

July 29, 1969

M. R. CLELAND ET AL

3,458,743

POSITIVE ION SOURCE FOR USE WITH A DUOPLASMATRON

Filed Dec. 19, 1966

3 Sheets-Sheet 1

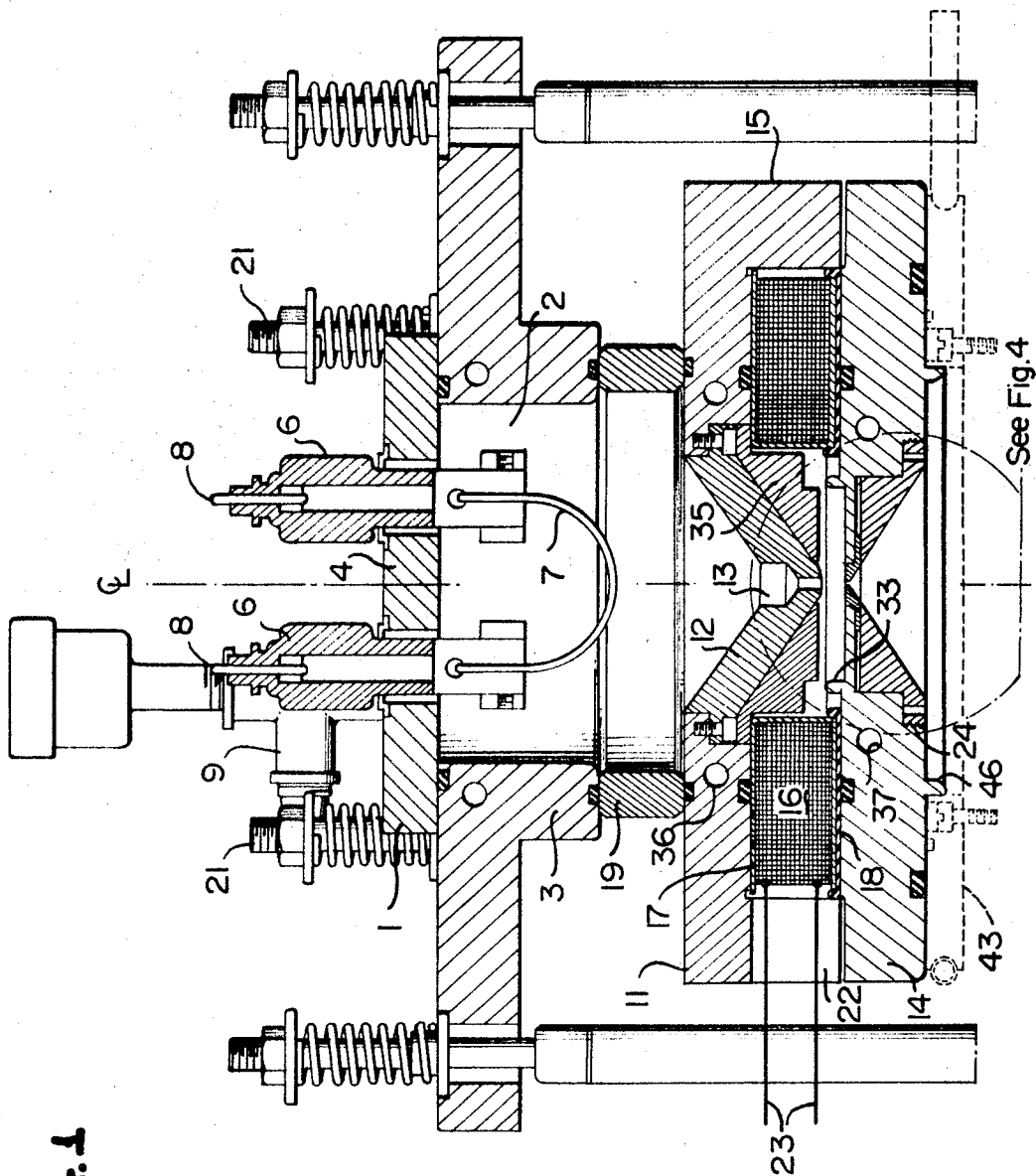


FIG. 1

INVENTORS
Marshall R. Cleland &
Chester C. Thompson, JR.

BY *Harvitz, Lee & Thorne*

ATTORNEYS

July 29, 1969

M. R. CLELAND ET AL

3,458,743

POSITIVE ION SOURCE FOR USE WITH A DUOPLASMATRON

Filed Dec. 19, 1966

3 Sheets-Sheet 2

FIG. 2

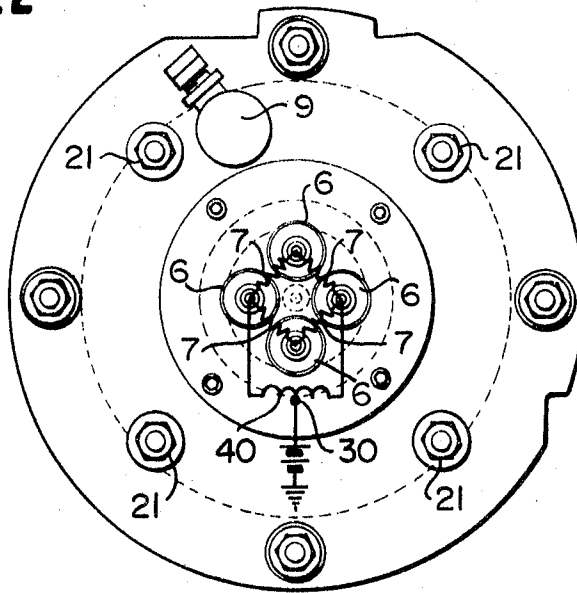
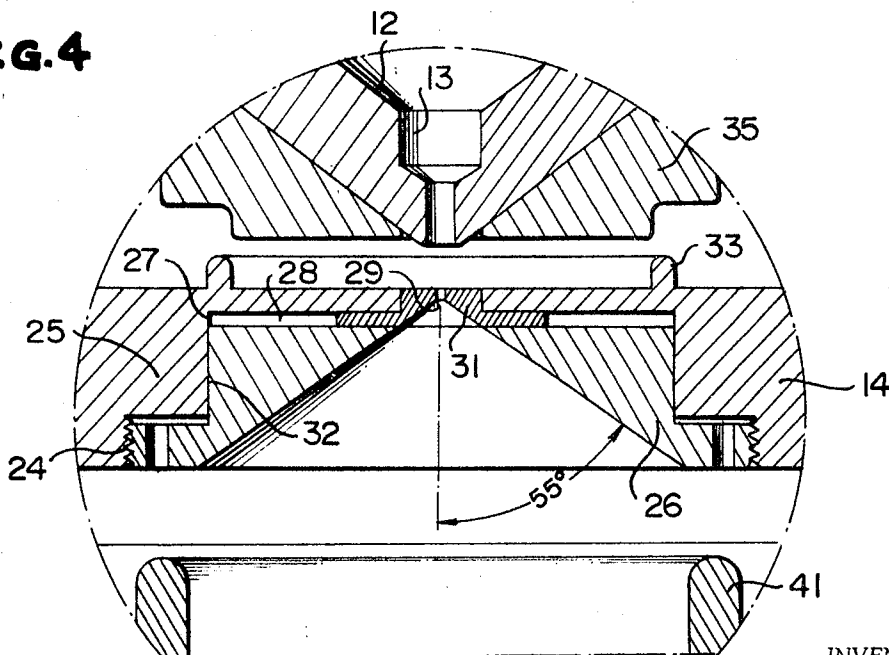


FIG. 4



INVENTORS

Marshall R. Cleland &
Chester C. Thompson, JR.

