

April 2, 1963

M. E. ABDELAZIZ

3,084,273

HIGH CURRENT RADIO FREQUENCY ION SOURCE

Filed Sept. 19, 1961

Fig. 1

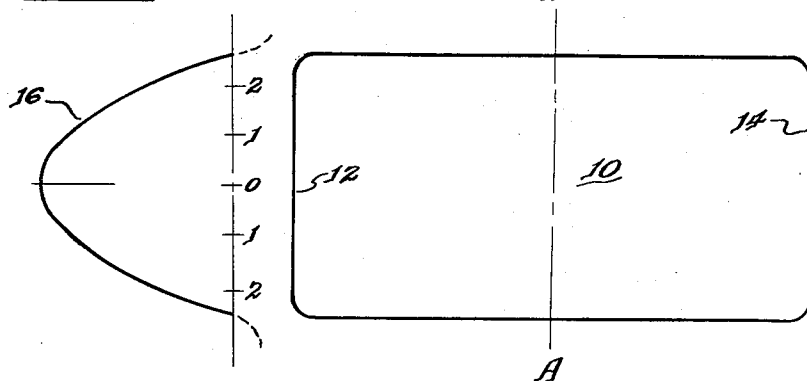


Fig. 2

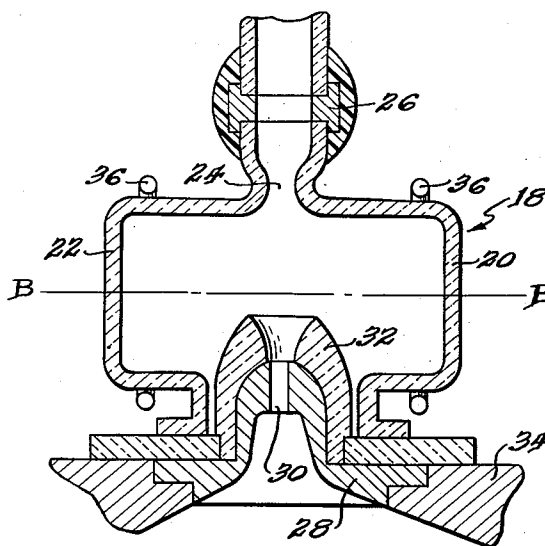
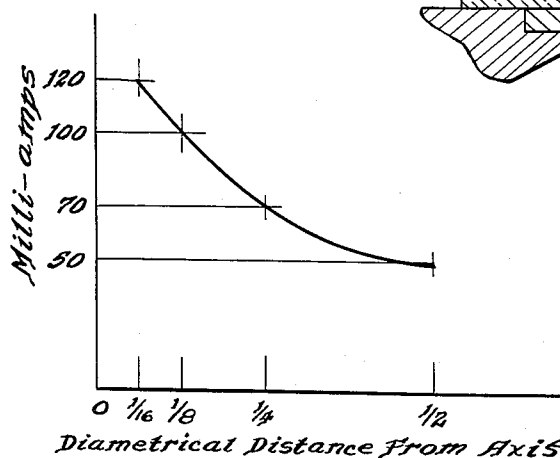


Fig. 3



INVENTOR.
Mohamed E. Abdelaziz

BY

Roland A. Anderson
Attorney

1

3,084,273

HIGH CURRENT RADIO FREQUENCY ION SOURCE

Mohamed E. Abdelaziz, Naperville, Ill., assignor to the
United States of America as represented by the United
States Atomic Energy Commission

Filed Sept. 19, 1961, Ser. No. 139,317

5 Claims. (Cl. 313-230)

The present invention relates to ion sources and more particularly to high current radio frequency ion sources.

The conventional high current radio frequency ion source employs a ceramic cylindrical envelope having a radio frequency field generated therein parallel to the longitudinal axis thereof. An anode and cathode are positioned in the ends of the envelope and excited with a D.-C. potential to extract ions formed by the radio frequency field along an axis parallel thereto. The ion beam current from this type of source is insufficient to meet the requirements of particle accelerators which require higher beam currents. The primary reasons for the lack of performance in higher beam currents result from (a) a limitation of the maximum extraction potential to a value of approximately 30 kv., (b) a decrease in percentage of extractable protons through recombination to molecular ions, (c) inability to focus the protons if the extraction cathode is extended too far through the plasma, and (d) loss of ionization from secondary electrons due to their random scattering at the anode and cathode ends of the plasma container.

It is therefore one object of this invention to provide a device able to produce high proton beam currents.

It is another object of this invention to provide a radio frequency ion source having ion extraction transverse to the radio frequency field.

It is still another object of this invention to provide a radio frequency ion source where extraction is effected from a region with lower recombination of protons to molecular ions.

It is yet another object of this invention to provide a radio frequency ion source having an extraction potential greater than 30 kv. and improved focusing of the extracted ion current beam.

