

DESIGN ASPECTS FOR A PULSED-MODE, HIGH-INTENSITY,  
HEAVY NEGATIVE ION SOURCE

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**Abstract:** A high-intensity, plasma-sputter, negative ion source, which utilizes multi-cusp, magnetic-field, plasma-confinement techniques, has been designed at the Oak Ridge National Laboratory (ORNL). The source is an axial-geometry version of the radial-geometry source which has demonstrated pulsed-mode peak intensity levels of several mA for a wide spectrum of heavy negative ion species. The mechanical design features include provisions for fast interchange of sputter samples, ease of maintenance, direct cooling of the discharge chamber, and the use of easily replaced coaxial LaB<sub>6</sub> cathodes.

Introduction

The radial-geometry, plasma-sputter, negative ion source, described in Refs. 1-5, has demonstrated the capability of producing high-intensity (several mA) pulsed beams of a wide spectrum of atomic and molecular negative ion species and also has shown promise for operation in dc mode.<sup>5</sup> The pulsed-mode performance characteristics of this source type are particularly well suited for use in conjunction with the tandem electrostatic accelerator when used as an injector for a heavy ion synchrotron, while the dc mode of operation is commensurate with stand-alone tandem accelerator operation. For heavy ion synchrotron injection applications, high-intensity, pulsed beams of widths 50-300  $\mu$ s at repetition rates of 1-50 Hz for a wide spectrum of atomic and molecular species are typically required. In recent experiments,<sup>4</sup> it has been demonstrated that high-intensity pulsed beams (mA) can be injected into large tandem accelerators without deleterious effects. The specific need for a high-brightness source for use in conjunction with the Holifield Heavy Ion Research Facility (HHIRF) 25URC tandem electrostatic accelerator at the Oak Ridge National Laboratory (ORNL), which would serve as an injector for the proposed Heavy Ion Storage Ring for Atomic Physics (HISTRAP),<sup>6</sup> was the primary motivating factor which led to the design of the source described in this report.

Source Design

The high-intensity, radial-geometry, plasma-sputter, negative ion source, described in Refs. 1-5, has proved to be a reliable, stably operating source with a long lifetime for pulsed-mode operation. The intensity levels obtained are often higher, by factors of 30-100, than those which can be generated in cesium sputter-type sources such as described in Refs. 7-9 and yet the emittances of beams

provided by the source are comparable for pulsed-mode operation to those provided by conventional sputter-type sources.<sup>10</sup> The emittances of these beams also match the calculated acceptances of large tandem accelerators such as the 25URC tandem accelerator at ORNL.<sup>11</sup> However, the radial-geometry source is not equipped with provisions for rapid sputter sample interchange as is required for use at a research facility which operates continuously and which must provide beams from a wide spectrum of species on user demand. The radial-geometry source, as well, was designed for exclusive use for generation of H<sup>-</sup> beams for low-duty-factor synchrotron injection applications which require no direct cooling of the discharge chamber and is, thus, improperly cooled for the high power requirements necessary for dc-mode operation. The LaB<sub>6</sub> filaments used to initiate and sustain the discharge are not designed for fast interchange. When they break, either as a consequence of physical erosion or mechanical stress, an extensive period of time is required for replacement. The source shown in Fig. 1 was designed in an attempt to overcome some of these handicaps and to provide a source which could be used for both pulsed and dc modes of operation.

The operational characteristics of the axial-geometry source are expected to be identical in almost every detail to the radial-geometry source.<sup>1-5</sup> The source is constructed primarily of stainless steel and utilizes metal-to-ceramic bonded high-voltage insulators and low-voltage feedthroughs. Design emphasis has been placed on the ability to rapidly change the source itself and all degradable components. The cesium oven is mounted externally, permitting easy access for servicing, while providing good thermal isolation between the discharge chamber and the oven itself. The main source can be quickly and easily disassembled for cleaning and other maintenance operations. The source assembly is composed of four major independent assemblies: (1) the sputter probe vacuum airlock assembly; (2) a freon-cooled, stainless steel discharge chamber onto which is attached the cesium oven, discharge gas support system, coaxial geometry LaB<sub>6</sub> cathodes, and SmCo and AlNiCo plasma confinement magnets, (3) a ceramic-to-metal bonded alumina (Al<sub>2</sub>O<sub>3</sub>) insulator to which is attached the high-voltage extraction electrode system, and (4) the coaxial LaB<sub>6</sub> cathode assembly. The power supply arrangement required for operation of the source is shown in Fig. 2.

