# A Multi-Sample Cs-Sputter Negative Ion Source for $^7BeO^-$ Generation

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**Abstract.** A multi-sample Cs-sputter negative ion source has been evaluated for generating $^7BeO^-$ beams for measuring the nuclear-astrophysically important $^7Be(p,\gamma)^8B$ reaction at the Holifield Radioactive Ion Beam Facility. The design features and operational parameters of the source are described and measured efficiencies for forming beams of $Ni^-$, $C^-$ and $MgO^-$ and estimated efficiencies for generating beams of $BeO^-$ for the proposed experiment are presented in this report.

## INTRODUCTION

Uncertainty in the cross section for the $^7Be(p,\gamma)^8B$ reaction is the major source of nuclear physics uncertainty in the solar neutrino puzzle [1]. A nuclear astrophysics experiment has been proposed for measuring the $^7Be(p,\gamma)^8B$ reaction in inverse kinematics, $^1H(^7Be,^8B)\gamma$, using a radioactive $^7Be$ beam and a windowless hydrogen target at the Holifield Radioactive Ion Beam Facility (HRIBF). Since beryllium only forms a metastable state negative ion, molecular beams, such as $BeO^-$ and $BeH^-$ are commonly injected into tandem accelerators [2,3]. The proposed research involves the generation of $^7BeO^-$ beams from enriched $^7BeO$ in a metallic matrix using a Cs-sputter ion source. The electrostatic $^7BeO^-$ beam is accelerated at HRIBF then injected into the 25-MV tandem dissociated and stripped to produce an accelerated $^7Be$ beam. This technique was recently used in an experiment designed to measure the cross section for the $^7Be(p,\gamma)^8B$ reaction in reverse kinematics [4]. Although $^8B$ nuclides from the $^1H(^7Be,^8B)\gamma$ reaction were successfully observed for the first time, the data observed were statistically insufficient for accurate cross section determination due to the short cathode lifetime experienced during the experiment. To successfully carry out the proposed experiment at HRIBF a multi-sample Cs-sputter negative-ion source has been evaluated off-line for this application using sputter cathodes such as graphite, Ni, Cu/MgO, and Ag/MgO that are readily available and pose no health hazards during installation and removal. During these experiments, the source operation parameters were optimized and the efficiency for negatively ionizing MgO was measured. The design features, operational parameters, and performance of the source are presented in this report.

## DESCRIPTION OF THE SOURCE

The multi-sample source has previously been characterized for stable ion beam generation [5]. A side view of the source assembly is displayed in Fig. 1. The major components are the ion source module, the vacuum-air-lock assembly, the water-cooled target-holder assembly, the indexing mechanism/target position read-out assembly, and the high-voltage acceleration electrode assembly. The ion source consists of a conical-geometry, W-surface ionizer for producing $Cs^+$ ions, which sputter the target material at energies between 1-5 keV, a water-cooled target holder that holds up to eight, 6.3-mm diameter sputter samples, and a Cs focusing electrode between the ionizer and the target holder to control the $Cs^+$ beam diameter on the sample. All the ion source components are enclosed in a stainless steel ionization chamber with a 4.8-mm diameter extraction aperture. Cs vapor is introduced into the ionization region of the source from an external oven. Target samples are screw-attached to a water-cooled Cu heat-sink assembly and an air-motor-driven indexing system, mounted at sample potential. The target holder is offset relative to the optics of the source so that a simple rotary motion can be executed to move

