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A Multi-Sample Cs-Sputter Negative-Ion Source

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A multi-sample Cs sputter negative-ion source, equipped with a conical-geometry, W-surface-ionizer has been designed and fabricated that permits sample changes without disruption of on-line accelerator operation. Sample changing is effected by actuating an electro-pneumatic control system located at ground potential that drives an air-motor-driven sample-indexing-system mounted at high voltage; this arrangement avoids complications associated with indexing mechanisms that rely on electronic power-supplies located at high potential. In-beam targets are identified by LED indicator lights derived from a fiber-optic, Gray-code target-position sensor. Aspects of the overall source design and details of the indexing mechanism along with operational parameters, ion optics, intensities, and typical emittances for a variety of negative-ion species will be presented in this report.

INTRODUCTION

Negative-ion sources based on the sputter principle have been used for many years for injection into tandem electrostatic accelerators for fundamental nuclear and astrophysics research applications, and for applied research such as Accelerator Mass Spectrometry (AMS), high-energy ion implantation and modification of materials. In addition, these sources are being used in a variety of low-energy, atomic and molecular physics research applications. As a consequence of these and other demands for sources with improved intensities and beam qualities, this technology has reached a relatively high degree of maturity. Several sources, designed to accommodate single samples, have been developed over the years, including those described in Refs. 1 and 2. For applications that require short-duration beam-on-target, including AMS, it is desirable to be able to quickly and remotely change samples without vacuum disruption to save time and to preserve similar surface conditions between samples. A few sources have been reported that have been designed with this capability, including sources described in Refs. 3-5. In this report, we describe a multi-sample Cs sputter negative-ion source, equipped with a conical-geometry, surface ionizer that permits sample changes without disruption of on-line accelerator operation. Aspects of the overall source design and details of the indexing mechanism along with operational parameters, ion optics, intensities and emittances for a wide variety of negative ion species are provided in this report.

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DESIGN FEATURES

As noted in Figs. 1 and 2, the source consists of five main assemblies: the high-voltage acceleration electrode assembly; the ion source module; the vacuum-air-lock assembly; the H_2O-cooled, rotary-motion target-holder assembly; and the indexing mechanism/target position read-out assembly. The ion source is designed to fit into the same ionization-chamber and vacuum chamber assemblies that accommodate single-sample sources routinely utilized for the generation of stable ion beams for the nuclear and astrophysics research programs at the Holifield Radioactive Ion Beam Facility (HRIBF) of the Oak Ridge National Laboratory (ORNL). The vacuum chamber of the source is re-entrantly attached to the high-voltage side of a metal-to-Al_2O_3 bonded high-

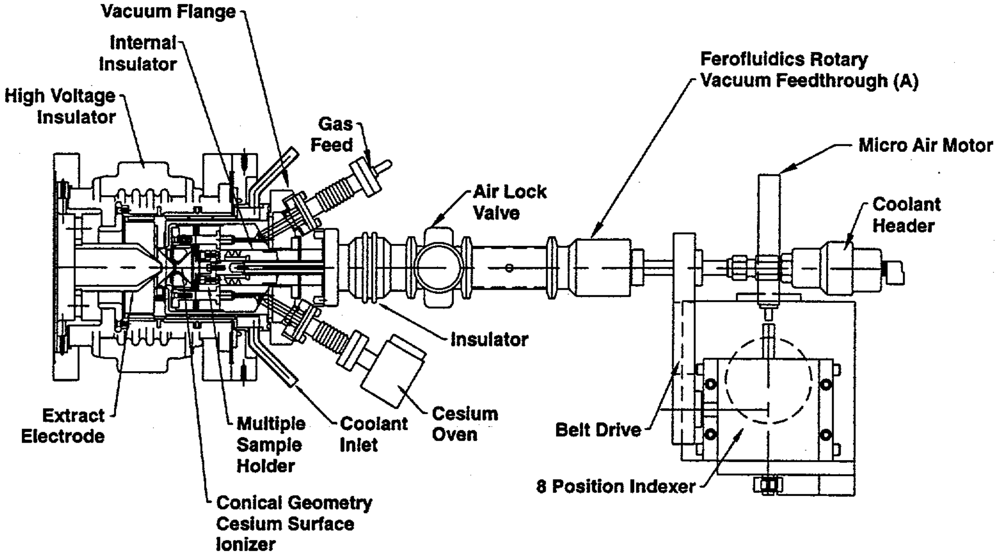

Fig. 1. Multi-sample negative-ion source (top view).