Sputter Probe Vacuum Airlock Assembly

The sputter probe assembly consists of a thin wall, 12.7-mm-diameter chromium plated copper tube to which is attached the 50-mm-diameter copper sample holder onto which is clamped the material of interest. The sample holder is cooled by continuous freon flow through a concentric tube arrangement. The probe can be inserted into and withdrawn from the source through the airlock valve which is sealed against atmospheric pressure by a conventional elastomer gasket. The

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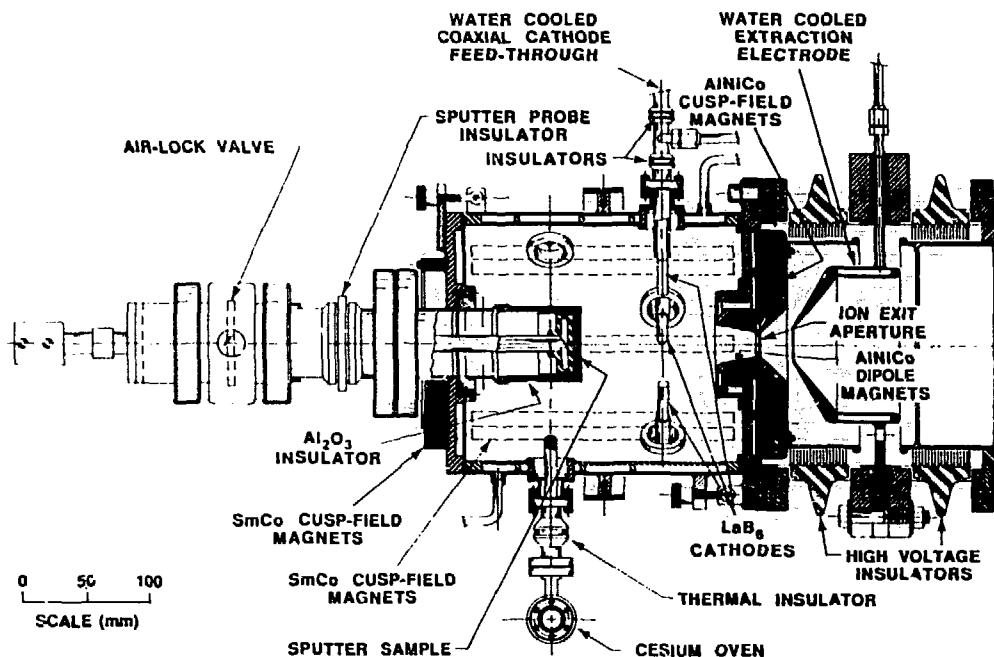


Fig. 1. Axial-geometry, plasma-sputter, negative ion source (top view).

vacuum interlock assembly is attached to an externally mounted ceramic-to-metal insulator which in turn is fastened to the back flange of the source. The insulator is used to isolate the probe-vacuum airlock assembly from the source body. Based on experience with sources equipped with similar provisions, the total time required for withdrawing, replacement, and reinsertion of the sputter probe sample material is expected to be the order of 10 minutes.

The sputter probe/airlock assembly is insulated from the source housing with an insulator designed to withstand potentials up to  $\sim 5$  kV. When fully inserted into the discharge chamber, the sputter probe is surrounded by an  $\text{Al}_2\text{O}_3$  insulating sleeve which prevents all internal negatively biased components other than the sample material from being bombarded by positive ions extracted from the surrounding plasma. Two geometries of sputter samples will be utilized. In cases where malleable metal sheet material containing the species of interest is readily available, samples 1-1.5 mm in thickness will be pressed by means of a die fixture into a 50-mm-diameter spherical sector probe with radius of curvature  $r \approx 210$  mm for focusing the negative ion beam generated in the sputtering process through the exit aperture of the source. Samples which are brittle must be formed from solid materials. Composite sintered compounds or mixtures of compounds will be typically 5 mm in thickness with a spherical radius of 210 mm machined into the face of the material. These samples will be indirectly cooled by clamping the sample to a spherical or flat geometry copper heat sink appropriately contoured to the respective sample geometry. The sputter probe assembly will be cooled by a freon heat exchange unit maintained at  $15^\circ\text{C}$ .

#### Vacuum Discharge Chamber and Plasma Confinement Arrangement

The vacuum/discharge chamber is made of stainless steel equipped with freon coolant passages to protect the ten sets of equally spaced SmCo and AlNiCo plasma discharge confinement magnets from thermal degradation by the radiant power incident on the walls of the chamber arising from the plasma discharge and high temperature  $\text{LaB}_6$  cathodes. Plasma confinement is effected by the use of ten rows of SmCo permanent magnets, equally spaced circumferentially around the diameter of the cylindrical chamber. The external and internal flanges of the chamber are equipped with ten equally spaced, azimuthally oriented SmCo and AlNiCo magnets, respectively. The internal flange is equipped with a set of dipole AlNiCo magnets to inhibit electron extraction from the source and thereby reduce loading to the extraction power supply and a replaceable tantalum aperture. Initially, the exit aperture will be 10 mm. The chamber is attached to the rear and front flanges by means of thumb screws for ease in disassembly for cleaning and other maintenance operations.