BY *Nuroitz, Rose & Preece*

ATTORNEYS

July 29, 1969

M. R. CLELAND ET AL

3,458,743

POSITIVE ION SOURCE FOR USE WITH A DUOPLASMATRON

Filed Dec. 19, 1966

3 Sheets-Sheet 3

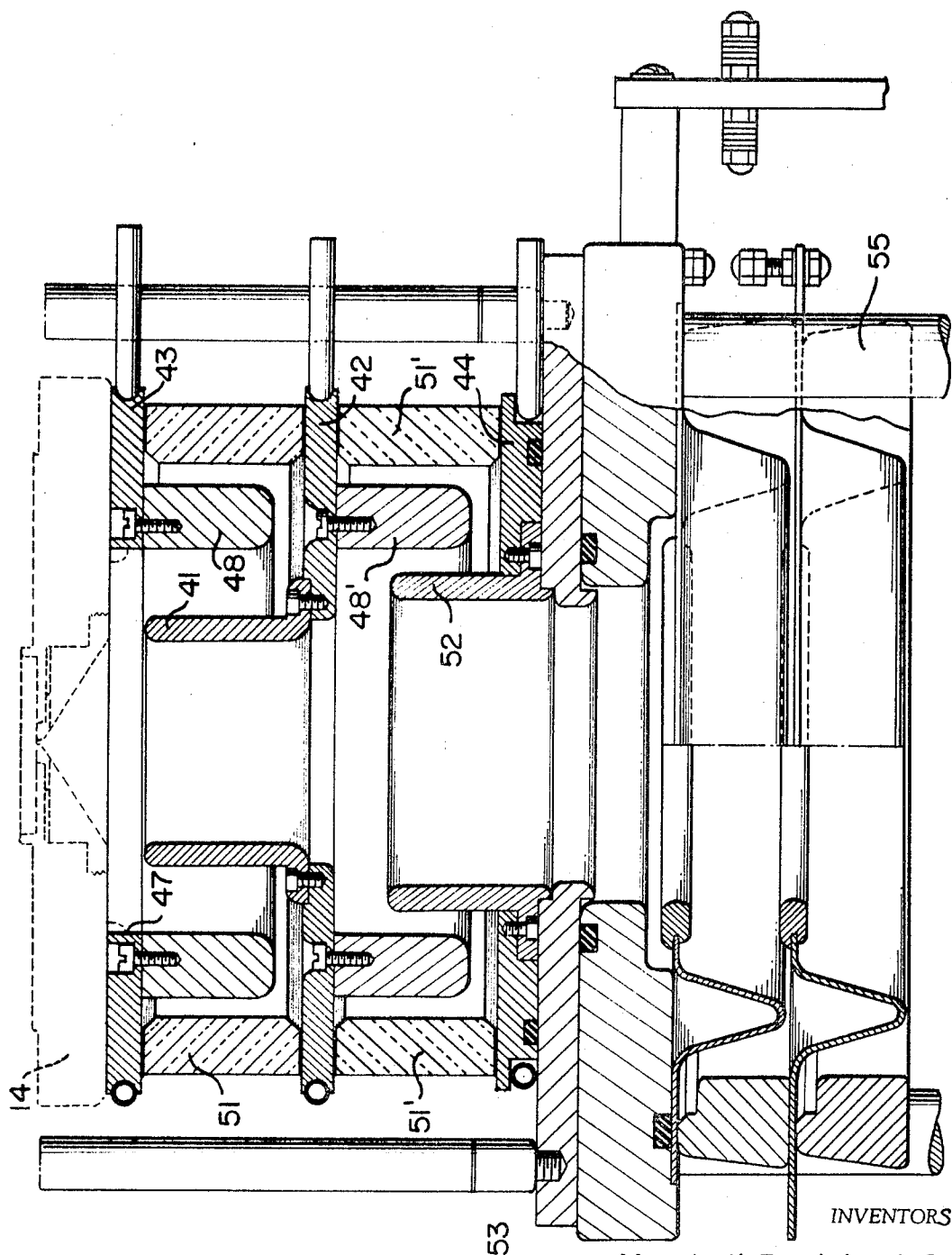


FIG. 3

INVENTORS
Marshall R. Cleland &
Chester C. Thompson, JR.

BY *Harvitz, Rose & Thorne*
ATTORNEYS

1

3,458,743

POSITIVE ION SOURCE FOR USE WITH A DUOPLASMATRON

Marshall R. Cleland, Huntington Station, and Chester C. Thompson, Jr., Roslyn Heights, N.Y., assignors to Radiation Dynamics, Inc., Westbury, N.Y., a corporation of New York

Filed Dec. 19, 1966, Ser. No. 602,990

Int. Cl. H05h 1/00

U.S. Cl. 313—63

37 Claims 10

ABSTRACT OF THE DISCLOSURE

A duoplasmatron ion source is provided employing a flat, annular focusing electromagnet housed in an aluminum housing. The housing is located between metallic rings supporting a flat anode and a conical intermediate electrode, and forms the ion chamber wall in this region. The magnet is cooled by conduction to the rings which are cooled by coolant flowing through internal passages. To increase X-ray absorption the outer conical surface of the intermediate electrode is enclosed, except at the tip opposite the anode, by a metallic insert. The anode is provided with a center insert which, during assembly of the source, is replaced by an aligning tool permitting rapid, precise alignment of the elements. The cathode comprises four elements encircling the axis of the ion source, the elements being electrically connected as a bridge circuit. A short glass chamber wall between the top plate and intermediate electrode permits viewing of the filament region. To permit effective evacuation of the extractor region, the ion extractor assembly employs a large diameter cylindrical extractor. To maintain a constant mean divergence with changes in beam current, the surface of the anode opposite the extractor is conical with an apical angle of at least 60° and a diameter of the order of the extractor.