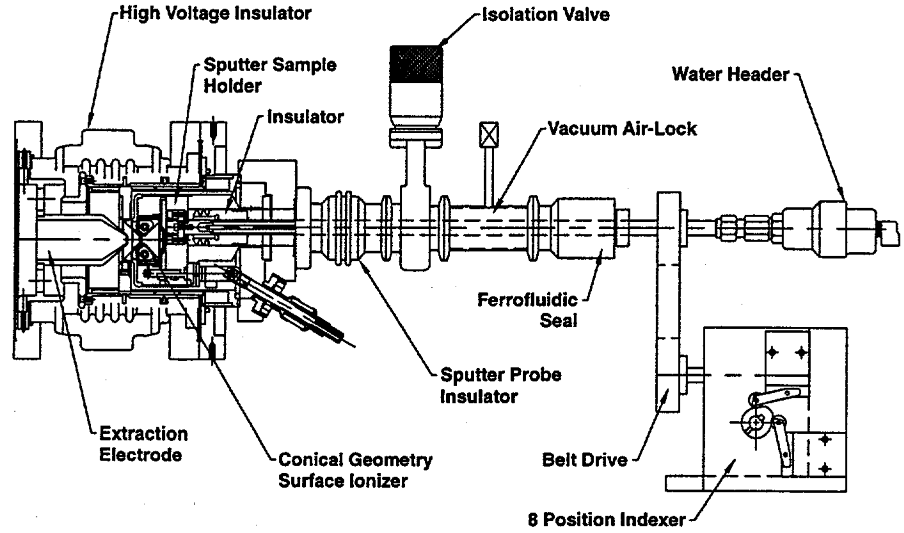

Fig. 2. Multi-sample negative-ion source (side view).

voltage insulator assembly while the acceleration electrode system is attached to the ground-side of the assembly. The source module can be quickly removed/installed from the vacuum housing by simply loosening/tightening thumbscrews. Power for the conical geometry Cs surface ionizer is fed through the stainless-steel ionization chamber support flange by means of a specially designed metal-to-ceramic bonded insulator, sealed with metal-to-metal gaskets. Cs vapor, from an external oven, is introduced into the ionization region of the source through the main vacuum flange by means of a metal-to-metal gasketed, transport tube, designed so that the transport tube is spring loaded against the body of the ionization chamber to eliminate vapor losses at the interface while allowing the oven assembly to be removed from the source module for servicing. Provisions are also made to feed gases through an analogous feed-through/transport system for in-situ formation of specific electro-negative compounds that serve as carriers for atomic species with low-negative electron affinities.

The sample indexing mechanism

The samples are screw attached to a Cu or Al holder that, in turn, is screw attached to a H_2O-cooled, Cu heat-sink assembly. The sample coolant is fed down and back through a coaxial conduit that allows H_2O to flow directly onto the Cu heat-sink assembly to which is attached the sample holder; the assembly is mounted at sample-plus-source potential. The sample holder is offset relative to the optic axis of the source (as illustrated in Fig. 3) so that a simple rotary motion can be executed to move individual samples into beam position. Because of physical restrictions in radius, in combination with the type of indexing mechanism chosen for moving samples into beam position, the sample holder is limited to eight, 7.9 mm-diameter samples. The belt-driven, coolant shaft is vacuum-sealed with a low friction, ferro-fluidic rotary-motion feed-through. Sample indexing is effected by applying 5 – 7 Pa air-pressure through plastic tubing to an electro-pneumatic

