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A UNIVERSAL NEGATIVE OR POSITIVE ION SOURCE

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Summary

This report describes a multipurpose negative or positive ion source which can be used in a variety of low energy or high energy research applications. Conversion from negative/positive modes of operation can be accomplished by simply reversing the polarities of pertinent extraction and beam transport power supplies. Preliminary results obtained from recent evaluative studies along with design details and negative and positive yields observed to data are given. Thus far, the source has demonstrated μA intensity capabilities for several negative and positive ion species including C^-, Cu^-, Au^-, N^+, N_2^+, P^+, A^+, and Cs^+.

The Negative Ion Mode of Operation

Introduction

Negative ion sources can be described in terms of their ion generation mechanisms and generally fall into one of the following categories: 1) charge exchange; 2) dissociative attachment; 3) or surface ionization. The source described in this report utilizes sputtering in the presence of a diffuse cesium plasma for the production of negative ion beams from a surface ionization mechanism. The source, in essence, is an axial configuration of the University of Aarhus source[2,3] but differs significantly in observed operational characteristics.

The most important discovery which has led to the recent advances in negative ion source technology is attributable to Krohn who, in 1962, discovered that negative ion yields can be greatly enhanced by sputtering in the presence of cesium.[1] This method has proven to be an almost universal means of generating negative ion species and has served as the basis of several negative ion source developments.[2-12]

Of the sources reported to date, the source of Andersen and Tykesson of the University of Aarhus,[2,3] or sources similiar in principle, appear to produce higher intensities with better beam qualities than preceding sputter sources. For example, the intensities exceed considerably those obtained from sources which utilize a positive cesium ion beam for both sputtering and as a simultaneous means of lowering the surface work function.

The negative ion generation mechanism in sources such as the one described in this report provides a means of producing and controlling the cesium layer thickness which is so important for maximum negative ion generation. In sources of this type, neutral cesium is introduced into an ionization chamber from a cesium vaporization oven where a plasma is generated by surface ionization or electron impact. The material of interest is maintained at a negative potential (∿-1000 V) relative to the discharge chamber and is sputtered by positive cesium ions extracted from the plasma under space charge limited conditions. The sputter probe is usually spherical in geometry and is positioned a distance away from the exit aperture which corresponds to its radius of curvature. Negative ions, produced in the sputtering process, are accelerated across the thin plasma sheath and focused through the exit aperture. This geometry permits ions to be efficiently extracted from relatively large surface areas with good optical properties.

Negative Ion Generation Mechanism

The mechanism for negative ion generation in cesium sputter sources can be described according to classical surface ionization theory.[9] Whenever a dissimiliar surface is coated with a monolayer of cesium the work function ϕ_0 is lowered. The amount $\Delta\phi$ by which the work function is lowered relative to the electron affinity E_a of the material determines the degree of negative ionization of particles leaving the surface at temperature T.

A schematic of the process, similiar to the arrangement of Krohn,[1] is shown in Fig. 1. A positive ion beam, usually cesium, is allowed to impinge on a surface of work function ϕ_0 and temperature T covered with a monolayer of cesium. The sputtered particles which leave the surface may have a greatly enhanced probability of becoming negatively ionized depending on their electron affinities E_a and the surface work function ϕ_0 and the change in surface work function $\Delta\phi$ effected by the cesium coverage.

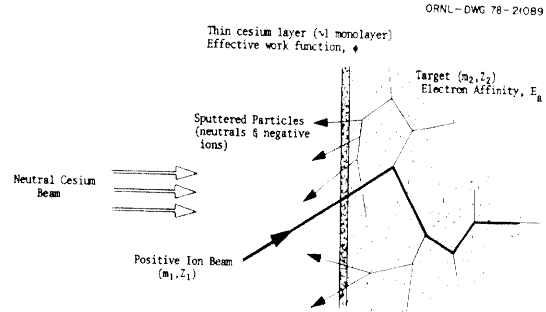

Fig. 1. Illustration of Negative Ion Generation Mechanism via Sputtering in the Presence of Cesium.

The layer of cesium may be provided by thermal evaporation or ion implantation into the surface. The former method provides a means of adequate coverage necessary for effecting a minimum surface work function while the latter method rarely provides optimum cesium surface coverage.

Under steady state conditions, the rate of arrival of cesium in the form of neutral or positive ions is just balanced by the rate of cesium reevaporation

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and sputtering from the surface. In this way, a steady state effective thickness of cesium is established which may be altered by changing one or more of the source controllable parameters. (For example, the cesium oven temperature and/or sputter probe voltage.)