The duoplasmatron is basically the result of the work by Von Ardenne and comprises a plasma generating chamber having a filamentary cathode, an anode for accelerating electrons through a neutral gas to produce positive ions and a conical intermediate electrode for regulating the electron flow and establishing an electric focusing field in the region between the apertured apex of the conic and the anode. The intermediate electrode and the anode are fabricated from magnetically permeable material; for instance, iron and a magnetic field is also established between the intermediate electrode and the anode. In the Von Ardenne sources, the focusing magnet is located in the source housing and requires special cooling arrangements for the magnets since they are subject to direct heat radiation from the filament. The cooling arrangement greatly complicates the design of the plasma chamber and, as a result of the location of the magnet, it is not possible to view the filament area which is important for purposes to be described subsequently. Additionally, the complex chamber structure requires long filament leads which are subject to bending and thus shorting to adjacent walls.

An improvement on the Von Ardenne source was provided by Eklund in U.S. Patent No. 3,178,604. In this patent, the focusing magnets were located externally of the source, and as a result, provided the ability to view the filament region. Also, being located externally of the device, they were not subject to high temperatures and air cooling could be effected. Since special cooling structures did not have to be provided internally of the ion source, the chamber design was far less complex and the filament leads were somewhat shortened. Other difficulties of the Von Ardenne magnetic structure, however, were not

2

eliminated by Eklund. Specifically, due to long parallel paths in the magnetic circuits of both Von Ardenne and Eklund, considerable stray fields were experienced which, particularly in Eklund, tended to distort the field in the region between the intermediate electrode and the anode, thus producing a non-uniform cross-section beam.

Eklund attempted to overcome a further difficulty in the Von Ardenne source, that relating to alignment of the various elements which alignments are extremely critical. Eklund provided for external control of the position of the intermediate electrode relative to the anode and of the extractor electrode relative to the anode. In laboratory work, the source is found to be completely effective for this purpose. However, in use of the source with particle beam machines and in other commercial applications, it is found that the adjustments provided by Eklund do not hold their positions due to vibration and other factors and thus, are not useful in the particular environments mentioned above.

Additional difficulties have arisen in the prior art relative to the extractor region. In the Von Ardenne devices, a Pierce extractor is normally employed, such an extractor constituting a quite narrow opening immediately adjacent the anode. As a result of this narrow opening, it is extremely difficult to evacuate the region between the anode and the extractor. This feature is quite undesirable since the ion beam exits from the ion forming region through the anode and some of the neutral gases present in the plasma chamber leak through the anode opening into this region. The gas produces scattering and increases the emittance of the emerging beam, a highly deleterious effect. Further, as a result of the presence of this neutral gas in a very narrow region having as much as 30 to 50 kilovolts across the elements, considerable sparking is encountered with subsequent destruction of the extractor and the anode. Also, the sparking produces instability in the beam direction, this defect being quite unacceptable where a source is being used in experimental and commercial beam acceleration machines.

It has been known in the prior art to employ large diameter extractors for producing high current ion beams of the order of several hundred milliamps. Reference is made to two particularly useful articles on such devices: "Study and Operation of Duoplasmatron Type Ion Sources" by Vincent and Warnecke, *Annales de Radioelectricite*, vol. XX, No. 80, April 1965, pages 101-114 and "The Production of Intense Neutral and Negative Ion Beams" by P. H. Rose, *Nuclear Instruments and Methods*, 28 (1964), pages 146-153. Both of the articles are concerned with forming, among other things, high current ion beams, and one of the methods described for producing such a beam is the plasma expansion method illustrated quite clearly in FIGURE 2 of the Vincent et al. article. The difficulty with this type of extraction is that, although it serves a very useful purpose in its intended environment, it provides a very poor ion source for ion or electron beam accelerators of the type described in U.S. Patent No. 2,875,394 to Cleland.

The reason that the Vincent et al. beam expansion method of extraction is not suitable is that, as the ion beam current is changed, as is often required in experimental and commercial work, the configuration of the periphery of the plasma changes. Since the ion current at any point along the periphery of the plasma boundary issues perpendicular to the periphery at that point, changes in the shape of the boundary produce changes in the beam convergence, a result materially affecting the particle optics required to produce a concentrated beam, i.e. a well-focused beam at the end of the accelerator tube. Specifically, with a low beam current, the plasma boundary in the expansion type of arrangement of the

aforesaid article is concave whereas when the beam current is increased, the boundary becomes flat and subsequently becomes convex. In the former case, the beam is a convergent beam. In the intermediate case, i.e. with a flat boundary, the beam is parallel and in the latter case, with the convex boundary, the beam is divergent. Obviously, the particle optics required for these three conditions and all intermediate points are considerably different and such a source cannot be utilized with a beam tube machine where the focusing point is a considerable distance from the source.

In accordance with the present invention, a large diameter extractor is employed which, while permitting excellent evacuation of the region between the extractor and the anode provides in conjunction with a specially shaped anode a substantially constant curvature plasma boundary over large variations in beam current. This is effected by employing an anode having a conical recess in the wall opposite the extractor electrode. The apical angle of the cone is at least 60° and the maximum diameter of the cone is of the same order as the diameter of the extractor electrode. A cone of the aforesaid characteristics provides a substantially constant slope so that the angle of attachment of the plasma to the surface does not change materially as the plasma expands and contracts with changes in beam current. Since the shape of the boundary, specifically the curvature of the boundary, remains relatively constant with changes in ion current, the apparent source of ions relative to the particle optics of the system remains at a relatively fixed point behind or upstream of the anode. Thus, a fixed particle optic system can be employed with a long beam tube and still insure focusing of the beam at the target. The reason for the particular constraints on the angle and extent of the conic surface will be explained subsequently.

A further feature of the particular arrangement described above is that the backstreaming electrons, which are always encountered in a system of this type, do not impinge upon the extractor and, to the extent that they contact the anode, the contact is primarily in a small region about the anode aperture. There is provided a tungsten insert which may be readily replaced without requiring disassembly of the plasma chamber as will be described subsequently.

A further important feature of the extractor assembly of the invention is that extremely precise alignment of the extractor and the anode is not required. Aligning flanges are provided on the anode for alignment with the extractor so that relatively unskilled workers may assemble the device without being able to produce any severe misalignment of the beam with the axis of the beam tube.

Returning now to the plasma forming chamber, the difficulties with the Von Ardenne device relate to the placement of the magnet internally of the housing and stray fields and loss of field strength due to long parallel elements in the magnetic path. In Eklund, difficulties also relate to stray fields and also non-uniformity of the field due to the particular arrangement employed. Eklund, however, did solve the problem of ability to view the filaments, removal of the magnet from the high temperature region internally of the device and the ability to rapidly assemble and disassemble the source of means of cinch rods.

