

April 26, 1960

A. ZIEGLER
ION SOURCE

2,934,665

Filed Sept. 12, 1956

2 Sheets-Sheet 1

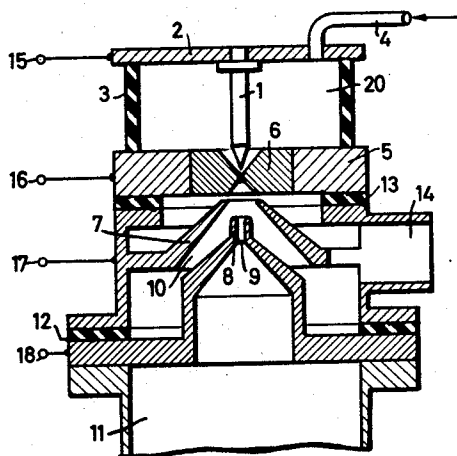


Fig. 1

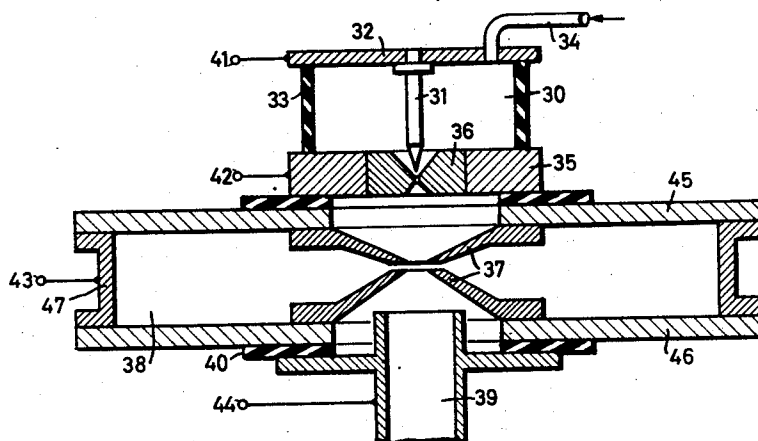


Fig. 2

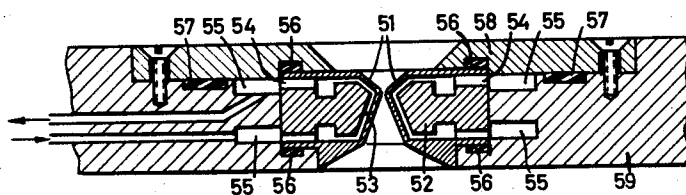


Fig. 3

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2 Sheets-Sheet 2

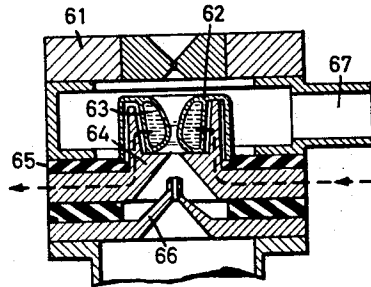


Fig. 4

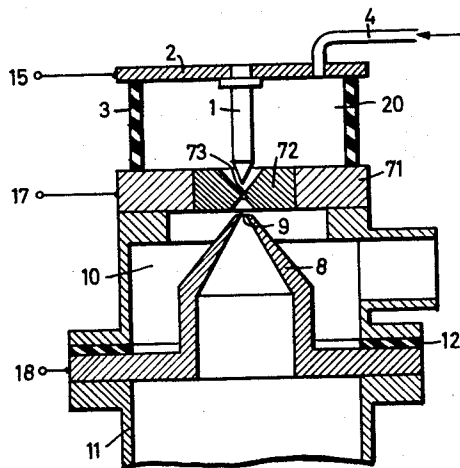


Fig. 5

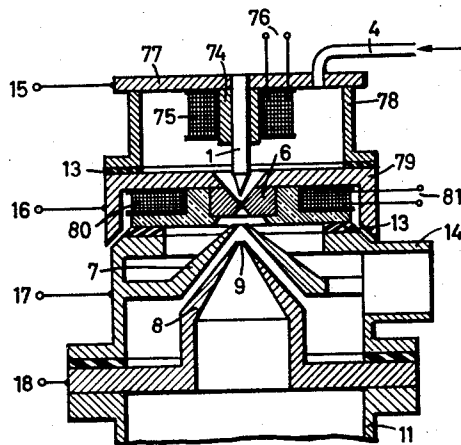


Fig. 6

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2,934,665

ION SOURCE

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25 Claims. (Cl. 313-63)

My invention relates to apparatus for the thermionic production or emission of ions and has for its general object to devise an ion source of increased ion output or improved operating efficiency as compared with the ion sources heretofore available.

