member of the Group VIIA elements (Cl(E_A:3.61 eV); Br(E_A:3.36 eV); I(E_A:3.09 eV); and At(E_A: 2.8 eV)) are higher than the intrinsic work function of a polycrystalline LaB_6 ionizer (~ 2.7 eV [2]), the efficiency for ionization of these elements in atomic form is very high. LaB_6 was chosen as the ionizer for this application, despite its widely publicized propensity for poisoning [3], because of its relatively low work function and ready availability. High flow-rate conditions, whereby, residual gases interact with the ionizer, have the effect of raising the work function of LaB_6 in which case, the probability for negative ion formation is exponentially diminished, and consequently, the extracted beams intensities are reduced. A few sources, based on the use of LaB_6 as the ionizer, have been described in the literature [4-6], including their use at ISOL facilities for negative ion generation of high electron affinity radioactive species [6].

II. THEORY OF NEGATIVE ION FORMATION

For thermodynamic equilibrium processes, the ratio of ions to neutrals that leave an ideal surface can be predicted from Langmuir-Saha surface ionization theory appropriate for either positive or negative ion formation. The form of the Langmuir-Saha equation for the probability, P_i, of negative ion formation of neutral particles of electron affinity, E_A, interacting with a hot metal surface at temperature, T, and work function, ϕ, is given by

$$P_i = \frac{\omega_-}{\omega_0}\left(\frac{1-r_-}{1-r_0}\right)\exp\left(\frac{E_A-\phi}{kT}\right)x\left[1+\frac{\omega_-}{\omega_0}\left(\frac{1-r_-}{1-r_0}\right)\exp\left(\frac{E_A-\phi}{kT}\right)\right]^{-1} \quad (1)$$

where r_- and r_0 are the reflection coefficients of the negative or neutral particle at the surface and ω_- and ω_0 are statistical weighting factors for the negative ion or neutral atom, respectively. ω_- and ω_0 are related to the total spin of the respective species, $S = \Sigma s_i$, given by

$$\omega = 2\Sigma s_i + 1 \tag{2}$$

where s_i is the spin of the electron. The Langmuir-Saha equation clearly illustrates that negative ion formation can be enhanced by either lowering the work function, ϕ, or increasing the surface temperature, T, for elements where $E_A \leq \phi$.

III. DESCRIPTION OF THE SOURCE

A cross sectional view of the source, showing the target reservoir, the vapor transport tube, the ionization region and extraction electrode system is displayed in Fig. 1. The target material reservoir is heated resistively to temperatures exceeding 2000 ^{0}C by passing a current through a Ta tube surrounding the reservoir. The solid spherical geometry ionizer (spherical radius: 2.5 mm, diameter: 4.3 mm) fits in a Ta-holder with annular apertures that permit vapor flow into the volume surrounding the ionizer. The current flow through the transport tube is adjusted so that the temperature of the ionizer can be varied, typically between 1650 ^{0}C and 1730 ^{0}C (LaB_6 begins to dissociate at ~1730 ^{0}C). The spherical geometry optics are designed to focus negative ions, evaporated from the LaB_6 surface, through a small aperture (ϕ: 0.41 mm) by applying a positive voltage to the extraction electrode.

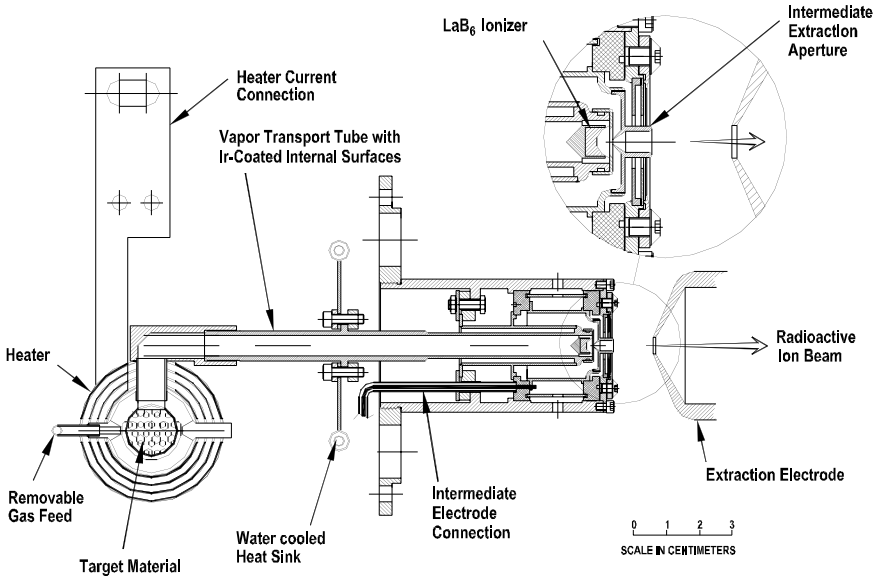

Fig. 1. Schematic drawing of the negative ionization source equipped with a spherical geometry ionizer.