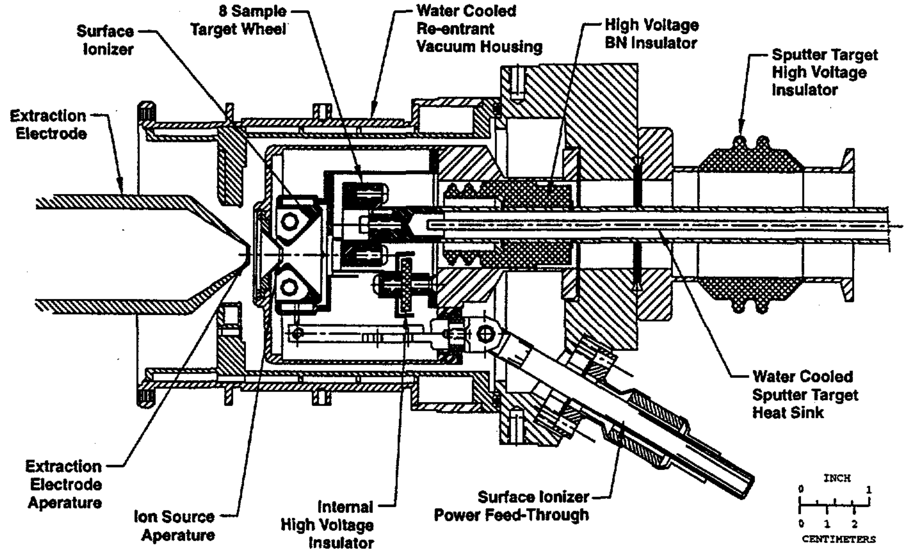

Fig. 3. Cross-sectional top-view of the multiple-sample, Cs-sputter negative-ion source showing details of the W-ionizer/sputter-sample and ion extraction electrode systems.

switch system, located at ground-potential, that actuates an eight-position, Geneva-type mechanism mounted at source potential. In-beam-position samples are identified by means of an LED display derived from a fiber-optic link in combination with a Gray binary encoder wheel mounted on the indexing mechanism. This system eliminates the necessity of having to mount power supplies at source potential or source-plus-sample potential that would otherwise be required to identify and sense sample position.

Ion optics

Since the rate of sputtering depends on the physical properties of the particular projectile/target combination as well as the energy and beam intensity of the Cs^+ projectile, the negative beam intensity depends on the Cs^+ ion beam intensity and the efficiency of transport through the electrode system. Therefore, the ion optics of both the Cs^+ and negative-ion beams are very important. The space-charge limited flow for Cs^+ ion current, $I_{Cs}{}^{+}$, 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 for the conical-geometry/sputter-sample electrode system with value $P = 4.9 \times 10^{-9}\ [A/V^{3/2}]$. The computer code described in Ref. 6 was utilized to assist in the design of the ionizer/sputter sample electrode system. The computed optics for space charge limited extraction of Cs^+ at 2 kV are shown in Fig. 4 while those for the corresponding negative-ion beam, generated in the sputter process, are shown in Fig. 5. Simulation of the negative-ion beam optics are made under the assumption that the negative ions leave the surface in a typical sputter-particle energy-angular distribution and mimic the Cs^+ ion beam distribution on the surface in terms of initial intensity profile. As noted, negative-ion beams are efficiently transported back through the electrode system. One of the excellent features of sources based on this principle is that negative-ion beam intensities can be easily controlled between zero and saturation by simply changing the potential difference between the sputter sample and ionizer.

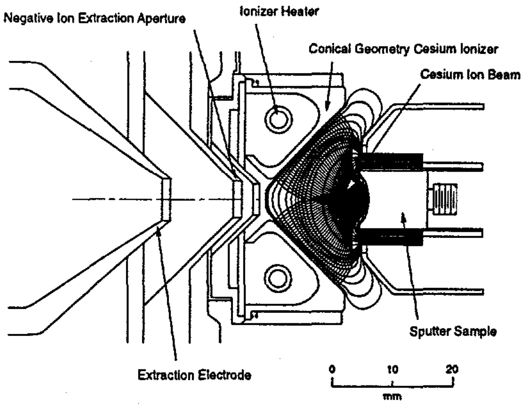

Fig. 4. Cs^+ beam optics as simulated by use of the computer code described in Ref. 6.