The various ion sources so far known differ from one another essentially by the method employed for producing the plasma from which the ions are extracted. The known methods involve the production of plasma by canal-ray discharges, low-pressure discharges, oscillating electrons or high-frequency. The electrode arrangements for extracting the ions from the plasma are fundamentally similar; in all cases a negatively biased electrode, the so-called probe, extracts ions from a space-charge region, and the extracted ions pass through a bore of the probe into the high-vacuum space where the ions are to be utilized.

These various apparatus have in common that the plasma production takes place in a space of low pressure, for instance between 10^{-2} and 10^{-4} mm. Hg. In all cases the ionization is caused by electron collision. For highest possible probability of ionization, strong magnetic fields or high voltages must be applied. Nevertheless, the attainable degree of ionization amounts to only about 10%, and the atom-ion proportion, particularly with hydrogen plasmas, is far below 100%.

Another disadvantage of the known apparatus and methods is the fact that the replenishment of ions to the probe is limited by the diffusion velocity of the ions, so that an ion depletion may occur in the region ahead of the probe and may result in an unfavorable ratio of the ion density to the density of the neutral portion of the plasma.

It is, therefore, a more specific object of my invention to provide an ion source that minimizes or obviates the above-mentioned deficiencies and affords a fundamental improvement over the known ion sources, particularly with respect to efficiency and attainable magnitude of ion current.

According to a feature of my invention, the ion plasma is produced by means of an arc discharge, and a nozzle with a relatively narrow nozzle orifice is disposed between the cathode and the anode of the arc discharge gap so as to divide the discharge space into two chambers. I further provide means for maintaining the gas pressure in one of the two chambers much higher than in the other space, the difference amounting preferably to three to four orders of magnitude. The expression "order of magnitude" signifies a difference by a factor of ten.

The foregoing and more specific objects, advantages and features of my invention will be apparent from the embodiments illustrated on the drawing and described in the following. On the drawing:

Fig. 1 is an axial, sectional view of an ion source according to the invention equipped with a probe for extraction of the ions in the direction of the plasma beam.

Fig. 2 shows, in axial section, another ion source ac-

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cording to the invention with a radially symmetrical probe for extraction of ions perpendicular to the direction of the plasma beam.

Fig. 3 shows, in cross section, a nozzle member and cooling system applicable in devices according to the invention.

Fig. 4 illustrates, also in section, a nozzle arrangement comprising two nozzles in series.

Figs. 5 and 6 are partial, sectional views of two respective modifications of ion sources similar to the one shown in Fig. 1.

According to Fig. 1, the cathode 1 of an arc gap device is disposed within a housing which comprises a cover plate 2 of metal, a cylinder 3 of insulating material, and a bottom plate 5 of metal. A nipple pipe 4 for the supply of gas communicates with the cathode chamber 20 through the cover plate 2. The bottom plate 5 is provided with a nozzle insert 6 which has a single nozzle orifice located in its center. The anode 7 of the arc discharge device is ring-shaped and located in coaxial relation to the cathode 1 and to the orifice of nozzle member 6. Located behind the arc anode 7 is a probe electrode 8 also of annular shape which has a nozzle bore 9 on its center axis. The nozzle bore 9 connects the anode space 10 with a high-vacuum space 11 into which the ions are extracted for further utilization. The anode chamber 10 is enclosed and sealed by metal structures integral with the arc anode 7 and the probe 9. Insulation as well as tight sealing of the anode chamber is effected by means of insulating ring members 12 and 13. A nipple pipe 14 connects the anode chamber 10 with a pre-vacuum pump. The cathode 1, nozzle plate 5, anode 7 and probe 9 are electrically connected to respective terminals 15, 16, 17 and 18.

During operation of the device, plasma is produced by means of an arc maintained between cathode 1 and anode 7. High pressure, for instance of 40 mm. Hg is maintained in the cathode space 20, whereas the anode chamber 10 is maintained at low pressure, for instance of about 0.001 mm. Hg. Due to the pressure gradient there occurs a flow of plasma at extremely high velocity from the cathode chamber 20 through the orifice of nozzle member 6 in the direction toward the anode 7. The arc burns entirely or partly through the orifice of nozzle member 6. On the cathode side of the nozzle orifice the discharge has the character of a high-temperature arc discharge, whereas on the anode side of the nozzle there occurs a discharge of a type which I have not found described in available literature and which is essentially a high-current glow discharge.

By maintaining a sufficient current intensity of the arc, the gas in the chamber 20 between the cathode 1 and the orifice of nozzle member 6 can be kept virtually fully ionized, the gas being at a temperature between 10,000° C. and 20,000° C. depending upon the current magnitude. The flow of plasma caused by the above-mentioned pressure gradient may reach supersonic speed and may enter into the anode chamber 10 either as a beam or diffused, depending upon the particular design of the apparatus. Hence, for securing good orientation, i.e. beam or jet formation, of the plasma beam, it is generally preferable to give the nozzle a Laval-type design (see Fig. 3). The anode 7 serves only to receive the electron current which may attain a magnitude of some amperes. With such current intensities, the current density at the narrowest cross section of the nozzle orifice may attain values of approximately $5 \cdot 10^4$ amps. per cm^2 corresponding to the heretofore attained maximum current density in high-pressure plasmas. Even at a slight gas density of 0.001 mm. Hg in the anode chamber, the conductivity of the plasma is sufficient, due to the high degree of ionization,

to sustain a discharge current of several amperes at approximately 60 volts voltage drop in hydrogen.