#### Coaxial $\text{LaB}_6$ Cathode Assembly

The source will utilize directly heated coaxial-geometry  $\text{LaB}_6$  cathodes to initiate and sustain the plasma discharge. The cathode structure is very similar to the design described by Leung et al. in Ref. 12. The high melting point, chemical inertness, low work function, and low sputter ratio properties make  $\text{LaB}_6$  especially attractive for such applications. The coaxial geometry is desirable because it minimizes the magnetic field surrounding the cathode and thus permits emission and escape of low-energy electrons from the surface. More importantly, the design allows easy and fast interchange of cathodes through a single metal-to-metal vacuum seal feedthrough.

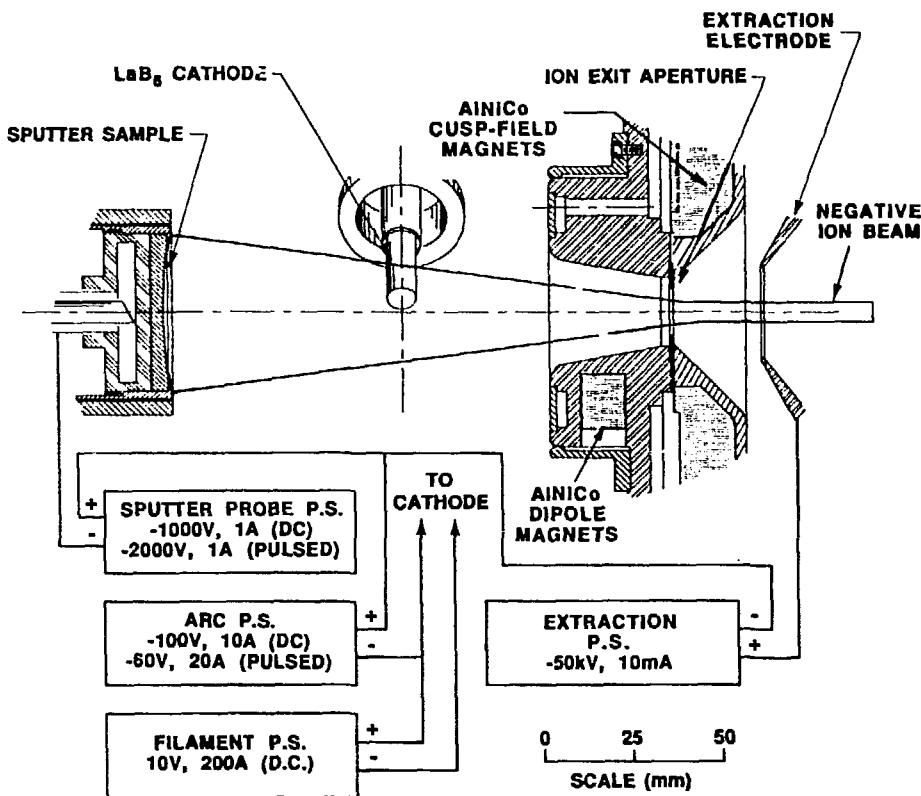


Fig. 2. Power supply arrangement for the axial-geometry, plasma-sputter, negative ion source.

#### The Ion Extraction Electrode System and Extraction Optics

One of the advantages of the plasma-type sputter negative ion source lies in the fact that, when operated in a high-density plasma mode, the negatively biased sputter probe containing the material of interest is uniformly sputtered. This characteristic makes it possible to take advantage of the large area spherical-geometry lens system which is formed between the spherical sector sputter probe and the plasma sheath which conforms to the geometry of the probe. Negative ions created in the sputter process are accelerated and focused through the plasma to a common focal point, usually chosen as the ion exit aperture of the source, and then pass into the field region of the extraction electrode system. Within the plasma, the ion beam is free of space charge effects. Thus, the sputtered particle energy and angular distributions, and aberrations in the acceleration plasma lens system determine the beam size at the focal point of the spherical lens system. At high beam intensities, space charge effects come into play when the beam exits the plasma and enters the extraction region of the source. However, because the beam energy is 500-1000 eV upon exit from the plasma region of the source, space charge influences on the beam are reduced. After exiting the source, the beam is further accelerated by a two-stage electrode system insulated by high-quality  $\text{Al}_2\text{O}_3$  insulators. Typically, the ion beam will be accelerated through a potential difference of 20 kV in the first stage and by an additional 30 kV in the second stage. The optics of the ion extraction aperture and second stage field regions are designed to provide inwardly directed radial restoring forces to the beam to offset, in part, space charge effects which will suddenly appear in the slow moving, intense heavy negative ion beams upon exit from the plasma region of the source.