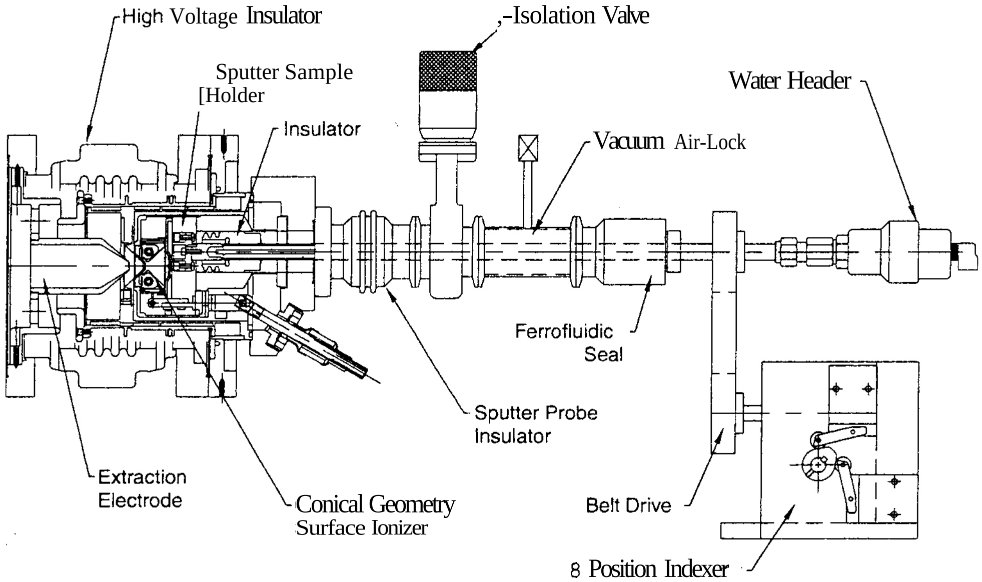


**FIGURE 1.** Side view of the multi-sample negative ion source.

individual samples into beam position without interruption of on-line accelerator operation. Sample changing is effected by an electro-pneumatic control system located at ground potential that actuates the eight-position, Geneva-type indexing mechanism mounted at high voltage. In-beam-position samples are identified by means of an LED display derived from a fiber-optic link in combination with a Gray code encoder wheel mounted on the indexing mechanism.

## Ion Optics

The ion optics for acceleration of $Cs^+$ and extraction of negative ions were designed using the simulation code PBGUN [6]. The space-charge limited $Cs^+$ ion current, extracted through a potential difference V, is given by the familiar Childs-Langmuir equation

$$I_{Cs^+}(A) = PV^{3/2}. \qquad (1)$$

where P is the perveance. The calculated perveance for the conical ionizer and sputter-sample electrode system is $P = 2.5\times10^{-9}$ [$A/V^{3/2}$], correlating to a $Cs^+$ beam of 225 μA at 2 kV.

## OPERATIONAL PARAMETERS

In order to realize optimal performance of the source, it is necessary to determine the dependence of the negative-ion beam intensity on the important operational parameters of the source, including the Cs oven temperature, ionizer temperature, and sputter-probe voltage. The operating parameters of the source were characterized using graphite and Ni samples.

## $Cs^+$ Beam Intensity

**A** water-cooled, electron-suppressed Faraday cup detector was specially designed for measuring the $Cs^+$ ion currents striking the samples. The Faraday cup was mounted in the in-beam sample position and space-charge limited currents were observed. As shown in Fig. 2, the measured $Cs^+$ currents at various sputter voltages are in excellent agreement with PBGUN simulations.

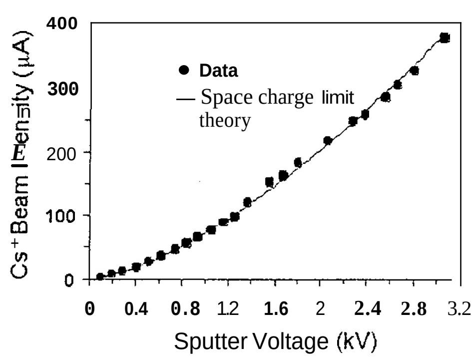


**FIGURE 2.** Measured $Cs^+$ ion intensity versus sputter voltage. Ionizer current: 23A; Cs Oven: 180 °C.

## Beam Current vs Cs-Oven Temperature

The probability for negative ion formation during sputtering depends exponentially on the difference between the electron affinity $E_A$ and the work function $\phi$ of the sample surface; low work-function surfaces are prerequisite for efficient negative ion formation. The supply of Cs into the source provides both $Cs^+$ beam for sputtering and a neutral flux of Cs vapor for lowering the work function of the sample surfaces. Since the effective Cs coverage depends on the difference between the rate of arrival and departure of Cs vapor to and from the sputter sample surface, the work function of the surface and, consequently, the negative-ion beam intensity is sensitively dependent on Cs-oven temperature. The measured $^{58}Ni^-$ beam intensity versus Cs-oven temperature, obtained at fixed ionizer temperature and sputter voltage is shown in Fig. 3. The negative-ion beam intensity peaks at a Cs-oven temperature of–230°C. Thus, the Cs-oven is usually operated at temperatures up to 230°C.

