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PUMPING ION SOURCE

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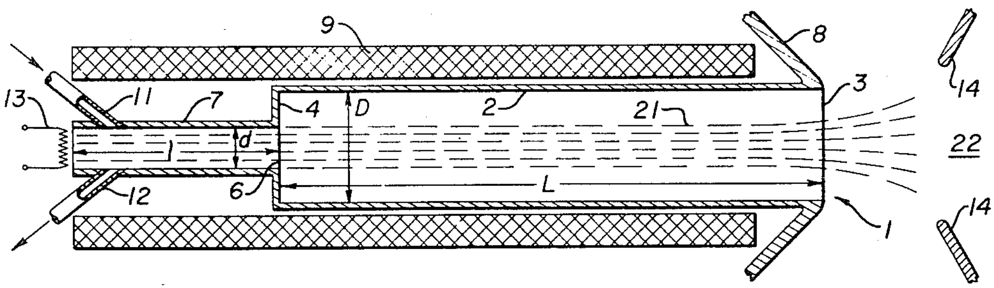

FIG_1_

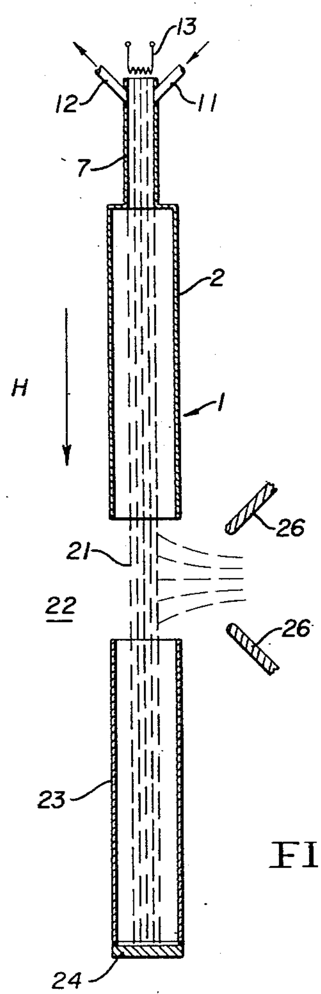

FIG_3_

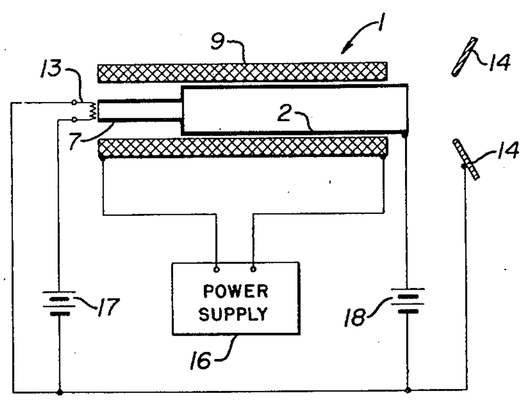

FIG_2_

INVENTOR.

JOHN S. FOSTER JR.

BY

Roland A. Anderson

ATTORNEY.

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PUMPING ION SOURCE

John S. Foster, Jr., Livermore, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

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8 Claims. (Cl. 313—161)

The present invention relates to an improved ion source adapted not only to produce copious quantities of ions but also to evacuate by the process of ionization the ion source itself and attached separation or analyzing chambers.

Ion sources, which are widely employed in both industry and research, are evaluated upon a value of factors, and one of these factors which is of paramount importance in certain ion source applications is the ratio of ions to gas molecules that are expelled or escaped from the source proper into the attached apparatus operating upon the ions. Conventional ion sources have present therein a certain amount of gas either produced during the ionizing process or directly introduced into the source as the material to be ionized. Substantially all applications of ion sources include an evacuated chamber wherein electromagnetic, electrostatic or other means are employed to utilize the ions produced by the source, and this utilization is universally accomplished in a vacuum. Particularly in the instance where ion beams of very large currents are employed difficulty arises in maintaining an adequate vacuum in the chamber wherein the ions are utilized, for as the ion production is increased, likewise the amount of gas escaping from the ion source increases. It has been shown that for conventional ion sources producing high current ion beams, the ion current is proportional to the ion source opening through which ions are extracted from the source so that an increase in ion beam current for any particular source appears necessarily to increase the volume of gas flow from the source through this opening. The present invention entirely overcomes this above-noted limitation upon ion sources and not only is it possible with the present invention to increase the ion current from an ion source without increasing gas flow therefrom, but also the present invention operates to extract gas molecules from the chamber into which the ion beam is directed so that there is actually produced the reverse of the above-noted ion-gas relationship.

