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NEGATIVE ION SOURCES EQUIPPED WITH CONTINUOUS ANNULAR AND SPHERICAL GEOMETRY SURFACE IONIZERS*

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Summary

Axial geometry negative ion sources have been designed, developed, and evaluated for use in conjunction with tandem accelerator applications. These sources utilize continuous surface solid tungsten ionizers in either annular or spherical geometries to effect ionization of cesium vapor, which in turn is used to sputter a negatively biased probe containing the material of interest. The annular ionizer geometry source has been incorporated as an "on-line" source for routine operation of the Holifield Heavy Ion Research Facility (HHIRF) tandem accelerator. Both test stand and tandem accelerator operational experience indicate that such sources are reliable, long lived, stably operating and prolific producers of a wide spectrum of negative ions. To date these sources have been used to produce more than 18 negative ion species including Ag^-, Au^-, B^-, CaH_3^-, Cl^-, CrH_2^-, Cu^-, Lu^-, MgH_3^-, Mo^-, Ni^-, O^-, S^-, Si^-, Sn^-, TiH_3^-, Tm^-, and Yb^-. Details of the mechanical design features and computational techniques utilized in arriving at the final electrode configuration are presented in the text. Examples of data pertinent to source operation, the dependence of negative ion yields on certain source operational parameters and of intensities typical of a particular negative ion source are also given.

Introduction

The improved radial geometry negative ion source[1] which is used for routine operation of the HHIRF tandem accelerator at the Oak Ridge National Laboratory can be easily converted to an axial geometry source by installation of a cesium surface ionizer mounted in axial alignment with the negatively biased sputter probe. Thus, this configuration utilizes all of the design features of the improved radial geometry source. The axial geometry sources described in this report were designed in 1981 and are second generation developments of a similar source designed and developed in 1978.[2] These sources however, possess significantly improved mechanical design features; both sources also exhibit very different performance characteristics than the earlier source (Reference 2). These sources, like other sources which have been developed in recent years,[3,4] utilize the technique of secondary ion yield enhancement by sputtering a sample containing the material of interest in the presence of minute amounts ($<$ 1 monolayer) of Group IA elements.[5] (For a review of other negative ion source developments, the reader is referred to references 6 and 7 and the literature cited therein.) The sources described in this report utilize continuous surface solid tungsten annular[8] or spherical geometry ionizers rather than the helically wound ionizer incorporated in the original source[2] for producing the cesium ion beam used to sputter the sample material. The spherical geometry source is similar to that proposed by White.[9] Schematic drawings of each of the sources are shown in Figs. 1 and 2.

Computer-assisted techniques were employed to design the respective ionizer/sample sputter probe electrode systems for both sources. As a consequence, the sources performed immediately as predicted without requiring further development. Simple continuous ionizer surfaces offer well-defined boundaries for positive ion generation which are more amenable to computer simulation than those associated with more complex emission surfaces. More importantly, negative ion yields from the surface surrounding the usual axially located, concentrated wear pattern on the sputter probe appear to be lower than those

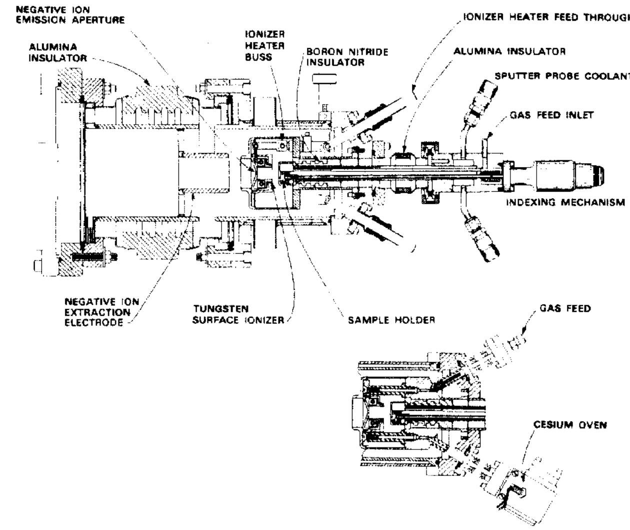

Fig. 1. The annular geometry ionizer cesium sputter negative ion source.