Source Design and Description

The axial geometry form of the Aarhus source offers a degree of simplicity over that of its predecessor and is a natural evoluntionary consequence. Recently, sources similiar to the one which will be described here have been reported by Caskey *et al.*,[10] Billen,[11] and Middleton.[12] All of the sources, though similiar in principle, differ in design detail and modes of operation.

The source is shown in Fig. 2 and illustrated schematically in Fig. 3. The plasma is initiated by surface ionization of cesium in contact with a heated one and one-half turn 1½ mm dia. tantalum wire. Although the source is provided with an arc discharge power supply, it is never used during negative ion operation. A modular holder, mounted from the top of the ionization chamber, contains the filament and an electron reflector. The reflector discourages axially directed discharges which could collisionally attenuate the ion beam during transit through the plasma discharge. However, this effect is expected to be small (∿ 1-2%).

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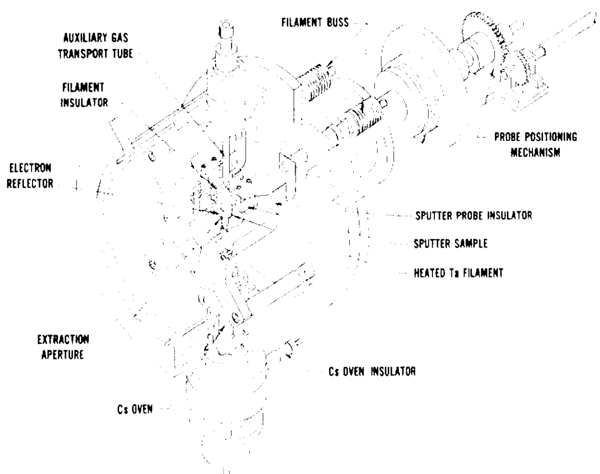

Fig. 2. Axial Geometry Negative or Positive Ion Source.

Auxilliary gases may also be metered into the discharge chamber to provide reactive gases for chemical combination with the sputter probe material in the formation of molecular negatives.

A weak transverse magnetic field may be used during operation. In fact, as will be shown later, the source may be operated in either of two different modes (with or without a magnetic field). The cathode wear pattern depends on the particular mode of operation.

The sputter probe is typically operated at ∿-1000 V relative to the discharge chamber. In the uniform wear mode, the thin sheath (∿ 1½ mm at 1000 V) conforming to the spherical contour of the sputter probe, extracts positive ions from the plasma boundary which sputter cathode material back through the thin cesium layer. In the nonuniform wear mode, most of the cesium positive ions are localized on axis and negative ions are principally sputtered from this area of the cathode.

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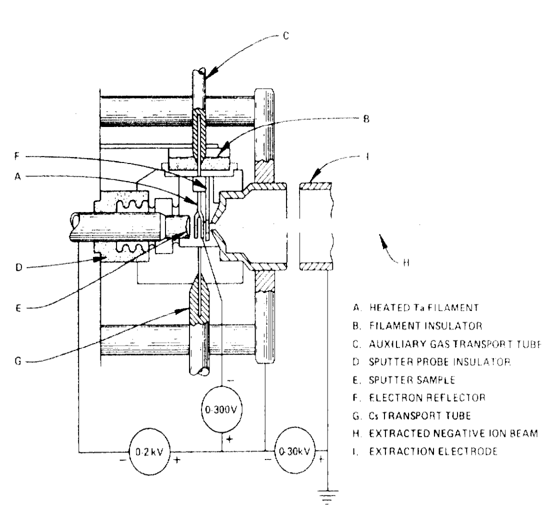

Fig. 3. Axial Geometry Negative Ion Source.

The source is also equipped with a mechanism for positioning the sputter probe relative to the exit aperture which enables efficient extraction over extended run times due to errosion of the cathode surface.

Oven Design

In the source, cesium is introduced into the ionization chamber by means of a carefully designed oven and vapor transport system which effectively thermally decouples the oven from the discharge chamber. The vapor is introduced into the ionization chamber under conductance limited flow conditions through a 5.9 cm long stainless tube of 3/4 mm dia. In the regime of operation, the Knudsen flow relation is assumed appropriate.

Figure 4 displays a theoretically derived flow rate curve which incorporates the Knudsen formulation and an integrated form of the Clausius-Clayperon equation which relates vapor pressure of cesium as a function of temperature.[13] The open circles were obtained by reversing the polarity of the source and measuring the positive ion beam as a function of oven temperature.