The present invention provides an ion source producing an ion beam of readily controllable current wherein this ion beam actually evacuates the chamber into which it is directed. Rather than expelling gas molecules from the source, the present invention removes gas molecules from the attached chamber so as to consist not only of an ion source, but also of an ion pump. The relative magnitude of ion production and ion pumping may be readily varied by controlling the various parameters of the herein described ion source.

It is an object of the present invention to provide an improved ion source.

It is another object of the present invention to provide an improved pumping ion source.

It is a further object of the present invention to provide a combined ion pump and ion source.

It is yet another object of the present invention to provide an improved high current ion source of the oscil-

lating electron type capable of establishing by the ion production mechanism a vacuum whereby attached chambers may be evacuated.

Various objects and advantages of the present invention may become apparent to those skilled in the art from the following description taken together with the accompanying drawings of a preferred embodiment thereof, wherein:

Figure 1 is a longitudinal center section of the ion source;

Figure 2 is a simplified wiring diagram of the source of Fig. 1; and

Figure 3 is an embodiment of the source adapted for use in a particular accelerator, such as a cyclotron.

Considering now the structural details of the present invention and referring to Fig. 1 of the drawing, the ion source **1** includes an electrically conducting anode cylinder **2** having an open end **3** and at the opposite end thereof an end wall **4** provided with a central aperture **6**. Attached to the cylinder **2** exterior of the end wall **4** is an open ended tube **7** which mates with the aperture **6** in end wall **4** and extends therefrom in axial alignment with cylinder **2**. Attached about the open end **3** of cylinder **2** is a thick walled flange **8** which extends outwardly therefrom and slanted away or back from the end of cylinder **2**. About cylinder **2** and attached tube **7** there is provided a solenoid winding **9** which upon energization provides a magnetic field through cylinder **2** and tube **7** axially thereof. A pair of small pipes **11** and **12** are connected to tube **7** in communication with the interior thereof; tube **11** being adapted for connection to a source of gas to be ionized and tube **12** being adapted for connection to an evacuation system whereby a continual flow of gas through pipe **11**, across tube **7** and out pipe **12** may be attained. Adjacent the free end of tube **7** and in alignment therewith there is provided an electron emissive filament **13** and adjacent the free or open end **3** of cylinder **2** there is provided a plurality of electrodes **14** which may be arranged in a circular configuration with the diameter greater than that of cylinder **2**.

Considering the electrical connections of the ion source, and referring to Fig. 2, it will be seen that there is provided a magnet power supply **16** which is connected across solenoid winding **9**. A filament current supply **17**, shown for convenience as a battery, is connected across filament **13** to provide heating current therefor and electrical connection is made between filament **13** and electrodes **14**. A high potential source **18**, also shown merely for purposes of illustration as a battery, is connected between cylinder **2** and the connection between filament **13** and electrodes **14**. Thus electrically, filament **13** and electrodes **14** are maintained at the same potential and cylinder **2** is maintained at a highly positive potential with respect thereto.

Considering the operation of the embodiment of the invention described above and illustrated in Figs. 1 and 2 with reference only to the production and extraction of ions from the source, energization of the filament **13** by the filament current supply **17** causes this filament to become electron emissive so that electrons are freed from the surface thereof. The anode cylinder **2** and attached tube **7** are maintained at a positive potential with respect to the filament **13** by the power supply **18** so that electrons emitted from the filament **13** are attracted toward the adjacent tube **7** by the relatively positive potential thereof. With the solenoid **9** energized by the power supply **16**, there is established axially of the anode cylinder **2** and tube **7** a uniform magnetic field and electrons attracted from the filament **13** are constrained by this magnetic field to substantially traverse the lines of force thereof.