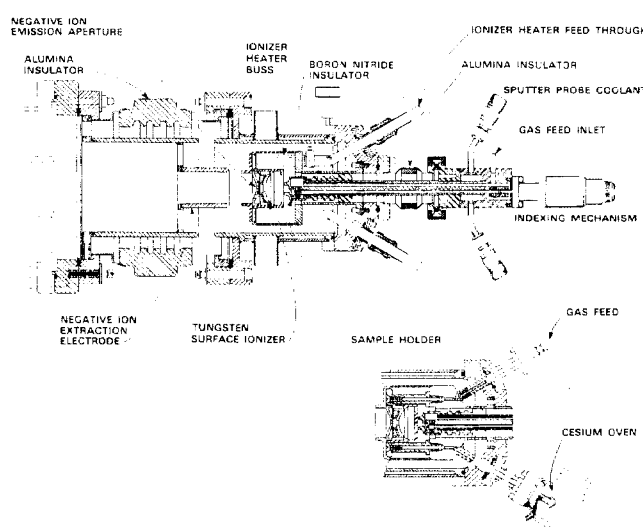

Fig. 2. The spherical geometry ionizer cesium sputter negative ion source.

associated with helically wound ionizers. This beam is often referred to as a halo beam. The halo effect is reduced to almost zero in the spherical geometry ionizer source. In these sources, only ions generated from the desired surface of the ionizer are accelerated; all other heated surfaces are obscured from the electric field region of the ionizer/sputter probe electrode system. The sputter pattern in the annular geometry ionizer source exhibits a weakly, uniformly worn area surrounding the concentrated wear pattern located on axis; thus, the halo effect is more pronounced than in the spherical geometry source.

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Principles of Operation

The method utilized in the source for positive ion formation is based on the thermodynamic equilibrium surface ionization phenomenon and thus the familiar Langmuir-Saha relation can be utilized to predict the ratio of positive ions to neutral atoms leaving a hot surface. The negative ion generation process cannot be described in terms of the analogous Langmuir-Saha relation for negative surface ionization due to the nonthermodynamic nature of the sputter process. Progress toward a more satisfactory theoretical basis for the secondary negative ion generation process has been made in recent years.[10]

Computational Analyses of the Positive and Negative Ion Generation Regions of the Sources

The geometric configurations of the positive and negative ion generation regions of the sources are readily amenable to simulation by solving Poisson's equation numerically for the chosen electrode system. The Stanford Linear Accelerator Center electron trajectory computer code[11] was used to calculate ion trajectories in the presence of space charge.

The Annular Geometry Ionizer Source. For the annular geometry ionizer source, the electrode configuration was arbitrarily chosen at the onset and optimized by altering the geometry in a series of iterations until acceptable beam profiles were achieved for both the positive and negative ion beams. An example of positive ion trajectories through the ionizer/sputter probe region of the source is shown in Fig. 3; the computed ion current density resulting from positive ion impact at the sample surface is shown in Fig. 4.

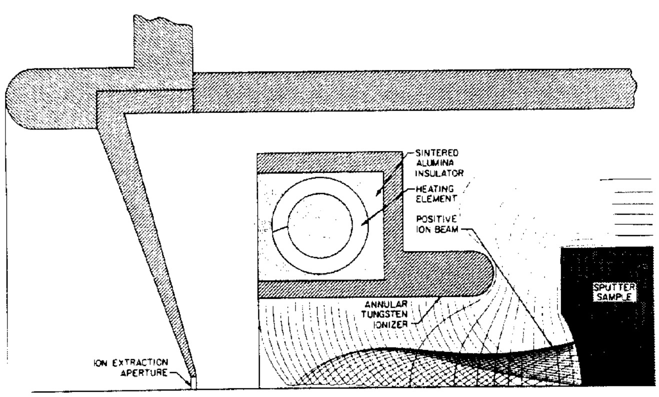

Fig. 3. Calculated positive ion trajectories in the ionizer/sputter probe region of the annular geometry ionizer source.