The ion optics of the ion generation and extraction regions of the source have been studied computationally through use of the code described in Ref. 13. Examples of such calculations which display ion trajectories for a 3.5-mA  $\text{O}^-$  or a 1-mA  $\text{Au}^-$  ion beam are shown in Fig. 3. Negative ions, generated at the sputter probe surface and accelerated across the plasma sheath, drift through the field-free region of the plasma and exit into the extraction lens system where they are accelerated further to energies up to 51 keV. The characteristics of mA-intensity-level ion beams in the extraction region of the source are found to be dominated by space charge effects.

#### Expected Performance of the Source

The operational parameters and intensity capabilities of the subject source are expected to be similar to those of the radial-geometry source and therefore, the reader is referred to Refs. 1-5 for specific information concerning the species and intensity capabilities, as well as the qualities (emittances) of beams produced in this type of source. The anticipated operational parameters for pulsed-mode operation of the source are shown in Table 1. For example, the source is expected to generate peak beam intensities close to those reported in Ref. 4 for the radial-geometry source, which includes a list of more than 20 negative ion species, including 6 mA  $\text{C}^-$ , 10 mA  $\text{Cu}^-$ ; 8 mA  $\text{Pt}^-$ ; and 10 mA  $\text{Au}^-$ . The emittances of beams extracted from the source are also expected to be close to those of the radial-geometry source (typically,  $11\text{-}17 \pi \text{ mm.mrad (MeV)}^{1/2}$  at the 80% contour level, depending on the beam intensity).

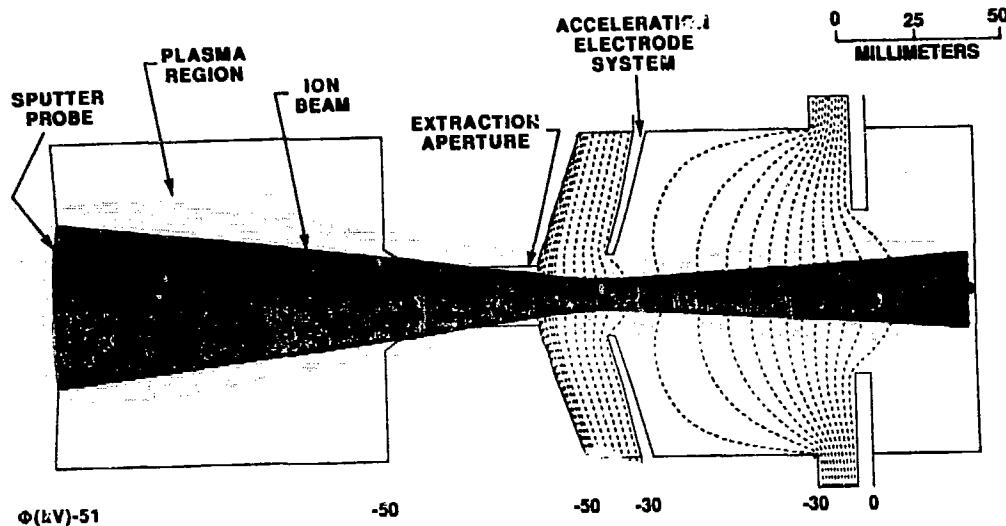


Fig. 3. Negative ion optics of the axial-geometry, sputter heavy negative ion source equipped with a two-stage extraction electrode system shown in Fig. 1. Ion beam: 3.5 mA O<sup>-</sup> or 1 μA Au<sup>-</sup>; ion energy: 51 keV.

#### Acknowledgements

The author is indebted to Dr. K. N. Leung for supplying information concerning the coaxial LaB<sub>6</sub> cathode assembly design used at Lawrence Berkeley Laboratory.

Table 1. Expected pulsed-mode source operating parameters.

Arc current	15-20 A
Arc voltage	30-60 V
LaB <sub>6</sub> cathode current	130 A
LaB <sub>6</sub> cathode temperature	1450°C
Xe gas pressure	2.3 x 10 <sup>-4</sup> Torr
Sputter probe voltage	500 V
Beam extraction voltage	50 kV
Cesium oven temperature	190-205°C
Beam pulse width	1-5 Hz
Repetition rate	1-50 Hz

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