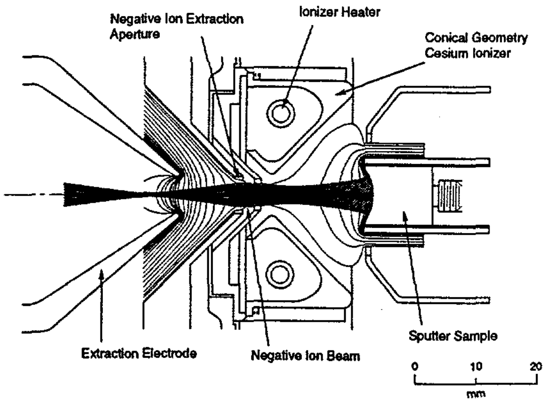

Fig. 5. Negative-ion beam optics as simulated by use of the computer code described in Ref. 6.

OPERATIONAL PARAMETERS

In order to realize optimum performance of the source, it is quintessential to know the dependence of the negative-ion beam intensity on important operational parameters of the source, including Cs oven temperature; ionizer temperature; and sputter-probe voltage.

Negative-ion beam intensity versus cesium oven temperature

Since the probability for negative ion formation depends exponentially on the difference between the electron affinity E_A and the work function ϕ of the surface that the particle leaves, low work function surfaces are prerequisite for reasonable negative ion formation efficiencies [7]. The flow of Cs into the source offers a general and dynamic means for lowering the work functions of surfaces and a means for overcoming deleterious poisoning effects that may occur due to the presence of certain impurities in the ionization chamber of the source. Since the effective Cs coverage depends on the difference between the rate of arrival and departure of Cs vapor to and from the sputter probe surface, the value of the work function of the surface and consequently the negative-ion beam intensity is sensitively dependent on Cs-oven temperature [8]. Knowledge of the negative-ion yield or relative negative-ion yield on this parameter is quintessential for optimizing negative-ion yields from the source. Relative negative-ion yield versus Cs-oven temperature, obtained at fixed ionizer power, and sputter-sample voltage are displayed in Fig. 6. Once known, the Cs-oven temperature, as a general rule, can be set at a fixed value up to T_{max} where T_{max} is ~ 200 °C. It also important to note that the Cs-oven temperature can not be used as a real-time control parameter because of the characteristically slow response times of thermal equilibrium processes. Values higher than T_{max} should be avoided since higher temperatures can be deleterious to the intensity and lead to operational instabilities due to sparking.

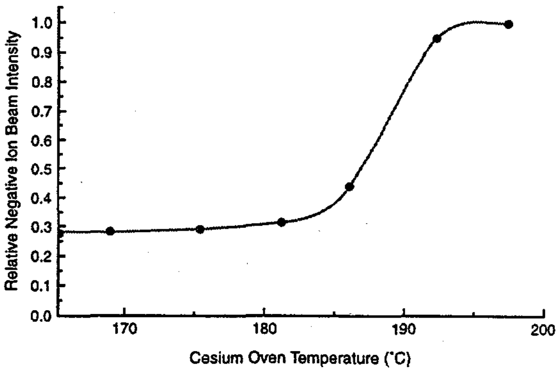

Fig. 6. Relative negative-ion beam intensity versus Cs-oven temperature for the multi-sample, Cs-sputter negative-ion source equipped with a conical geometry ionizer. Species P^-; Sputter-sample voltage: 6 kV.

Negative-ion beam intensity versus ionizer current

The surface ionization process is characterized by an abrupt initiation of ionization that occurs at a specific temperature, often referred to as the critical temperature [9]. This abrupt onset is associated with the fact that Cs^+ formed on the surface is bonded to the surface by the negative image charge, induced into the surface. The critical temperature for Cs occurs at ~ 1100 °C. This value correlates to an ionizer current of ~ 26 A, as noted in Fig. 7. Once the relationship between negative-ion yield and ionizer temperature or ionizer current/power is known, then the ionizer can be operated at fixed value. Typically the present source operates at a fixed ionizer current of ~26-27 A.

Negative-ion beam intensity versus sputter-probe voltage

Since the sputter ratio varies from material-to-material for a given projectile at fixed energy, the probe voltage required to reach steady-state negative-ion beam intensities also varies from species to species. An example of this dependence is displayed in Fig. 8 for a GaP sputter sample. Higher sputter-ratio materials such as Au reach saturation at lower sputter-probe voltages than do lower sputter-ratio materials such as C, and therefore, every compound or elemental material has a different intensity vs. sputter-sample voltage dependence.