A. Flow rate of molecules into the source

The flow rate of molecules, dN/dt, into the source is estimated from the following formula, taken from the kinetic theory of gases [7]:

$$dN / dt = F_D\{2\pi a^3 / 3k_B T\}\, \nu_M \Delta p / l \tag{3}$$

where F_D is the dissociation fraction for releasing molecules, Δp is the pressure drop across the transport tube of length, l; a is the effective radius; T is the average temperature; and ν_M is the average velocity of molecules. The equilibrium dissociation fraction for $AlBr_3$ is 0.66 at T ≥ 1500 ^{0}C. For optimum efficiency, the LaB_6 ionizer was operated at ~ 1722 ^{0}C.

IV. SOURCE PERFORMANCE: EXPERIMENTAL RESULTS

The mass spectrum and the emittance diagram are shown in Fig. 2. The selective nature of the surface ionization process is clearly demonstrated by the purity of the spectrum. The only masses with significant intensity are the two isotopes of interest: ^{79}Br and ^{81}Br. The emittance plot corresponds to a 20 keV Br^- beam and is quite small, as noted.

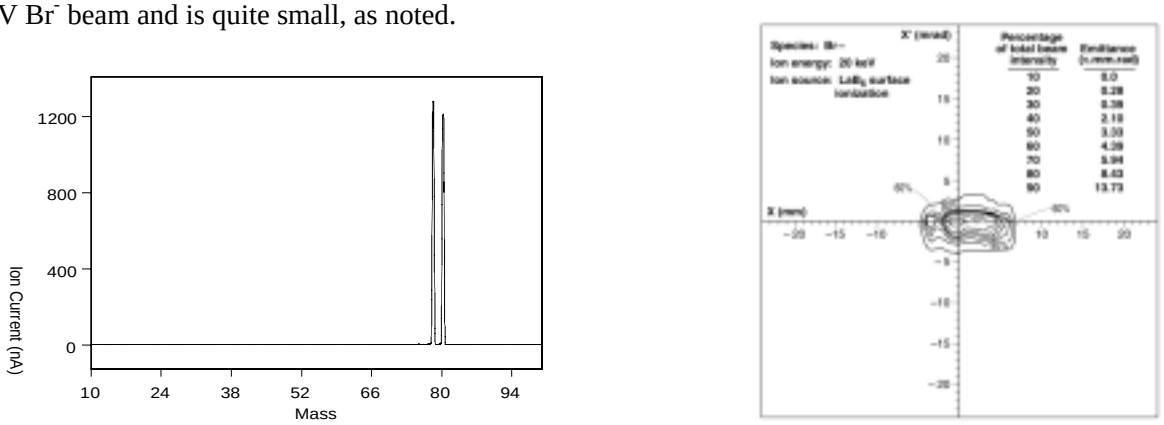

Fig. 2. Mass spectrum (left) and typical emittance diagram (right).

Mass analyzed $^{79}Br^-$ intensities, ranging between 0.8 and 1.5 μA, were typical of the currents recorded during source evaluation, corresponding to a range of total efficiencies from ~10 to 17%, as illustrated in Fig.3. Thus, the overall efficiency for generating beams of Br^- is quite high (~24.3% for the *First Day* of operation), as required for on-line RIB experiments.

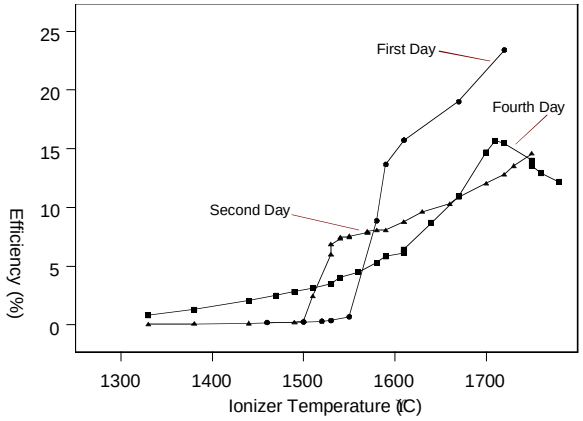

Fig. 3. Efficiency versus surface ionizer temperature.

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