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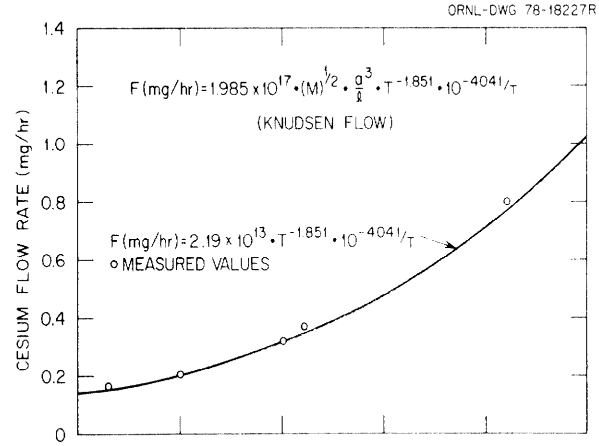

Fig. 4. Cesium Flow Rate as a Function of Oven Temperature. (The solid line is a theoretically derived; the open circles are measured values.)

The oven consists of a reservoir for the cesium or other material surrounded by a boron nitride cylinder which is heated by a spiral wound tantalum wire (3/4 mm in dia.). The maximum oven temperature which can be achieved with the present power supply arrangement is 365°C at a power input of 86 W. Therefore, the present arrangement only allows one to process high vapor pressure materials. Lower vapor pressure materials may be processed by increasing the power input. This, of course, is not required for the negative ion mode of operation since cesium is exclusively used in the oven. The oven is also equipped with removable heat shielding which is desirable for higher temperature oven operation.

The knowledge of yield versus source operational parameters such as cesium oven temperature and sputter probe voltage is essential for optimum, efficient and stable operation.

Yield Versus Cesium Oven Temperature

The oven temperature determines the rate at which cesium flows into the ionization chamber and therefore the effective cesium layer thickness. The relative negative ion yields as a function of oven temperature for C^- and Au^- are shown in Fig. 5. The yield curves are quite flat in contrast to similiar curves obtained from a modified Aarhus geometry source.[9] The C^- data were obtained while operating the source with a transverse magnetic field (∿ 150 G) while the Au^- data were taken without a magnetic field.

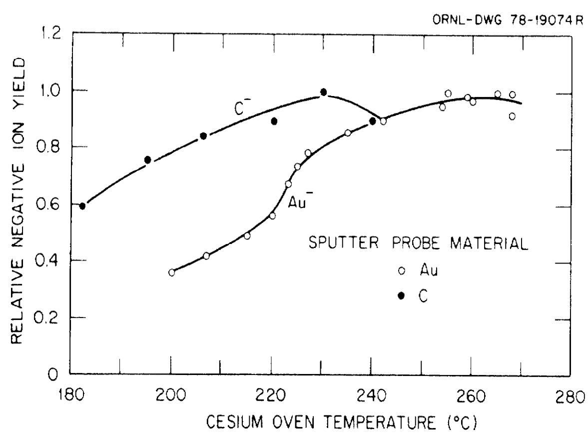

Fig. 5. Relative Negative Ion Yields as a Function of Cesium Oven Temperature.

Influence of the Magnetic Field on Cathode Wear

Examination of the C and Au cathodes after equivalent use revealed a uniform wear pattern over the cathode surface of C (with a transverse magnetic field) and a deeply pitted axial wear pattern of very small diameter (∿1½ mm) located an axis for the Au cathode (without a magnetic field). This suggests that a radially distributed plasma density exists with maximum on axis when the source is operated without a megnetic field. The magnetic field apparently homogenizes the plasma density and thus produces more uniform cathode wear. This effect has been observed for a limited number of cathode materials but is believed to be reproducible.

Yield Versus Sputter Probe Voltage

The oven temperature and sputter probe voltage are the controllable parameters, which in combination, can be regulated to maintain optimum cesium coverage and thus maximize the negative ion yields. The sputter probe voltage affects the cesium layer thickness due to variation of sputtering rate with voltage. A voltage too low will not produce maximum negative ion yields at optimum cesium flow rates because of the low sputtering rate which serves to optimize the cesium layer as well as provide material for negative ionization. In contradistinction, too high a voltage can detrimentally disturb the cesium layer by sputtering away the monolayer too fast which results in an increasing work function and thus reduces the negative ion yield. The yield versus sputter probe voltage curves for the two cases are shown in Fig. 6. The yields rise linearly for Au^- and almost linearly for C^-.