In accordance with the present invention, the magnetic field problems are substantially eliminated by forming the coil as a flat, multi-layered pancake winding enclosed in an aluminum housing. One side of the coil housing is coated with an epoxy layer to insulate the housing from the anode which it contacts. The other side of the housing is in electrical contact with the grid. The coil housing thus serves the dual function of encapsulating the winding and also forming a part of the high vacuum enclosure. In this latter function, the housing serves to help with X-ray shielding of the device. The coil is cooled by con-

tact with the anode and intermediate electrode, both of which are cooled internally by means of a coolant, such as Freon, flowing through channels formed in the interior of the elements. The coil, because of its design, is quite inexpensive to manufacture and assembly of the entire plasma chamber is greatly simplified.

The grid structure is basically a flat steel flange with a thick rim and an outer edge having a short thick cylindrical extension providing a low reluctance return path through the anode, a small air gap preventing electrical contact with the anode. The intermediate electrode is a conical steel insert in the center of the electrode ring and it may be readily removed for cleaning or replacement. An additional insert of non-magnetic, tungsten-copper alloy is provided to increase the X-ray absorption in the region between the intermediate electrode and the anode.

As previously indicated, the anode is also a flat steel ring with a tungsten insert in the center. The insert has a very small aperture through which the plasma passes into the extractor region. This insert is held in place by a retaining ring which threads into the rear or the side of the anode ring facing the extractor electrode. An aligning tool is inserted in the anode in place of the center tungsten button during assembly. The aligning tool has an accurately located axial extension directed toward the intermediate electrode. This extension seats in the center bore or aperture of the intermediate electrode so that the electrode ring and anode ring are accurately located during assembly. The rings of the intermediate electrode and anode are thick and made of steel, increasing heat conduction and also increasing X-ray shielding from the critical regions adjacent the intermediate electrode and the anode. The plasma chamber elements are held together by cinch rods extending between a plasma chamber end plate and the anode, the end plate also receiving the filament support plate. Additional cinch rods are also employed to tie the end plate to the extractor apparatus.

The end plate also has a cylindrical extension toward the intermediate electrode ring extending approximately as far as the bottom of the filaments, i.e. the same distance towards the electrode ring as the filaments. The space between the electrode ring and the cylindrical extension on the end plate is occupied by a glass ring so that the plasma glow may be viewed from externally of the apparatus. It is known that, when the plasma glow begins to approach the filaments, the filaments are losing their efficiency and should be replaced. The short glass ring is in contact with the cooled and thick electrode ring and is maintained so cool that one may place his hand on it. In the Eklund design which employed a glass ring in the entire region between the grid and the upper ends of the filaments, the glass temperatures were the order of several hundred degrees Fahrenheit.

The filaments, and there are four, are located in approximately a square about the centerline of the device. Thus, none of the filaments are in direct line with the reverse streaming particles and their life is greatly extended. The use of the four filaments permits them to be connected in a bridge circuit and electrically, this is found to be quite useful. This arrangement reduces interaction between the filament supply and the arc or plasma beam current and permits the use of A.C. on the filaments with only minor and tolerable modulation of the beam current.

It is an object of the invention to provide a duoplasmatron ion source having a magnetic structure for developing a highly symmetrical and intense magnetic field to produce a symmetrical and axially aligned ion beam.

It is another object of the present invention to provide an ion source structure permitting viewing of the filament area of the source through a glass wall which wall is not unduly heated by emission from the filaments.

Another object of the present invention provides a

filament design for duoplasmatron which permits A.C. excitation of the filaments.

It is another object of the present invention to provide an intermediate electrode and anode structure for duoplasmatrons which is economical to manufacture and permits rapid and accurate alignment of the elements during assembly.

It is another object of the present invention to provide an extractor arrangement for ion beams which reduces beam emittance as a result of reduction of beam scattering.

It is another object of the present invention to provide a large diameter extractor for ion sources in order to permit better evacuation of the region between the anode and extractor.

It is another object of the present invention to provide an extractor assembly for ion beam machines in which the back streaming electrons contact only a small center section of the anode formed of a material that can withstand such bombardment.

It is a further object of the present invention to provide an extractor and anode assembly for an ion beam machine in which plasma expansion and contraction does not materially change the source point of the beam so that a relatively fixed set of particle optics may be employed with varying beam currents.

It is still another object of the present invention to provide an extractor assembly for ion sources which can be assembled by relatively unskilled workers due to the large tolerances permitted by the particular design employed.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a sectional view of the plasma forming chamber of the present invention;

FIGURE 2 is a front elevation of the top plate of the plasma chamber with the filament plate secured thereto;

FIGURE 3 is a large sectional view of the intermediate electrode and anode regions of the apparatus of the invention; and

FIGURE 4 is a cross-sectional view of the extractor region of the present invention.

Referring now specifically to FIGURE 1 of the accompanying drawings, the plasma chamber structure includes a top plate 1 having a large central aperture 2 and a hollow cylindrical extension 3 having an inner diameter equal to the diameter of the aperture 2. Secured to the top or left edge of the plate 1, as viewed in FIGURE 1, is a filament plate 4 having four filament bushings 6 extending therethrough. The bushings 6 can be seen clearly in FIGURE 2. The plate 4 is appropriately secured to the plate 3 with an O-ring therebetween to insure a vacuum seal.

The apparatus is provided with four filaments 7, only three of which are illustrated in FIGURE 1, arranged in a square symmetrical relative to the centerline of the apparatus. The bushings 6 have filament leads 8 extending therethrough for connection to an external source of voltage. A neutral gas feed, generally designated by the reference numeral 9, is provided for introducing neutral gas through the end plate 1 into the interior of the apparatus for formation of ions.

The plasma forming structure further comprises a plate 11 for supporting a conical intermediate electrode 12, also variously referred to in the art as the grid or lens. The intermediate electrode 12 is secured to the annular plate 11 as by bolting and comprises a hollow conical member having an aperture 13 extending therethrough along the centerline C_L of the apparatus. The plate 11 has an annular hollow cylindrical extension 15 which is coaxial with the centerline of the apparatus and extends toward an anode plate 14.

A magnetic winding, a flat, annular, multi-layer, multi-turn magnet 16 is encapsulated in a housing 17 and is disposed between the plates or annular rings 11 and 14. It should be noted that the hollow cylindrical projection 15 of plate 11 is slotted as at 22 to permit passage through the ring of leads 23 to the magnet 16. In order to insure a vacuum-tight enclosure, O-rings are provided between the can or housing 17 and the rings 11 and 14, respectively, and an electrically insulating epoxy cement 18 is provided between the housing 17 and the anode so as to insulate it from anode ring 14 and permit the development of a suitable voltage between the rings 11 and 14.

A glass annulus 19 is disposed between the hollow cylindrical extension 3 of the end plate 1 and the intermediate electrode ring 11, again with appropriate O-ring seals provided.

The entire structure is held together by four cinch rods 21, which extend through the end plate 1 and are screw-fitted into the ring 14.