Other objects will become more apparent as the detailed description proceeds.

In general the present invention comprises a Pyrex cylindrical plasma container having a radio frequency field therein parallel to the longitudinal axis thereof. Means are provided for the extraction of the ion beam current transverse to the radio frequency field from an area midway between the ends of the container about the longitudinal axis thereof.

More complete understanding of the invention will best be obtained from consideration of the enclosed drawing in which:

FIG. 1 is a graphical representation of the electron concentration in a plasma container along a diameter A—A.

FIG. 2 is a cross section view of the ion source of the present invention.

FIG. 3 is a graphical representation showing variations in extracted beam currents with distance from the axis B—B of the device of FIG. 2.

Reference is made to FIGURE 1 to explain the theory for the present invention. A cylindrical plasma container 10 is shown having flat ends 12 and 14. When the interior of the evacuated container 10 is supplied with a gas such as hydrogen at a low pressure and a radio frequency field is generated within the container 10 parallel to the axis thereof, the hydrogen gas will be ionized into electrons, protons, and molecular ions. The electrons

2

are the result of processes of electron production in the plasma, including secondary emission from the wall surfaces of the container 10, and their number "N" is obtained in the steady state when equilibrium between electron production and losses is established.

The cloud of "N" electrons will oscillate from one end of container 10 to the other according to the direction of the oscillating radio frequency field. When the "N" oscillating electrons hit one of the ends 12 or 14 of chamber 10, they produce "δN" secondary electrons, where δ is the secondary emission coefficient presumably greater than unity. In the collision, the "N" primary electrons are lost and the "δN" secondary electrons are accelerated to the other end of the container 10 by the reverse polarity of the radio frequency field. In their passage, to the other end, some of the "δN" electrons will collide with gas molecules or wall sides of the container 10, since electrons will be emitted at all angles to the emitted surface. The remaining electrons will be equal to "N" by the time they reach the other end where they collide and emit another "δN" cloud of electrons. This process will be continually repeated.

The curve 16 shows the electron density distribution existing in the container 10 for the equilibrium conditions recited supra. As can be readily seen, the electron density is a minimum at the walls of the tube and rises to a maximum at the longitudinal axis of the container 10. The shape of the curve 16 exists throughout the longitudinal length of the container 10. The curve 16 is represented by the equation $n_r = n_0 J_0(x)$, where n_r is the concentration of electrons at a radial distance r from the longitudinal axis of the container 10, n_0 is the concentration of electrons at the longitudinal axis ($r=0$) and $J_0(x)$ is a Bessel function of the zero order. The greatest value that x can have in the Bessel function of zero order is 2.405 which is when r equals the radius of the container 10. Greater values of x than this result in negative values of n which are meaningless.

The distribution of the ion density, that is, proton and molecular ion density, necessarily follows that of the above described electron density.

Turning now to FIGURE 2, a radio frequency ion source is illustrated which utilizes the above described analysis. A Pyrex cylindrical container 18 having flat ends 20 and 22 is the plasma container. Midway between the ends 20 and 22 of the container 18, the wall of the container 18 is opened and extended outwards to form an inlet passage 24 into the container 18 for unionized gases. A circular nickel anode 26 is mounted and sealed with epoxy glue in the walls of the passage 24.

Diametrically opposite the inlet passage 24, the wall of the container 18 is opened and extended outwards to provide for the insertion of an annular aluminum extraction cathode 28, having a cylindrical exit canal 30. The cathode 28 is shielded by a Pyrex-shield 32. The shield 32, cathode 28, and the extended walls of the container 18 are sealed to a stainless steel mounting plate 34 to give a gas tight seal.

A radio frequency coil 36 is wound around the exterior surface of container 18 along the longitudinal axis B—B thereof.

For operation of the ion source disclosed in FIGURE 2, an unionized hydrogen gas is fed through the passage 24 from a gas source (not shown). A radio frequency generator (not shown) applies a signal to coil 36, thereby causing a radio frequency field to be generated within the container 18 along the longitudinal axis B—B thereof. The radio frequency field ionizes the gas as hereinbefore described for FIGURE 1. A D.-C. generator (not shown) generates a voltage which is applied across the anode 26 and cathode 28, whereby the positive ions ex-

isting in the ionized gas within container 18 are extracted via the exit canal 30 in a direction transverse to the radio frequency field.