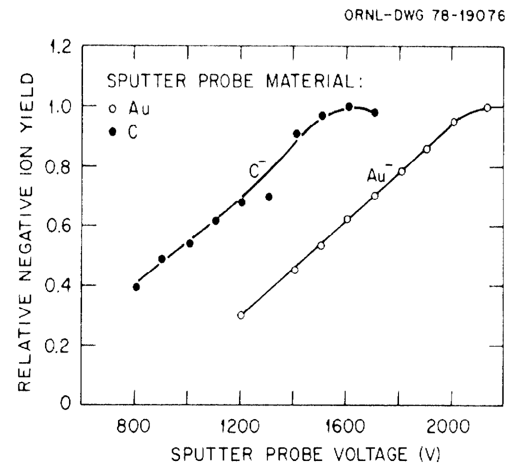

Fig. 6. Relative Negative Ion Yields as a Function of Sputter Probe Voltage. (C^- with transverse magnetic field, Au^- with no magnetic field.)

Yield Versus Sputter Probe Position from the Extraction Aperture

As mentioned before, the source is equipped with a mechanism for adjusting the probe position relative to the exit aperture. The mechanism is extremely useful in assuring efficient negative ion extraction over prolonged periods of source operation due to changes in surface contour with time. Figure 7 displays the results obtained for C^- and Au^-. We note that the Au^- yield curve falls linearly with distance from the aperture while the C^- yield is maximized whenever the probe is situated at a position corresponding to the radius of curvature of the spherical surface. This is typical behavior for uniform cathode wear over the entire cathode surface.

Negative Ion Yields

The source produces negative ion currents slightly lower than those observed from its Aarhus geometry counterpart. Maximum negative ion yields of 20 μA C^-, 20 μA Cu^-, and 28 μA Au^- have been observed.

Discussion and Conclusions

The axial geometry negative ion source has demonstrated the capability of producing rather intense negative ion beams from the materials thus far evaluated while operating with reasonable stability for a plasma discharge source. The source may be operated in either of two modes depending upon the desired

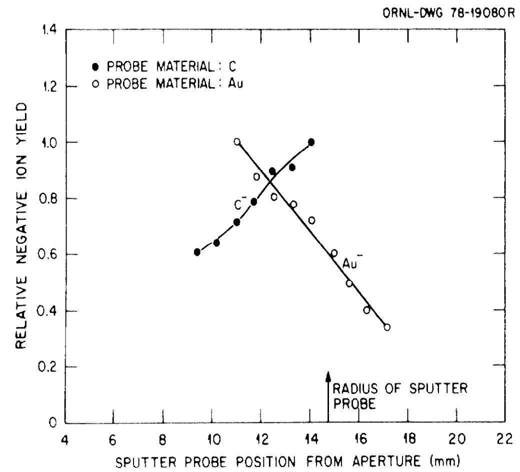

Fig. 7. Relative Negative Ion Yields as a Function of Sputter Probe Position from Aperture. (C^- with transverse magnetic field, Au^- without magnetic field.)

cathode wear pattern. In cases where the material is limited and expensive, as in the case of highly enriched rare isotopic material, it would be desirable to operate the source without a magnetic field. In this mode of wear, a very small pellet mounted on axis could be used. On the other hand, whenever there is an abundance of inexpensive material, it would probably be desirable to operate with a magnetic field for uniform wear of the cathode. In this mode of operation, the material of interest would last for a much long time.

Although the source is in the early stages of development, it appears to produce negative ion intensities comparable to those of the Aarhus geometry source which are adequate for the requirements of most low energy atomic and tandem accelerator applications.

The Positive Ion Mode of Operation

Introduction

The applications to which a source, such as described in this report, can be put to use are many and varied. For example, a versatile heavy ion source which can be readily converted from negative to positive and vice versa could be used in a variety of low energy atomic and molecular physics as well as in high energy accelerator based atomic and nuclear research programs. The previously described source, originally designed primarily for negative ion generation can be easily converted from negative to positive ion operation by simply turning the modular filament holder around and reversing the polarities of the extraction and other pertinent beam transport supplies. Investigation of the positive mode of operation is in the early stages of evaluation and the data presented here are the results of first attempt—short duration measurements.