Thus, these electrons are attracted toward the tube **7** but do not directly impinge upon same, for instead the electrons travel axially through the tube **7** and anode cylinder **2** and thence out the open end of the anode cylinder. The accelerating electrodes **14** are electrically connected to the filament **13** and are thus maintained at a substantial negative potential with respect to the anode cylinder **2** by the power supply **18**. Consequently, electrons leaving the open end of anode cylinder **2** experience the repelling electrostatic field of the electrodes **14**. These electrons, or at least a majority thereof, are repelled back into the anode cylinder and thence reverse their path until they are again repelled by the filament **13**. There is thus established by the present invention an oscillating electron discharge similar to that employed by Penning Patent No. 2,146,025, for example, in similar fields. This oscillating electron discharge is a very strong ionizing medium for the electron path is materially elongated and aside from a relatively small radial drift of electrons within the source, the oscillating electrons continue oscillation until collision with gas molecules within the source so that the probability of any particular gas molecule being ionized within this source is extremely high.

Ions are produced within the source by the admission of gas therein, and this is accomplished through the pipe **11** connected to the tube **7** adjacent the filament **13**. In practice it has been found advantageous to provide a continual flow of gas through this portion of the source so that a gas return path is provided by the pipe **12** also connected to the tube **7** whereby a gas flow is produced directly across the filament **13** within the tube **7**. Gas entering tube **7** through pipe **11** is ionized by the oscillating electron discharge, and this ionization changes the characteristic of the discharge to that of an arc plasma **21**. The filament **13** extends substantially over the entire end of the tube **7** so that electrons are emitted over substantially the entire cross section of tube **7**, and thus the resulting arc discharge or arc plasma has substantially the same cross section as the tube **7**. This arc discharge extends from the vicinity of filament **13** through the tube **7** and anode cylinder **2**. At the open end of anode cylinder **2** the arc reaches the vicinity of the accelerating electrodes **14** whereat the relatively negative potential thereof repels the electrons in the arc plasma and attracts the ions therein so that the arc looses its unity at this point and the ions thereof are accelerated away from the ion source. The arc **21** may be controlled at the open end of the anode cylinder **2** in the manner illustrated in Fig. 1 by expanding the magnetic field at this point to expand the arc, as illustrated. The provision of a low reluctance path in the form of the flange **8** slanted from the open end of the anode cylinder **2** back toward the solenoid windings **9** causes the magnetic lines of force to diverge at the open end of the cylinder **2**, and, as the arc tends to follow the magnetic lines of force it, too, is expanded. Particular advantages may be obtained from this type of arc control and in this respect reference is made to my copending application for a Coasting Arc Ion Source, Serial No. 297,629, filed July 8, 1952. The expanded ion beam may be operated upon in any desired manner either to refocus it or to utilize it in its expanded form as dictated by the one practicing the invention.

In addition to the production of copious quantities of ions in the above-noted manner, the ion source of the present invention is further adapted to evacuate the chamber with which it communicates. As the arc discharge **21** is a strong ionizing medium, substantially all gas molecules therein are ionized so that the pressure at the arc is lowered thereby and gas molecules from the exterior of the source drift into the open end thereof toward the low pressure region therein. Pressure within the source cylinder **2** is determined by the number of ions that strike the cylinder walls and the end wall **4** whereat they are neutralized and become gas molecules again. The magnetic field established axially through the cylinder **2** by winding **9** restricts ion movement radially of the cylinder so that of the ions escaping from the arc within the cylinder **2**, the great majority, will travel generally longitudinally thereof. These ions in the main thus emerge from the open end of the cylinder **2** or impinge upon the end wall **4** and only the latter group pick up electrons to become neutral gas molecules for establishing the base pressure of the source. Gas molecules neutralized at the end wall **4** leave same with a random motion so that with an adequate length L to diameter D of the cylinder **2**, a desired proportion of same, will re-enter the arc **21** and become re-ionized prior to leaving the open end of the cylinder. It is preferred that $L/D \cong 5$ for high vacuum within the source and attached chamber, although higher ratios may be employed and even lower ratios may be used but with decreased pumping effects. A further important criteria is the ratio of arc diameter d to the cylinder diameter D. An increase in arc diameter places the outer arc surface nearer the cylinder wall so that a greater proportion of ions escaping the arc impinge upon the cylinder walls to increase the base pressure within the source; however, this same increase in arc diameter also provides a greater probability of gas molecules from the end wall falling back into the arc for re-ionization before leaving the open cylinder end. A balance of these opposite effects dictates an intermediate value for the ratio of arc diameter to cylinder diameter, and it is preferable that this ratio $d/D \cong 2$ to 3.