The wear pattern which would result from the positive ion distribution shown in Fig. 4 is composed of two parts: a region of concentrated wear with full diameter of ~ 0.75 mm, and a low density uniform wear region with diameter ~ 4.5 mm. The probe wear patterns observed in practice are found to closely approximate those predicted from such calculations.

An example of the negative ion trajectories through the electrode system which would result with full space charge compensation is shown in Fig. 5. The radius of curvature, r, of the negative ion generation surface was chosen to focus the ion beam through the exit aperture; a value for r of 10.2 cm was found to be optimum. Due to the difference in magnitudes of the positive and negative ion beams, there will be an overall net positive ion space charge effect. However, because of the difference in particle velocities near the points of generation for both the positive and negative ion beams, there may be differential space charge effects present in the anode and cathode surface regions of the source. Of course, the sputtering process will modify the ideal surfaces used in these simulations after a period of time and the optics will change somewhat.

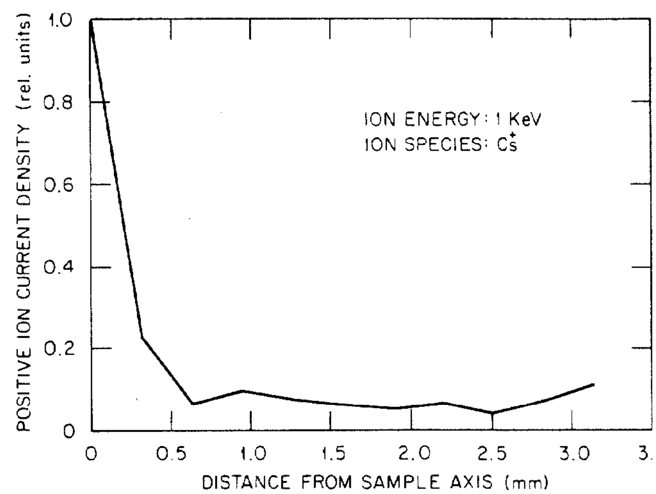

Fig. 4. Calculated positive ion current density distribution at the sputter probe sample surface of the annular geometry ionizer.

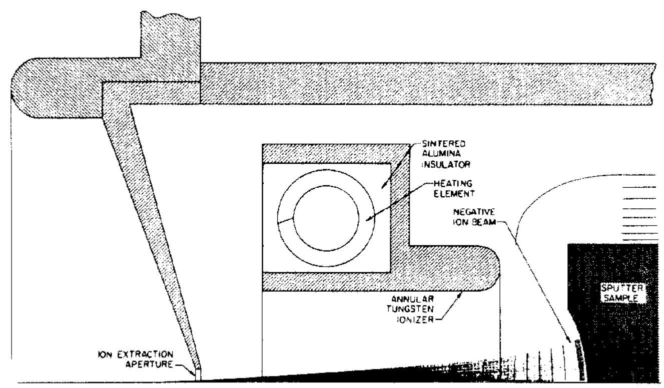

Fig. 5. Calculated negative ion trajectories in the ionizer/sputter probe region of the annular ionizer geometry source.

The Spherical Geometry Ionizer Source. The radius of curvature for the spherical geometry ionizer was arbitrarily chosen at the onset to be 25.4 mm. A 6.4 mm diameter aperture, located on axis, was chosen for extraction of negative ions. The sputter sample housing configuration and sample position within the housing was determined by iterative changes in the geometry until a satisfactory configuration for transporting the negative ion beam through the exit aperture was achieved. An example of computed positive ion trajectories between the ionizer and sputter sample is shown in Fig. 6 and the corresponding current density distribution is shown in Fig. 7. Note the lack of an appreciable halo surrounding the high current density distribution for this ionizer. The full width of the beam at impact with the sample surface is approximately the same as that of the concentrated wear region in the annular ionizer source (~ 0.75 mm). Based on the apparently smaller halo, this source should, in principle, have a lower emittance than the annular ionizer geometry.

An example of negative ion trajectories through the electrode configuration finally chosen for beam transport through the anode aperture is shown in Fig. 8. It should be pointed out that this design is not unique and other configurations may be equally as effective in transporting the negative ion beam to the exit aperture.