Referring specifically to FIGURE 3 of the accompanying drawings, there is illustrated in detail the anode assembly, including the anode aperture button and the anode insert. The anode ring 14 has in its lower edge, as viewed in FIGURE 3, a shallow, large-diameter internal circular recess 24, the walls parallel to the centerline of the apparatus being threaded to receive an anode insert 26. The threaded walls 24 terminate in a flat annular wall 25 perpendicular to the centerline. The wall 25 extends inwardly for some predetermined distance and terminates in a further recess having a wall 27 parallel to the centerline. This recess provides a guide surface for the insert 26, which will be explained more fully subsequently. The walls 27 terminate in a further circular wall 28 perpendicular to the centerline of the structure. This wall terminates in a central aperture 29 for receiving the apertured anode button 31.

The button 31 is in the form of a flat disc having an axial projection from one side thereof. This projection has an external diameter precisely the same as the internal diameter of the wall 29. The button has a small axial aperture, 0.005" to 0.008" diameter, for instance which, when the button is inserted in the anode ring 14, lies coaxial with the centerline of the source. When the button 31 is inserted, as illustrated in FIGURE 3, the anode insert 26 is screwed into the recess. The insert 26 has a wall 32 symmetrical relative to the axis of the insert and has a diameter substantially identical with the diameter of the wall 27 of the ring 14. Thus, the walls 27 and 32 provide guide surfaces for the insert 26 to insure precise alignment of the insert with the ring 14. The insert 26 is screwed into the apparatus until the flat disc portion of the button 31 is clamped between the wall 28 of the ring 14 and the opposing or parallel wall of the insert 26. It will be noted that the walls 28 and 25 of the ring 14 are not contacted by corresponding walls of the insert and the threads 24 of the ring 14 and mating threads of the insert 26 are somewhat loose so that all of the guiding of the insert is done by the walls 27 and 32, respectively, and depth of penetration of the insert into the ring 14 is determined wholly by the thickness of the button 31. This arrangement permits a person relatively unskilled in such work to assemble the device without fear of inaccuracies in alignment.

It will be noted that the insert 26 has a conical recess in the lower wall forming a smooth continuation of a mating conic surface in the button 31. The reason for this will be described subsequently.

The upper surface of the anode ring 14 is provided with a thin annular projection 33 coaxial with the apparatus and directed toward the intermediate electrode 12. Referring again to FIGURE 1 of the accompanying drawings, the annulus 33 is employed to shield the epoxy layer 18 from radiant heat and bombardment by ions and/or electrons and thus prevent destruction of the epoxy which could produce a subsequent short circuit between the

anode and intermediate electrode rings 14 and 11, respectively.

In assembling the members forming the plasma chamber, the cinch rods 21 are secured in or to the ring 14. The coil housing abuts the ring 14, the plate 11 and the glass ring 19 are placed in position and the end cap 1 is also positioned with the cinch rods 21 passing through the appropriate apertures therein. In order to align the rings 11 and 14, or more particularly to align the aperture 13 of the intermediate electrode 12 button 31, a member which is very nearly the same as the button 31 is assembled in the anode plate 14 with the insert 26 holding this member in place. The member, however, does not have a center aperture but is provided with a projection illustrated with dashed lines and designated by the reference numeral 34 in FIGURE 3. The diameter of this projection is substantially identical with the smallest diameter of the aperture 13 through the intermediate electrode. The projection 34 is long enough to extend substantially into the narrowest portion of the aperture 13 in the electrode 12, thus aligning the centerlines of the anode 14 and electrode 12. The cinch rods align the plate 1 and the anode 14 and thus the glass annulus 19. The cinch rods may then be tightened, or more particularly, the nuts on the ends of the cinch rods are tightened so that the entire assembly is clamped in place. The insert 26 may now be removed and the temporary button removed with the appropriate button 31, as illustrated in FIGURE 3, inserted and the insert 26 reapplied. The filament plate 4 may now be added so as to complete the assembly of the plasma chamber. The chamber must then be assembled with the remainder of the apparatus before operation.

Referring again to FIGURE 2, the four filaments 7 are illustrated diagrammatically as resistors 7. The four resistors are, in effect, connected as in a bridge configuration and, as illustrated in FIGURE 2, an A.C. power source is applied directly across the filaments. In addition, a D.C. arc supply 45 is connected to the neutral corners of the filament bridge or to a center tap 30 on a secondary winding 40 of a filament transformer. In consequence of this arrangement, the effect on the plasma of A.C. modulation of the single phase A.C. source is relatively small and sources requiring two and three phase currents may be eliminated. The degree of modulation is no worse with this type of source than with the more elaborate sources described immediately above.

One additional feature of the chamber is the member 35 having a hollow conical interior. The member 35 is disposed about the conical exterior of the intermediate electrode 12 and is formed from a non-magnetic metal such as a tungsten-copper alloy so as to absorb X-rays which are formed by the presence of high-energy electrons in this region. To complete the discussion, the rings 11 and 14 are provided with hollow channels 36 and 37, respectively, to receive a cooling fluid, such as Freon, employed to maintain the apparatus at appropriate temperatures.

An important feature of the structure illustrated in FIGURE 1 is the magnetic circuit. The pancake coil located very close, by prior art standards, to the electrode-anode gap, the thickness of the rings 11 and 14 and the extension 15 of the ring 11 provide a very low reluctance magnetic path which results in a beam current or beam brightness for a given energization of the filaments and magnets which exceeds that available from prior art devices. Further, it will be noted that there is substantially no region of the magnetic circuit for the formation of shunt magnetic fields. The only region in which shunt fields could be formed is in the region defined axially by the intermediate electrode 12 and the anode plate 14 and radially between the centerline and the coil 16. However, it will be noted that the gap between these two members decreases uniformly to the very location at which the field is to be concentrated and thus leakage flux in this area is exceedingly small. As a result of the

aforesaid configuration, specifically the annular construction and low leak circuit, a highly symmetrical beam is achieved which is of great importance in any ion source and particularly so where the source is to be used with a beam accelerator tube where the beam has to travel over long distances to its target.

An additional advantage of the particular magnetic construction is that the coil is provided with good cooling without disrupting the organization of the apparatus as is true in the original Von Ardenne structures. As previously indicated, the plates 11 and 14 are quite thick in the region of the magnet 16 providing highly efficient cooling surfaces which, in conjunction with their internal cooling, extracts heat from the coil at a very high rate. In the prior art, the internally located coils are cooled by direct contact with a cooling fluid and problems develop due to attack of the coil insulation by the coolant. Another advantage attributable to the coil and magnetic circuit design is that the coil housing forms a part of the plasma chamber wall greatly simplifying the design and thus reducing the fabrication, assembly and maintenance costs of the apparatus.