At the closed end or filament end of the source the ions within the arc strike the filament by virtue of the attracting electrostatic field thereof and ions there pick up one or more electrons to become neutral gas molecules. Owing to the random motion of gas molecules some of same tend to pass axially along the source away from the filament and this is increased by the relatively high gas pressure thereat caused by the ions neutralized at the filament. These gas molecules are prevented from passing directly into the cylinder **2** by the tube **7** which retricts the opening between the cylinder **2** and the filament **13** to the arc diameter. As the arc substantially fills the tube **7**, there remains no free space for gas molecules to travel therealong without passing through the arc. Consequently, gas molecules can not travel through the tube **7** without passing through the arc wherein they are subjected to the ionizing effect thereof. By providing a sufficiently long tube **7** substantially all gas molecules entering same are ionized and none enter the cylinder to raise the pressure therein. This condition is produced by relating the tube length l to the tube and arc diameter d in substantially the same relation as similar proportions of the cylinder **2**, i. e., $l/d \cong 5$.

Summarizing the pumping action of the source it will be seen that the arc **21** ionizes gas molecules entering same, and also that despite the magnetic field some ions drift out of the arc sides. With $L/D \cong 5$ the base pressure produced by ion drift from the arc is minimized so that gas molecules move into the source through the open end thereof. The expanded arc adjacent electrode **14** ionizes some of these molecules and the ions then travel into the cylinder **2** wherein they enter the arc itself or travel to the end wall **4** where they are again neutralized. Molecules leaving the end wall **4** mainly reenter the arc plasma proper by virtue of the L/D and d/D ratios and are again ionized. Ions within the arc generally move axially thereof in both directions and those moving toward the filament **13** eventually strike same and are neutralized. Gas molecules so formed must pass through the arc within the tube **7** where they are re-ionized so that substantially no gas molecules as such enter the cylinder **2** from the filament **13**. The above mechanism provides a one way path for gas molecules from the chamber **22** into the source and thus the chamber **22** is evacuated by this pumping action of the source. At the filament the gas molecules formed may be removed by a pumping system attached to the pipe **12**; however, all gas molecules formed at the filament will chemically combine with the source elements in the vicinity of the filament in the absence of pumping means attached thereto so that none is required and a high pumping speed may yet be attained by the present invention.

The pumping ion source of the present invention may be employed in a variety of ways, as for example, as a pump alone, and may as an ion source be employed in connection with numerous different types of apparatus. There is shown in Figure 3 a modified form of the source **1** adapted for use in a particle accelerator of the cyclotron type. The cylinder **2** and attached tube **7** are aligned with the magnetic field H of the cyclotron and at a distance from the cylinder **2** in axial alignment therewith is disposed a second cylinder **23** having a closed end **24** adapted to terminate the arc discharge **21** extending through both cylinders. The second cylinder **23** may or may not be provided with a restriction tube like tube **7** and ion accelerating electrodes **26** are disposed adjacent the arc plasma **21** between the cylinders for drawing ions radially from the arc at this point and directing same into desired orbits within the cyclotron. The cylinders **2** and **23** are electrically connected together as are the filament **13** and the end plate **24** to establish an oscillating discharge through the cylinders **2** and **23** as explained above. Ion production and ion pumping are the same as previously explained with the main difference being in the manner of ion extraction.