For determining the optimum geometry and operating conditions, notation must be made to the characteristic ion density curve disclosed by the analysis of FIGURE 1, since this curve exists for the device of FIGURE 2. Since the ion density is greatest about the longitudinal axis B—B of the container 18, the extraction cathode 28 should be mounted so that the exit canal 30 of the cathode 28 and shield 32 is close to the longitudinal axis B—B. FIGURE 3 illustrates the increase in extracted ion current as the cathode 28 and its associated shield 32 is so mounted. There is a practical limit to the distance which the cathode 28 and shield 32 may be moved towards the longitudinal axis B—B. If they were to be moved so that they intercepted the axis, then disturbance of the motion of the electrons which oscillate between ends 20 and 22 due to the radio frequency field may occur, thereby causing deviation from their theoretical distribution with a resultant lowering of the ionization density. It has been determined that the closest distance which the cathode 28 and shield 32 may approach the longitudinal axis B—B without seriously affecting the behavior of the plasma is approximately $\frac{1}{16}$ the diameter of the container 18.

To extract the optimum percentage of protons in the ion beam, the cathode 28 and shield 32 is positioned approximately midway between the ends 20 and 22 of the container 18. At this point, the region from which the beam is extracted is geometrically furthest from the interior surfaces of the container walls where recombination of protons to molecular ions occurs. Thus, the maximum ratio of protons to molecular ions in the extracted beam is assured.

It will also be noted that in the conventional ion source, with extraction parallel to the radio frequency field, the radio frequency field and the D.-C. extraction field are additive during a portion of a cycle of the radio frequency field. These two additive fields greatly enhance the possibility of arcing between the anode and extraction cathode and thereby limit the extraction potential to approximately 30 kv. In the present invention, the radio frequency field and the D.-C. extraction field are mutually perpendicular and thus nonadditive. Further, the radio frequency field tends to distort and hence "blow" any arc which may occur between the anode 26 and cathode 28. This field arrangement allows an extraction potential of approximately 40 kv. to be applied between the anode 26 and cathode 28 without arcing taking place. The ability to apply a higher extraction potential to the ion source of FIGURE 2 permits better focusing of the extracted ion beam than heretofore possible.

When operated at a 30 kv. extraction potential (maximum for the conventional radio frequency ion source), the ion source of FIGURE 2 gives an ion current beam whose density is 25 to 30% higher than that of the conventional source and which contains a proton percentage of 90% as opposed to 85% for the conventional source. Further, as the extraction potential is increased to 40 kv. (not possible without danger of arcing in the conventional ion source), the ion current density increases 25% over that at 30 kv. with the proton percentage remaining the same.

Persons skilled in the art will, of course, readily adapt the teachings of the invention to embodiments far differ-

ent than the embodiment illustrated. Accordingly, the scope of protection afforded the invention should not be limited to the particular embodiment thereof illustrated in the drawings and described above, but shall be determined only in accordance with the appended claims.

What is claimed is:

1. A radio frequency ion source comprising a cylindrical plasma container, means for injecting an unionized gas into said container, means for generating a radio frequency field within said container parallel to the longitudinal axis thereof, said radio frequency field ionizing said gas, and means for extracting transverse to said radio frequency field the positive ions created by said radio frequency field.

2. A radio frequency ion source comprising a cylindrical plasma container, means for injecting an unionized gas into said container, means for generating a radio frequency field within said container parallel to the longitudinal axis thereof, said radio frequency field ionizing said gas, and means for extracting transverse to said radio frequency field from an area midway between the ends of said container along the longitudinal axis thereof the ions created by said radio frequency field.

3. A radio frequency ion source comprising a cylindrical plasma container, means for injecting an unionized gas into said container, means for generating a radio frequency field within said container parallel to the axis thereof, said radio frequency field ionizing said gas, an anode mounted midway between the ends of said container and having access to the interior surface thereof, a cathode mounted diametrically opposite said anode and projecting through the walls of said container to approximately the longitudinal axis of said container, and means for applying a D.-C. potential across said anode and cathode, said cathode extracting the positive ions created by said radio frequency field.

4. A radio frequency ion source comprising a Pyrex cylindrical plasma container, a coil disposed around the exterior surface of said container along the longitudinal axis thereof, means for applying a radio frequency signal to said coil, means for injecting an unionized gas into said container, an anode mounted midway between the ends of said container and having access to the interior surface thereof, a cathode mounted diametrically opposite said anode and projecting through the walls of said container to a maximum of $\frac{1}{16}$ the diameter of said container, and means for applying a D.-C. potential across said anode and cathode, said cathode extracting the ions created by said radio frequency field.

5. A radio frequency ion source comprising a Pyrex cylindrical container having flat ends, a coil disposed around the exterior surface of said container along the longitudinal axis thereof, means for applying a radio frequency signal to said coil, means for injecting unionized hydrogen gas into said container, an anode mounted midway between the ends of said container and having access to the interior surface thereof, a cathode mounted diametrically opposite said anode and projecting through the walls of said container a distance of $\frac{1}{16}$ the diameter of said container, and means for applying a 40 kv. D.-C. potential across said anode and cathode, said cathode extracting the ions created by said radio frequency field.

References Cited in the file of this patent

UNITED STATES PATENTS

2,934,665 Ziegler Apr. 26, 1960