Mechanical Design

The axial geometry sources are identical in almost every detail to the radial geometry source,[1] with the exception

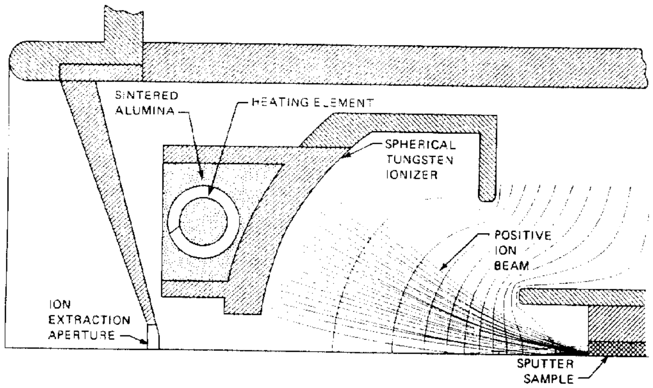

Fig. 6. Calculated positive ion trajectories in the ionizer/ sputter probe region of the spherical ionizer geometry cesium sputter negative ion source.

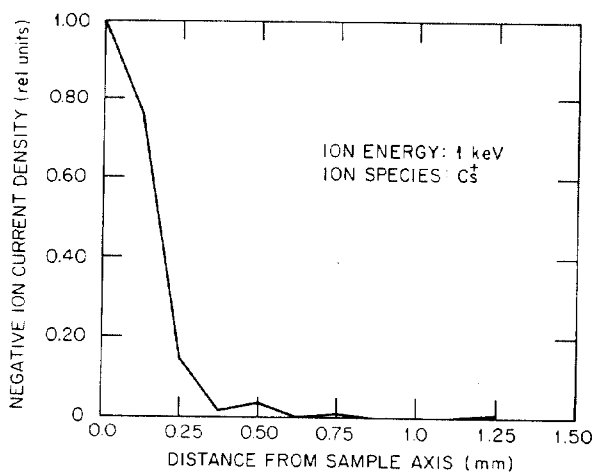

Fig. 7. Calculated positive ion current density distribution at the sputter probe region of the spherical geometry ionizer source.

of the location and type of the cesium ionizer. Conversion from the radial geometry source to either of the axial geometry configurations can be accomplished in a few minutes. The sources are constructed primarily of stainless steel and utilize metal-to-ceramic bonded high-voltage insulators and low-voltage feedthroughs. Boron nitride insulators are used in positions where vapor or sputter deposits could lead to degradation of the insulator. Design emphasis has been placed on the ability to rapidly change the source unit itself and all degradable components. The cesium oven is mounted externally, permitting easy access for servicing while providing thermal isolation between the ionization chamber and the oven itself. The main source subassembly can be quickly and easily withdrawn from the freon-cooled housing in a few minutes so as to reduce accelerator down time during periods of required maintenance. An important design feature allows removal and replacement of the internally mounted boron-nitride insulator without major disassembly of the source. Thus, insulators which have been contaminated during prolonged source operation can be quickly replaced without significant accelerator down time.

Extensive experience has been gained with the radial and annular ionizer sources during routine HHIRF tandem accelerator operation. The spherical geometry source has only been evaluated during test stand operation. The merits of the design have proven themselves through significant reduction of accelerator down time over that of the original source[12] during required periods of maintenance, source interchange, sample interchange and oven servicing. Change of individual samples

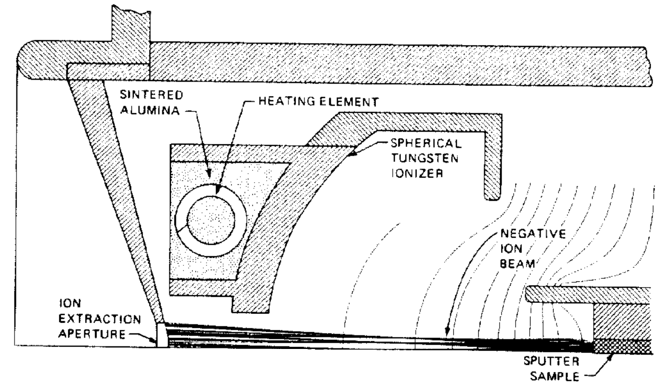

Fig. 8. Calculated negative ion trajectories in the ionizer/ sputter probe region of the spherical geometry ionizer source.

can be effected in ≤ 15 minutes through an airlock assembly (not shown in Figs. 1 and 2.) However, the axially located wear pattern characteristics of these sources are compatible with the employment of a multiple sample indexing mechanism (Figs. 1 and 2). A device of this kind has been designed, fabricated and will soon be evaluated. This feature will be the subject of a future report.