What is claimed is:

1. A pumping ion source comprising an open ended tube, a cylinder disposed in axial alignment with said tube and having a diameter at least twice the diameter of said tube, an annular wall connecting adjacent ends of said cylinder and tube, means establishing a magnetic field axially of said cylinder and tube, a first electrode disposed adjacent the free end of said tube and having an electron emissive surface facing and substantially covering same, a second electrode disposed at the free end of said cylinder, and power supply means electrically connecting said first and second electrodes and maintaining same at a negative potential with respect to said cylinder and tube for establishing an ionizing oscillating electron discharge through said cylinder and tube of substantially the same diameter as said tube whereby gas within said cylinder is ionized and said cylinder is evacuated thereby.

2. A pumping ion source comprising a cylinder having an open end and a tubular axial extension of reduced diameter at the other end thereof, means establishing a magnetic field having lines of force axially through said cylinder, a filament disposed adjacent said small cylinder end with an electron emissive surface adjacent same and substantially coextensive therewith, an ion accelerating electrode disposed adjacent the large open end of said cylinder, power supply means maintaining said filament and electrode at a negative potential with respect to said cylinder for establishing an ionizing oscillating electron discharge through said cylinder, and means supplying gas to said source adjacent said filament whereby said electron discharge ionizes said gas to produce an arc plasma through said cylinder.

3. A pumping ion source as defined in claim 2 further characterized by the diameter of said tubular extension and of said arc plasma being at most one-half the diameter of said cylinder and the length of said cylinder excluding said extension being at least five times the cylinder diameter whereby said cylinder is evacuated by said arc discharge.

4. A pumping ion source as claimed in claim 2 further defined by the length of said tubular cylinder extension being at least five times the diameter thereof whereby substantially all gas molecules entering said tubular extension are ionized by the arc filling same.

5. A pumping ion source comprising means establishing a magnetically collimated oscillating electron discharge and including an anode cylinder through which said discharge extends, means introducing gas to said discharge for producing an arc discharge therefrom, a tube of smaller diameter than said cylinder disposed at one end thereof about one end of said arc discharge and being substantially filled therewith, said tube having a length-to-diameter ratio of at least five whereby substantially all gas molecules entering said tube are ionized, and ion extraction means adjacent said arc for removing ions therefrom.

6. A pumping ion source comprising a cylinder having a lateral opening near the center thereof and at least one end with a reduced diameter of substantial axial extension, a pair of electrodes disposed one at each end of said cylinder with at least one electrode being electron emissive, power supply means maintaining said cylinder at a positive potential with respect to said electrodes for establishing an electron discharge, means establishing a magnetic field axially through said cylinder for collimating said discharge to pass through said cylinder and oscillate between said electrodes, gas supply means connected to said cylinder adjacent one end thereof for introducing gas therein whereby same is ionized to produce an arc plasma through said cylinder, and electrodes disposed adjacent the central cylinder opening for attracting ions therethrough from said arc plasma, said cylinder having a diameter that is substantially one-fifth the cylinder length from the central opening in each direction for the extent of the large cylinder diameter.

7. A pumping ion source comprising a cylinder having one unrestricted end and one restricted end with an aperture in the latter axially of the cylinder and at most one-half the cylinder diameter, a tube extending axially from said cylinder about said aperture and having a diameter not more than one-half the cylinder diameter, an electron emitter disposed adjacent the outer end of said tube in alignment therewith, means maintaining said cylinder and tube at a positive potential with respect to said emitter whereby electron discharge occurs from the latter toward the former, and means establishing a collimating magnetic field through said electron emitter and axially through said cylinder and tube for confining electron discharge to a path through said tube and cylinder with discharge diameter in said cylinder limited to tube diameter.

8. A pumping ion source comprising an elongated hollow anode having one restricted end, a tube extending from said restricted anode end of lesser diameter than said anode and communicating therewith, a cathode disposed across the outer end of said tube for establishing a discharge of substantially the diameter of said tube, and means establishing a magnetic field through said tube and anode for collimating said discharge to a substantially constant diameter therethrough.

References Cited in the file of this patent

UNITED STATES PATENTS

906,682	Birkeland	Dec. 15, 1908
2,182,736	Penning	Dec. 5, 1939
2,232,030	Kallmann	Feb. 18, 1941
2,282,401	Hansell	May 12, 1942