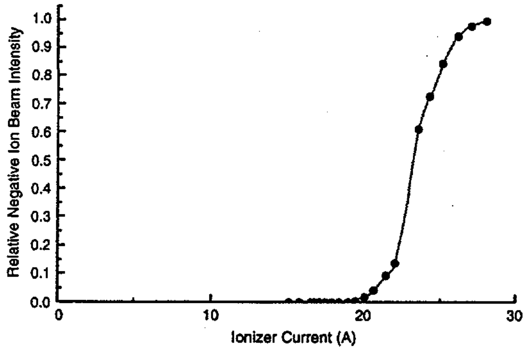

Fig. 7. Relative negative-ion beam intensity versus ionizer current for the multi-sample, Cs-sputter negative-ion source equipped with a conical-geometry ionizer. Species: C⁻ Sputter-sample voltage: –2 kV; Cs-over temperature: 195 °C.

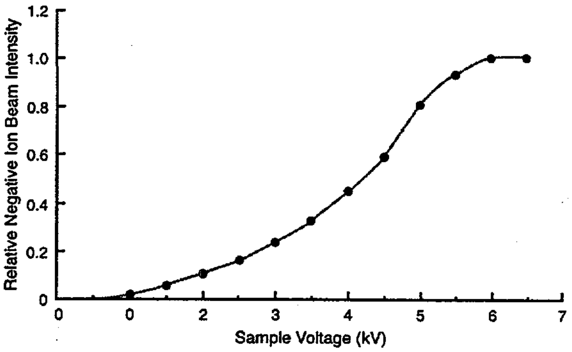

Fig. 8. Negative-ion beam intensity versus sputter-sample voltage for the multi-sample Cs-sputter negative-ion source equipped with a conical geometry ionizer. Species: P⁻; Cs-oven temperature: 195 °C.

NEGATIVE-ION BEAM INTENSITY AND EMITTANCE DATA

Negative-ion beam intensity data

Single-sample sources, equipped with this ionizer geometry, have been utilized for several years at the HRIBF for stable beam generation. Intensity data for several negative ion species derived from operation of these sources are shown in Table I.

Table 1: Negative-ion beam intensity data

Species	Sputter-Probe Material	Beam Intensity (μA)
C^-	C	160-275
Li^-	Li	3-12
B^-	B(90%) + Ag(10%)	30-60
O^-	Metal Oxides	250-310
F-	LiF, CaF	50-110
Si^-	Silicon	300-440
P^-	GaP, InP	90- 125
S^-	ZnS	60-110
Cl^-	NaCl	100-150
Ni^-	Ni	80-120
Cu^-	Cu	100-150
As^-	GaAs	50-60
Se^-	CdSe	30-100
Ag-	Ag	20-50
Pt^-	Pt	40-80
Au^-	Au	50-90

Emittance Data

Emittances have measured for the single-sample equivalent of the present source for a number of species using the equipment and procedures described in Refs. 10 and 11. An example of the normalized emittance versus percentage of total negative-ion beam for a Ni-beam is shown in Fig. 9. In general, the emittances for the source are very close to those measured for Cs sputter sources equipped with other ionizer geometries. The emittances vary with species (see, e.g., Ref. 12) and typically have values ranging between 6 and 8.5 πmm.mrad.(MeV)$^{1/2}$ depending on the species.

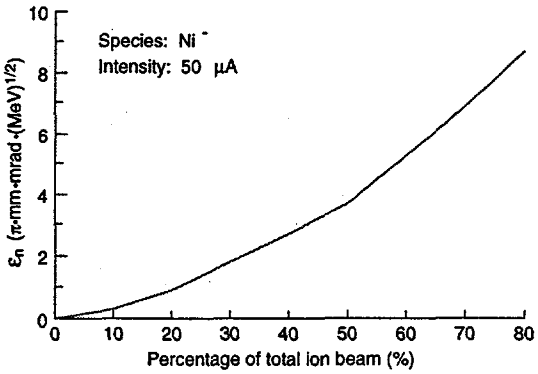

Fig. 9. Normalized emittance ε_n versus percentage of total negative-ion beam. (Taken from a single-sample source with identical ionizer and extraction optics.).

ACKNOWLEDGMENTS

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