It should be noted that the anode and electrode rings may be readily hogged out of metal stock since the final alignment technique compensates for relatively loose manufacturing tolerances. Additionally, the location of the greatest mass of metal is in the region of the greatest formation of X-rays and thus, good X-ray shielding is inherent in the design. These masses of metal plus the short magnetic path involved also provide for excellent shielding from stray magnetic fields. An additional advantage that is achieved because of the pancake design and location of the magnet is the unusually short distance between the end plate 1 and the anode 14. As a result of this arrangement, quite short filaments leads may be employed thus greatly extending their life. It has been found that, in devices of this type, the long leads tend to bend and subsequently short to the adjacent walls and materially shorten the life of the filament as a result. Also, the particular design employed keeps all of the filaments out of the way of backstreaming electrons and ions since no part of the filament is actually located along the centerline of the apparatus and thus, the life of the filaments is again extended. The use of the separate filament plate assembly 4 also facilitates rapid replacement of filaments without it being necessary to disassemble any other part of the apparatus and particularly the gas and coolant connections.

An additional feature of the chamber design, which frankly is not understood, is that the plasma does not oscillate. As pointed out in the Rose article, various kinds of instability can be excited in a plasma which result in characteristic oscillations that have been described by many researchers in the field. Although the present source has been used, at first experimentally during the designing and initial construction thereof and for some time now in use, the developers and users have not run into any operating conditions which produce plasma oscillations. As indicated above, the reasons why this source is so stable are not fully understood, although it is believed that the design of the magnet and the immediately adjacent anode-intermediate electrode structures are important.

Another important feature of the plasma chamber design is the ability to operate the glass ring 19 at low temperatures. It will be noted that the hollow cylinder 3 which is an integral extension of the top plate 1 extends approximately to the end of the filaments 7. The glass insert, which insulates the electrode from the filaments and permits viewing of the critical region is sufficiently short to be very adequately cooled by conduction to the ring 11. In the Eklund design, the glass insert corresponding to ring 19 extends from the plate 1 to the ring 11 and achieves temperatures of several hundred degrees F. during operation of the apparatus. In the present invention, the temperature of the glass is reduced suf-

ficiently, by the simple expedient mentioned above, that a person can put his hand on the glass without any real discomfort.

The use of the insert 26 for retaining the tungsten button 31 permits replacement of the button without disassembly of the plasma chamber structure, although, as will become apparent subsequently, the extractor region must be dismantled to accomplish this conversion. The entire assembly must be disassembled if the intermediate electrode 12 must be replaced or the coil is required to be replaced. There have been no known coil failures since the apparatus was put into use due to overheating.

Referring now specifically to FIGURE 4 of the accompanying drawings, there is illustrated the extractor assembly of the present invention in conjunction with the anode assembly which is necessary to its proper functioning.

As previously indicated, a difficulty that has been experienced quite widely in the use of the Pierce extractor is that due to the very narrow opening through the extractor, evacuation of the region between the extractor and the anode is very difficult. The voltages between the extractor and the anode are relatively high (30-50 kv.) considering the spacing between the two members. The high voltages, taken in conjunction with the fact that some of the inert gas in the plasma chamber does pass through the opening in the button 31 means that the region under discussion, in the conventional design of extractor, is relatively dirty and is subject to repeated sparking. Sparking of an ion source is undesirable in any environment and is particularly troublesome when the source is being employed with a high voltage accelerator. In this use, sparking causes contamination of the beam tube, inaccurate dosages at the target and other related problems. In addition to sparking, gas in the extractor region produces beam scattering lowering the efficiency of the beam (increase of beam emittance). It has also been found that, due to the narrow opening through the Pierce extractor, the backstreaming electrons bombarded the extractor eroding it and occasionally melting it, requiring its replacement more often than is desirable.

In accordance with the present invention, a quite large internal diameter extractor is employed. The extractor, as designated by the reference numeral 41, which actually designates a thin-walled, large-diameter, hollow cylinder coaxial with the centerline of the device and secured to a thin metallic disc 42. The extractor assembly is provided with two further thin, metallic discs 43 and 44 parallel to disc 42 and disposed on opposite sides thereof. The disc 43 abuts the anode plate 14 of the plasma chamber and is aligned therewith by means of an annular, thin-wall, projection 46 formed on the surface of the plate 14 coaxial with the centerline of the apparatus. The thin-walled annulus 46 seats within a large hollow center aperture 47 of the ring 43 and thus positions the ring 43 relative to the anode plate 14.

The above arrangement overcomes one problem in the prior art design, that of exact alignment of the extractor mechanism relative to the anode. Where the Pierce extractor is employed, precise alignment is required particularly where an accelerating beam tube is being supplied from the source. A small skew of the beam may not be serious in a short tube. However, where one is feeding an accelerator tube, the skew over the length of the tube can cause the beam to miss the target completely and impinge upon the plates of the beam tube and destroy them. Very minor shifts of the extractor produce large shifts in beam position and therefore alignment was difficult. It will be noted that the center aperture 47 of the plate 43 is quite large compared with the outer diameter of the extractor 41 so that the plate does not affect the field relationships in the extractor region. Further, an annular, hollow, cylindrical wall 48 extends parallel to the centerline of the apparatus in line with the aperture defining surface 47 of the ring 43. This wall 48 extends

axially a considerable distance toward the ring 42 so as to shield glass tube 51 from electron or ion bombardment and the exterior from internally generated X-rays. Also, the wall 48 isolates the beam in the extractor region from stray fields generated by charges accumulating on the glass tubes 51, etc.

The hollow glass cylinder 51 is disposed between the discs 42 and 43 and is sealed to the discs by an epoxy cement or resin. A second annular wall 48' is of about the same diameter as the wall 48 and extends axially from the plate 42 towards the plate 43, serving the same purpose in this region as the wall 48 serves in the region between the plates 42 and 43. A further glass disc 51' is disposed between the plates 42 and 44 and cemented thereto and provides an airtight seal between the members. The plate 44 also supports an electrode 52 which is coaxial with the centerline in the apparatus and somewhat larger in diameter than the hollow cylinder 41. The electrode 52 constitutes a particle lens and will be described subsequently.

The plate 44 rests against an end plate 53; O-ring seals being provided between the two plates. A second set of cinch rods 54 extend between the top plate 1 and the plate 53 so that the whole ion source assembly is held together by cinch rods and, if desired, the extractor lens assembly may be readily removed from the plasma source assembly so that repairs may be made to either parts of the apparatus.

Referring now to the operation of the apparatus, as previously indicated, the extractor electrode is greatly increased in diameter. As an example of the sizes involved, the diameter of the extractor electrode should be at least as large as the diameter of the beam of backstreaming electrons, approximately $\frac{3}{8}$ inch. To provide a margin of safety then, the inside diameter of the extractor 41 should be at least $\frac{1}{2}$ inch. From the point of view of the effective evacuation of the region, the dimension is preferably somewhat more, for instance, $\frac{3}{4}$ inch. If the size of the hole in the anode button 31 is 0.005 inch, then the inside diameter of the extractor 41 should be about one hundred times the diameter of the anode aperture. In the actual ion source built in accordance with the present invention, the anode aperture is 0.008 inch and the extractor internal diameter is $1\frac{3}{4}$ inch, a ratio on the order of 200 to 1. One additional factor relative to the size of the extractor is the alignment question. The larger the internal diameter of the extractor, the less critical is alignment of the extractor and anode. Limits are placed on the extractor size, however, since as the size grows, the extractor function weakens due to the weakening of field concentration so that some practical constraints are encountered.