Source Description and Principle of Operation

The source, shown schematically in Fig. 8, is identical to the negative ion source with the exception of the orientation of the modular filament holder and the necessary polarity reversals. In this mode of operation, of course, the sputter probe is not used whenever the species of interest is introduced in the form of a gas though the auxilliary gas transport system or vapor from the oven. However, when biased negatively as in the negative ion mode of operation, material may be sputtered from the cathode and ionized in the plasma discharge. The source, then, is almost identical to the Hill-Nelson geometry[14] with the exception that a transverse magnetic field is usually necessary in order to maximize the positive ion yield from the source. To date, this sputtering approach for providing materials for ionization has not been investigated.

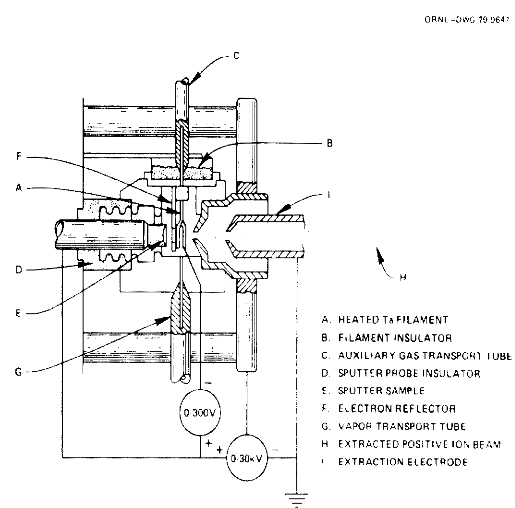

Fig. 8. Axial Geometry, Positive Ion Source

The plasma generation mechanism is similiar to that of the Freeman[15] source which in essence utilizes the magnetron principle.[16] Briefly, the source operates as follows: The heated tantalum filament (1½ mm dia.) is positioned directly in front of a 2 mm dia. aperture. A plasma discharge is initialed by electron impact ionization of an auxilliary support gas and/or the material of interest. Positive ions diffuse from the aperture and are accelerated through a potential drop of ∿ 20 kV.

Two filament configurations have been used: 1) a 1½ turn coil with axis oriented along the direction of ion extraction and 2) a "U" shaped filament with the straight bottom portion aligned with the transverse magnetic field. The latter configuration more nearly researches the Freeman source filament arrangement. Preliminary results from the two configurations do not differ substantially. Primary electrons emitted by the filament execute complex spiral trajectories due to the composite filament and transverse magnetic field orientation with respect to the discharge direction. A tantalum electron reflector, mounted behind the filament, directs the discharge toward the ion extraction aperture.

Typical source operation parameters are given below:

Extraction Voltage (kV): 20-30
Extraction Current (mA): 2-3
Filament Power: 5 V, 70 A
Discharge Power: 50-150 V; 0.5-2 A.

Oven Temperature Capabilities

The oven is identical to that used for negative ion production and has an upper temperature limit of

365°C which requires only 86 W power input. Therefore, only high vapor pressure solid materials can be processed with the present arrangement. This limitation is only an artifact of the power supply used which can be easily changed. For example, an upper temperature limit of ∿ 700°C can be achieved with a power input of ∿ 400 W without modification of the oven. Higher temperatures can be achieved by further increasing the available power. In addition to using gaseous or high vapor pressure feed materials, the source can be used to generate positive ions from almost every naturally occuring solid either by direct vaporization or utilizing the well-known internal hologenation technique – provided adequate temperatures can be achieved with the oven. (See Ref. 17 for discussion and other references on the subject.) At elevated temperatures, particularly whenever the hologenation technique is used, it would be advisable to change the ionization chamber material to either carbon or a refractory metal such as molybdenum or tantalum in order to prevent chemical errosion of the present stainless steel chamber.

Positive Ion Yield

The source has not been extensively operated in the positive ion generation mode and the ion yields given below reflect first attempt-short duration measurements. Data were taken using the ORNL ion source test facility. All ion currents are the momentum analyzed values.

Feed Material	Ion Species	Oven Temp.(°C)	Yield(μA)
N_2	N^+	---	0 - 30
N_2	N_2^+	---	0 - 20
P	P^+	∿270	0 - 10
A	A^+	---	0 - 40
Cs	Cs^+	∿255	0 - 200

Discussion and Conclusions

The preliminary results obtained with the source operated in the positive ionization mode are somewhat lower for most materials (with the exception of Cs^+) than anticipated initially. However, it is reasonable to believe that the yields for the materials can be increased significantly with further experience in operating the source. The source operated quite stably for periods of time $\leq$ 40 hours. The anticipated filament lifetime which is typical of hot cathode sources is ∿ 25-100 hours.

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