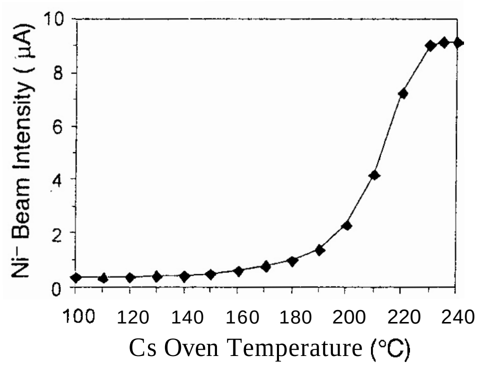


**FIGURE 3.** Negative ion intensity versus Cs oven temperature for the multi-sample ion source. Sample: solid Ni; ionizer current: 26A; sputter voltage: 1.5 kV.

## Beam Intensity versus Ionizer Current

The W-ionizer must be operated at temperatures above the critical temperature (–1 100°C) for efficient surface ionization of Cs [7]. An example of $C^-$ beam intensity as a function of ionizer current at a fixed Cs oven temperature and sputter voltage is shown in Fig. 4. One can see the characteristic abrupt onset of the surface ionization process as the ionizer current is increased above 19A. The ion intensities reach saturation at ionizer currents above 21A. Thus, the ionizer is typically operated at a fixed current of 23-24A. However, it was found that higher ionizer currents, ~26-27A, were required for Ni targets.

## Beam Current versus Sputter Voltage

Since the sputter ratio varies from material to material for a given projectile at fixed energy, the optimal sputter voltage required to reach maximum

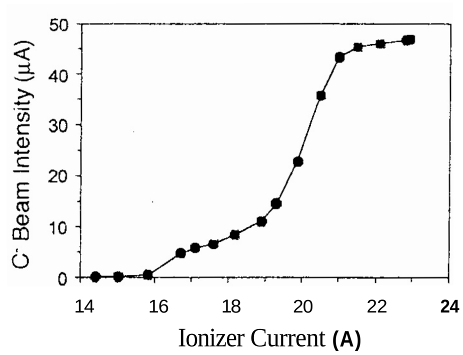


**FIGURE 4.** Negative ion intensity versus sputter voltage. Sample: graphite; sputter voltage: 2.5 kV; Cs oven: 160°C.

negative ion intensity is different for different materials. An example of the dependence of negative ion current versus sputter voltage is displayed in Fig. 5 for graphite and Ni samples. As noted, higher sputter ratio materials such as Ni reach saturation at lower sputter voltages than do lower sputter-ratio materials such as C.

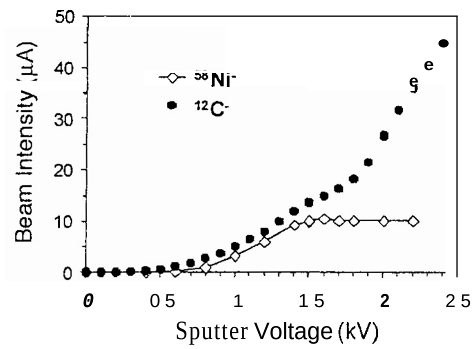


**FIGURE 5.** Negative ion intensity versus sputter voltage for C (ionizer current: **22A;** Cs oven: 160°C) and Ni (ionizer current: 27A; Cs oven: 230°C) targets.