Although the large diameter extractor improves the operation of the source relating to sparking and scattering, the source is still not acceptable particularly when used in conjunction with a beam tube accelerator since the large extractor alone introduces new problems relating to changes in beam characteristics. Specifically, the plasma formed in the plasma chamber extends through the small aperture in the anode button 31 and tends to form a bubble facing the extractor. The outer periphery of the bubble is the plasma boundary, in reality the limit of the neutral region beyond which the ions predominate and are formed into an ion beam. If a small narrow conical surface adjacent the extractor were employed, as in many of the prior art devices, the contours of the bubble change with changes in intensity of the ion beam. More particularly, if it were desired to increase the ion current, the plasma should be made more intense and would protrude a greater distance beyond the anode. As this bubble swells and contracts its contours change, changing the radius of the curvature in that surface of the bubble facing the extractor electrode.

It has been proposed in high intensity ion beam sources to spread the beam by means of a cylindrical extension

from the anode. Here again, the boundary of the plasma changes with ion current. It is believed that the reason for this is that, in a cylinder, the cross-sectional area remains constant even though the beam current increases or decreases as the case may be and thus the current density changes, altering the contour of the plasma boundary. It is also known that the beam which is extracted from a plasma is at all points perpendicular to the surface of the boundary. Thus, if the contours of boundary region change in shape, the beam directivity, convergence or divergence changes. Such changes result in an intolerable situation, particularly where a beam tube accelerator of great length is the load. The particle optics at the entrance to a beam tube are not greatly variable in a given machine, and although some changes can be effected, the basic field strength and contour are fairly constant so that the changes that can be made are not too great. Thus, a beam tube cannot accommodate an ion source in which the contour of the plasma changes too severely with beam current.

In the cylindrical plasma expansion arrangements discussed in the articles referenced hereinabove, as the ion beam current changes, the contour of the plasma in the beam spreader changes from convex to concave, changing the beam from a convergent to a divergent beam as the beam current increases.

In a beam tube accelerator, the electric field lines are basically as traced by the lines 54 (see FIGURE 4) at the field transition region between the extractor apparatus of the present invention and the beam tube designated by the reference numeral 55. It is apparent that the lens system is a convergent particle lens. The degree of convergency can be changed somewhat but the basic lens type cannot be so changed. Thus, it is necessary, if one is to employ the expanded extractor 41 of the present invention, to produce a slightly divergent ion beam from the source.

It has been found in accordance with the present invention that a substantially constant plasma boundary contour can be provided if the anode region opposite the extractor is a hollow conic having an apical angle of at least 60°. If this criteria is met and the conic is long enough (as discussed below), the degree of divergency of the beam is changed little as a function of beam current. Stating this otherwise, the apparent ion beam source so far as the particle lens system is concerned, remains at a relatively fixed location behind the anode, i.e. toward the filaments. It is believed that the conic permits a nearly constant current density to be achieved, it being the theory of the inventors that the conic, having at least a 60° apical angle, increases the beam area basically as a direct function of the beam current so that current density remains constant. Thus, if a small beam current is developed, the plasma boundary may be defined, for instance, by the line 56 and as the current is increased, the boundary increases or is extended through regions defined by the lines 57 or 58, respectively. It will be noted that these lines are basically concentric. Thus, over the range of the conical surface the divergence of the beam should not change. The present apparatus being manufactured employs an apical angle of 110°, i.e. 55° relative to the centerline. With this angle, the boundary lines are such that a slightly divergent beam is formed and over the range of beam currents for which the apparatus is designed, this divergent angle maintains the ion beam within the boundaries defined by the diameter of the physical entry into the beam accelerator tube 55.

The use of the two electrode extractor, i.e. electrodes 41 and 52, is to simplify the adjustment of the device and permit ready adaption of the source to different beam tube accelerators. Specifically, the voltage employed on the extractor 41 remains relatively constant and is chosen such that the appropriate beam divergence is obtained in a given system over the useful operating range or beam current range of the device. The electrode 52 is strictly

a particle lens as opposed to an extractor, and is employed to vary the ion injection energy (ion velocity) so as to control focusing of the divergent ion beam at the target of the accelerator. Thus, the adjustment on the device of the electrode 52 does not affect the optics of the extractor anode region, which is as it should be since the extractor voltages should remain purely a function of the best operating characteristic of the source.

While we have described and illustrated one specific embodiment of our invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

We claim:

1. A duoplasmatron ion source comprising a source of electrons, a centrally apertured anode located a predetermined distance from said electron source along the axis of said ion source, an axially symmetric, intermediate electrode located between said electron source and said anode and having an axially symmetric, centrally apertured conic section having its apex directed toward said anode, means for supporting said electron source, means for sealing the axially extending periphery of the region between said means for supporting said electron source and said anode, said anode and electrode being formed of magnetic material and means for developing a magnetic field between said intermediate electrode and said anode characterized by a flat annular coil of electrically conducting wire, a non-magnetic heat conductive annular container for said coil, said container being disposed between said anode and said intermediate electrode, means for maintaining a fluid-tight seal between said container and said anode and said electrode, and means for electrically insulating said container from one of said anode and said electrode.

2. The combination according to claim 1 further characterized in that said anode and said electrode each have a relatively axially thick outer region, said container being clamped between said thick regions.

3. The combination according to claim 2 further characterized in that said thick regions of said anode and said electrode are internally cooled.

4. The combination according to claim 2 further characterized in that said electrode has a hollow cylindrical wall extending from its outer periphery almost into contact with said anode and disposed outwardly of said means for developing a magnetic field.

5. The combination according to claim 1 further characterized in that the internal diameter of said container is approximately equal to the external diameter of said conic section of said electrode.

6. The combination according to claim 1 further characterized in that said means for electrically insulating is disposed between said anode and said container and said anode has a thin walled annulus adjacent said container extending toward said electrode a sufficient distance to shield said means for insulating from ions and electrons in the region between said electrode and said anode.

7. The combination according to claim 1 further characterized by said means for supporting said source comprising a flat plate having a cylindrical wall extending toward said electrode, said electron source comprising at least one filament extending toward said electrode approximately the same distance as said last-mentioned cylindrical wall, and a transparent cylindrical wall member extending between said last-mentioned wall and said electrode.

8. The combination according to claim 7 further characterized by said electrode having a relatively axial, thick outer region in contact with said transparent wall.