The Ionizer

The ionizers previously described are made of tungsten and are heated with non-inductively wound 97% W - 3% Re or molybdenum heating elements of typical diameter $\phi = 1\frac{1}{2}$ mm. The heating elements are embedded in sintered matrixes of Al_2O_3. The annular ionizer is 15.9 mm in length and has an inner bore radius of 6.4 mm. The spherical geometry ionizer has a radius of curvature of 25.4 mm and a cylindrical diameter of 32 mm. Negative ions are extracted through a 6.4 mm diameter aperture located on the axis of the spherical ionizer. In order to ionize cesium, the surface must be heated above the critical temperature which is ~ 1000°C for cesium. It should be pointed out, that the efficiency for ionization of Cs^+ will decrease if the temperature of the ionizer is too high.

Source Operational Parameters

Characteristics of the Cesium Oven. The cesium oven temperature determines the rate at which vapor flows into the ionization chamber and therefore the arrival rate of cesium onto the sputter probe sample surface. The oven heater utilized for both sources is a commercially available, 175-watt (120 VAC), band-type device that slips over the cylindrical body of the cesium reservoir. The oven is modular and positioned external to the main vacuum for easy access. During operation, the oven is wrapped with aluminum foil to provide radiation shielding and the temperature is monitored with a chromel-alumel thermocouple. The oven uses the conductance limited flow design principles utilized in the original radial geometry source[12] — a design which provides excellent flow control and very effectively thermally decouples the oven from the plasma discharge chamber.

Negative Ion Yield Versus Cesium Oven Temperature. The relationship between negative ion yield and cesium oven temperature has been found to be approximately the same for the annular and spherical geometry ionizer sources. Figure 9 displays total negative ion yields of Cu^- and Ni^- as a function of cesium oven temperature. The maxima in temperature for these elements are seen to both occur at ~ 265°C.

Negative Ion Yield Versus Sputter Probe Voltage. Total negative ion yields from the annular geometry ionizer source as a function of probe voltage for Cu^- and Ni^- are shown in Fig. 10. For these cases, the characteristic maximum in the negative ion yield versus probe voltage was not reached. The total negative ion yields from this source increase strongly with voltage over a range of probe voltages up to 1100 V.

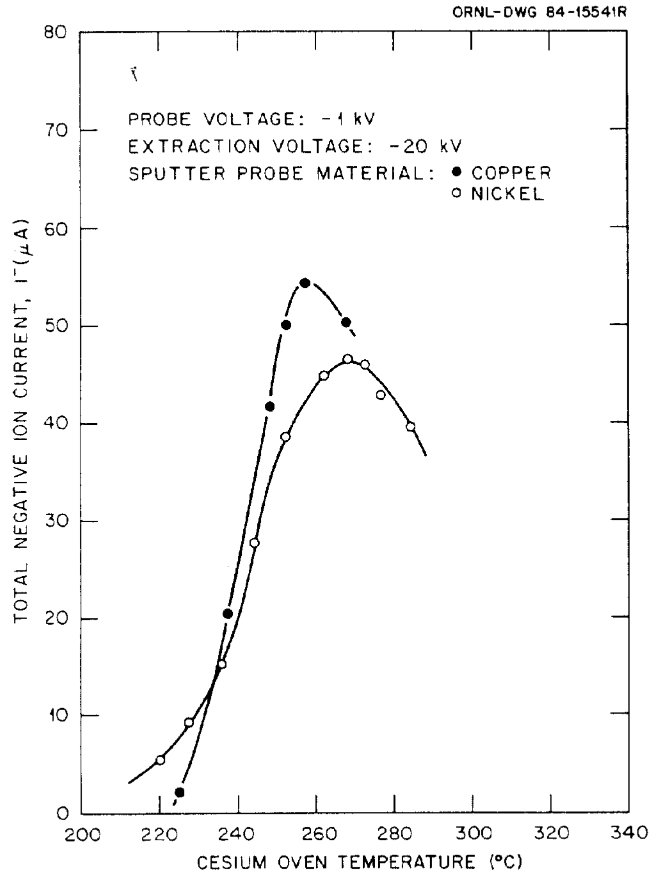

Fig. 9. Total negative ion yield as a function of cesium oven temperature for the annular geometry ionizer cesium sputter source.