## PERFORMANCE

The efficiencies for generating $Ni^-$ and $C^-$ beams were evaluated with nickle and graphite cathodes. Negative $^{58}Ni$ ion beam intensities of 10 µA were generated from a natural Ni target at a sputter voltage of 1.5 kV, corresponding to an ion source efficiency of ~4.5%, in agreement with design estimates. The intensities for $^{12}C^-$ were typically 40 to 50 µA at a sputter voltage of 2.5 kV, corresponding to an efficiency of –25%. The emittances of the source, measured using the equipment and procedures described in [8], were –7 πmm.mrad (MeV)'" for $C^-$ beams.

Cathodes for the $^7Be$ experiment will be made of a pressed metal powder, such as Cu or Ag, containing a small amount of $^7BeO$. During off-line evaluation of the source, MgO was used instead of BeO, because it is readily available, poses no health hazards, and because it is chemically similar to BeO. Two types of cathodes were tested: Cu and Ag mixed with MgO powder (3% by weight). $^{24}MgO^-$ intensities up to 440 nA were obtained from Cu/MgO samples at a sputter voltage of 3 kV, corresponding to an overall efficiency of 0.5% for negatively ionizing MgO. Typical $MgO^-$ intensities versus sputter voltage are shown in Fig. 6. The Ag/MgO samples yielded lower $^{24}MgO^-$ intensities than the Cu/MgO samples. Thus, cathodes made of Cu powders are recommended for the $^7Be$ experiment. Under optimum conditions, MgO beam intensities reached peak values in less than 10 minutes after sample change. The reproducibility of the sample position was tested by rotating the sample-indexing mechanism several times and observing changes in negative-ion currents from the same sample. No noticeable changes were observed.

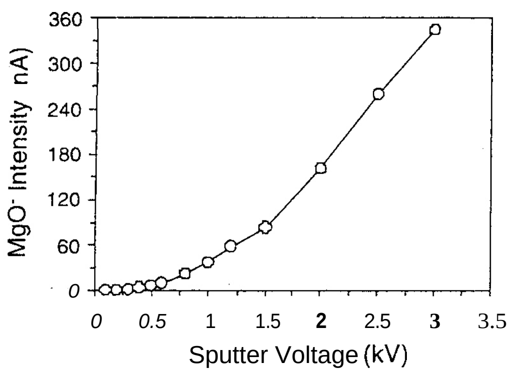


**FIGURE 6.** $MgO^-$ intensity versus sputter voltage for a Cu/MgO sample. Ionizer current: 24A, Cs oven: 180°C.

Although cathodes containing BeO were not evaluated, the efficiency for negatively ionizing BeO is expected to be higher than for MgO. Data from References 2 and 3 suggest that ionization efficiencies for $BeO^-$ using a Cs sputter ion source are 3-5 times higher than those for $MgO^-$. Thus, based on our results for $MgO^-$, the ionization efficiency of the multi-sample source for generating beams of $BeO^-$ is expected to be 2% to 3%, in agreement with a value of –2% obtained from a Cs sputter negative-ion source [9].

Cathode lifetime of sufficient length for acquiring statistically significant experimental data is crucially important and therefore lifetime measurements were conducted for Cu/MgO and Ag/MgO cathodes. The lifetime of a sample is highly dependent on the sputter rate. Higher sputter voltages yield higher beam intensities, but sputter sample material at faster rates, resulting in shorter cathode lifetimes. A 2-mm thick Cu/MgO cathode lasted for an integrated beam time of 18 hours at a fixed sputter voltage of 3 kV during which the beam current decreased from 440 nA of $MgO^-$ to 40 nA. The source operated continuously for >30 hours with a 3-mm thick Ag/MgO sample with $MgO^-$ beam intensities ranging between 80 and 120 nA; the sputter voltage was mostly kept at –2.2 kV, but later was increased to 3 kV as required for maintaining 100 nA of $MgO^-$. After 30 hours of bombardment, the maximum diameter of the sputter crater was about 3.5 mm, and the 3-mm sample was sputtered through. The results of these studies suggest that for useful beam currents and more than 12 hours of cathode lifetime, the cathode material for the on-line $^7Be$ experiment should be 3 mm in diameter and 4-5 mm deep. On-line use of this source for generating $BeO^-$ beams, using pressed Cu cathodes containing a very small amount of $^7BeO$, will be conducted in the near future at HRIBF.

## ACKNOWLEDGMENTS

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