9. The combination according to claim 8 further characterized in that said thick region is internally cooled.

10. The combination according to claim 1 further characterized by a non-magnetic metallic member disposed

13

about said conic section axially between said section and said anode and radially between said conic section and said container.

11. The combination according to claim 1 further characterized by said electron source comprising four filaments, said filaments being electrically connected in a bridge circuit.

12. The combination according to claim 1 further characterized by said electron source comprising four filaments rectangularly arranged, said arrangement being generally symmetrical with respect to the axis of said ion source.

13. The combination according to claim 1 further characterized by a centrally apertured anode button, means for seating said button in said anode along the axis thereof and means located on the side of said anode remote from said intermediate electrode for removably retaining said button in said anode.

14. The combination according to claim 1 wherein there is provided an extractor on the side of said anode remote from said intermediate electrode, said extractor comprising a generally cylindrical wall coaxial with said anode, said extractor having an internal diameter at least one hundred times the diameter of the central aperture in said anode, the side of said anode adjacent said extractor having a conical section extending outwardly from said aperture at a minimum apical angle of approximately 60°.

15. The combination according to claim 14 further characterized by the largest diameter of said conical section being such as to accommodate the plasma bubble at the highest beam current for which said source is designed within its voltage design range.

16. The combination according to claim 14 further characterized by said largest diameter of said conical section being of the same order of magnitude as the diameter of said extractor.

17. The combination according to claim 14 further characterized by a metallic shield ring surrounding at least the region between said anode and said extractor and disposed radially outwardly of said extractor.

18. The combination according to claim 17 further characterized by a narrow generally axial flange extending from said anode toward said extractor, said flange being of approximately the same diameter as the internal diameter of said shield ring and engaging the inner circumference of said shield ring to align said extractor and said anode.

19. The combination according to claim 1 wherein there is provided an extractor on the side of said anode remote from said intermediate electrode, said extractor comprising a generally cylindrical wall coaxial with said anode, said extractor having an internal diameter about 200 times the diameter of the central aperture in said anode, the side of said anode adjacent said extractor having a circular wall diverging outwardly from said central aperture 110°.

20. An extractor assembly for ions comprising a centrally apertured, conductive anode and a conductive extractor spaced from and coaxial with said anode characterized by said extractor constituting a hollow, generally cylindrical member having an internal diameter of the order of at least sixty times the diameter of the central aperture of said anode, the side of said anode adjacent said extractor having a circular recess diverging outwardly from said central aperture as a smooth continuous curve at an angle of approximately 60°.

21. The combination according to claim 20 wherein said curve is conic.

22. The combination according to claim 21 further characterized by the outer diameter of said conical section being such as to accommodate the plasma bubble at the highest beam current for which said source is designed within its voltage design range.

14

23. The combination according to claim 21 further characterized by said outer diameter of said conical section being of the same order of magnitude as the diameter of said extractor.

24. The combination according to claim 21 further characterized by a metallic shield ring surrounding at least the region between said anode and said extractor and disposed radially outwardly of said extractor.

25. The combination according to claim 24 further characterized by a narrow generally axial flange extending from said anode toward said extractor, said flange being of approximately the same diameter as the internal diameter of said shield ring and engaging the inner circumference of said shield ring to align said extractor and said anode.

26. The method of aligning a centrally apertured, intermediate electrode of an ion source and an anode having a large central aperture for receiving a centrally apertured anode button held in place by a removable insert comprising the steps of loosely assembling the plasma generating region of the ion source so that the removable insert side of the anode is exposed, a further button being assembled in the large central aperture of the anode, the further button having a projection of precise diameter to be received in the central aperture of the intermediate electrode, tightening the clamping means for the plasma source, and replacing the further button with the anode button.

27. The combination according to claim 20 wherein the internal diameter of said extractor is at least one-half inch.

28. The combination according to claim 20 wherein the internal diameter of said extractor is one and one-half inches and the size of said anode aperture is 0.008 inch.

29. A filament structure for high voltage particle accelerators which produce back-streaming particles generally along a central axis of the device comprising a plurality of individual filaments arranged symmetrically about and transversely offset from the center axis of the structure whereby substantially none of the back-streaming particles bombard said filaments.

30. The combination according to claim 29 wherein there are four of said filaments arranged generally in a square configuration with the diagonals of the square intersecting at the axis of said structure.

31. The combination according to claim 29 wherein four said filaments are provided, said filaments being connected in an electrical bridge circuit with each said filament defining a different arm of said bridge and an alternating current source connected across conjugate terminals of said bridge.

32. The combination according to claim 31 wherein said source includes a transformer having a center-tapped, secondary winding, said secondary winding being connected across the aforesaid conjugate terminals of said bridge and a direct current source connected to said center-tap of said secondary winding.

33. The combination according to claim 29 comprising a flat plate, said filaments mounted on said flat plate, a hollow metallic cylindrical member, said flat plate secured across one end of said member, an annular metallic member forming a part of a magnet structure, and a transparent hollow cylindrical member of electrically insulating material disposed between said hollow metallic cylindrical member and said annular metallic member, means for holding said members in an air-tight stack, said metallic members being dimensioned to provide effective heat sinks in contact with said transparent member.

34. The combination according to claim 33 further comprising means for internally cooling both said metallic members.

35. An anode structure for a high energy ion accelerator comprising a generally flat member having a relatively small, centrally located, circular opening in one of its

15

flat surfaces, a large circular opening in the other of its flat surfaces coaxial with said small opening, a cylindrical insert for said large opening, adjacent circular surfaces of said insert and said member being accurately formed to provide precise axial movement of said insert in said large opening, an anode button having a cylindrical body with a generally circular flange adjacent one end, said cylindrical body having a diameter to provide a close fit in said small opening, said flange being disposed between said member and said insert, said button having a small diameter axial aperture terminating in a conical opening, and said insert having a conical opening therein such that said conical openings provide a smooth hollow conical surface from said axial aperture to a location adjacent the surface of said insert remote from said button.

36. The combination according to claim 35 wherein said hollow conical surface has a minimum apical angle of approximately 60°.

37. The combination according to claim 20 further comprising a hollow cylindrical electrode spaced down-

16

stream from said member and coaxial therewith, said electrode having a voltage applied thereto to match the ion beam extracted by said extractor to the entry optics of an ion beam accelerator downstream of said electrode.

References Cited

UNITED STATES PATENTS

2,978,580	4/1961	Von Ardenne	313—230 X
3,164,739	1/1965	Werner	313—63 X
3,178,604	4/1965	Eklund	313—63 X
3,238,414	3/1966	Kelley et al.	313—230 X
3,265,918	8/1966	Wittkower	313—63 X
3,315,125	4/1967	Fröhlich	313—230 X

15 JAMES W. LAWRENCE, Primary Examiner
C. R. CAMPBELL, Assistant Examiner

U.S. Cl. X.R.

20 313—153, 230, 231; 315—111; 328—233