Negative Ion Yields

Experience with test stand operation and operation with the HHIRF tandem accelerator indicates that these sources are simple to operate, reliable and prolific producers of a wide spectrum of negative ions. With the annular geometry ionizer source operated at optimum cesium oven temperatures and with a -1000 volts probe potential, the following negative ion yields have been realized: 16 μA Ag^-; 125 μA Au^-, 1 μA B^-; 60μA Cu^-; 1 μA CrH_2^-; 1.4 μA Mo^-; 100 μA Ni^-; 20 μA S^-; 5 μA Yb^-. (The currents indicated above do not necessarily represent maximum values for the specific ion.) The spherical geometry ionizer source has not been utilized as extensively as the source equipped with the annular geometry ionizer.

Conclusions

Two axial geometry cesium sputter negative ion sources have been designed and evaluated. The annular geometry source has been employed for use during routine operation of the HHIRF tandem accelerator. Computer-assisted techniques were utilized in the design of the sources prior to engineering. The predicted characteristics of the positive and negative ion generation regions of these sources agree almost in detail with those observed experimentally. The sources have been designed for expeditious installation, removal and servicing so as to minimize accelerator down time during required source maintenance or sample change. The sources utilize a continuous-surface solid-tungsten annular or spherical geometry ionizers to effect positive ion formation. Use of the annular ionizer results in a highly concentrated wear pattern on axis surrounded by a uniformly distributed low density (halo) wear pattern while the spherical geometry source exhibits even weaker halo beam effects. Both sources are compatible with the employment of multiple sample indexing mechanisms. Each of the sources are extremely easy to operate and exhibit long lifetimes (~ 2500 hours). The sources have proven to be versatile producers of intense beams of many negative ions and are well suited for tandem acceleration applications.

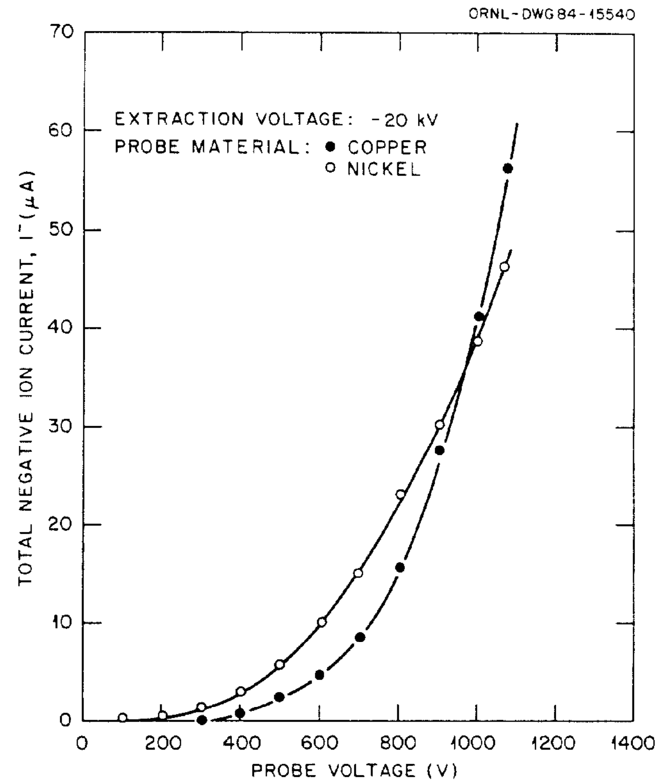

Fig. 10. Total negative ion yield as a function of sputter probe voltage for the annular geometry ionizer cesim sputter source.

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