The shape and location of the anode can be chosen in various ways. As shown in Fig. 1, the anode may be designed as a ring-shaped member so that the hot, quasi-neutral and currentless beam of plasma may pass through the anode without appreciable hindrance.

Using, for instance, hydrogen as a gaseous atmosphere in the ion source device according to Fig. 1, the distribution of electric potentials may be chosen in accordance with the following example:

The anode 7 (terminal 17) is at zero potential,
The nozzle plate 6 (terminal 16) is at minus 50 v.,
The cathode 1 (terminal 15) at minus 100 v.,
The probe 9 (terminal 18) is at minus 10 kv.

The embodiment illustrated in Fig. 2 differs from that of Fig. 1 essentially only by the arrangement of probe and anode. The cathode 31 for the arc discharge is located in a chamber 30 enclosed by a cover plate 32 and an insulating jacket 33. Gas is supplied through a nipple pipe 34. The bottom of chamber 30 is formed by a nozzle plate 35 with a nozzle insert 36. The probe 37 is radially symmetrical and slotted so that the direction of ion extraction is perpendicular to the direction of the plasma beam. Due to the very high negative potential of the probe, for instance, of minus 10 kv. as in the numerical example above given, the ions are extracted from the arc laterally into the high-vacuum space 38 in which they are to be utilized. The arc-discharge anode 39 in this embodiment is designed as a tubular member and serves simultaneously as a connection for the pre-vacuum pump for exhausting the excess of plasma. The anode 39 is insulated from the high-vacuum chamber with the probe by an insulating sealing ring 40; and a similar insulating ring is disposed between the high-vacuum structure and the nozzle plate 35. The electric potentials are supplied to terminals 41, 42, 43 and 44. The probe 37 is shown to be composed of two parts mounted on respective metal plates 45 and 46 which are electrically interconnected by a ring-shaped jacket member 47.

A preferred design of the nozzle member, applicable in devices of the kind described above with reference to Figs. 1 and 2, is separately illustrated in Fig. 3. The nozzle orifice is of the Laval type and is formed by a member 51. The narrowest diameter of the nozzle orifice amounts to some tenths of one millimeter. Disposed within the central nozzle member 51 are cheek portion 52 so that a narrow channel 53 is formed between the nozzle wall proper and the cheeks. The narrow channel communicates with coolant supply ducts 54 and 55. The coolant circulation system thus formed is sealed by means of gaskets 56 and 57. The nozzle insert further comprises a mounting plate 58 by means of which the nozzle insert and the cooling system are fastened to the nozzle plate 59. The flow of cooling liquid into and out of the system is indicated by arrows. The nozzle member is applicable in place of the nozzle plates and inserts described with reference to Fig. 1 (5, 6) and Fig. 2 (35, 36).

In order to attain low pressure ahead of the probe, two nozzles may be arranged in series and the space between the two nozzles may be connected to a pre-vacuum pump. Since in such an arrangement the second nozzle is located in a relatively high vacuum and hence is subjected to much lower thermal stress than the first nozzle, the second nozzle can be made of insulating material, for instance quartz. This reduces the recombination of the atom ions into molecule ions, which recombination is particularly large at metal surfaces, whereas the ionization is not impaired or is even increased due to the large electron-current density in the nozzle. As a result, a slight gas density together with a relatively large ion density is obtained in front of the probe. This is a prerequisite for the extraction of very large ion currents.

The embodiment shown in Fig. 4 exemplifies such a series arrangement of two nozzles. Denoted by 61 is the first nozzle member described in the previous paragraph. Nozzle 61 is composed of a nozzle plate and a nozzle insert which may be designed as described with reference to Fig. 3 but, for simplicity, is shown in Fig. 4 as having the same design as the nozzle members of Figs. 1 and 2. The second nozzle is formed by a hollow body 62 of quartz. Body 62 forms a cooling space 63 traversed by liquid coolant as schematically indicated by broken-line arrows. The anode 64 serves as a holder for the nozzle 62. An insulating plate 65 prevents an arc discharge other than through the nozzle orifice. The probe is denoted by 66. A nipple type 67 serves for evacuating the space between the two nozzles. Otherwise the apparatus may be designed in accordance with the one described with reference to Fig. 1.

It will be understood that the cathode, the anode and the probe in devices according to Figs. 1, 2 and 4 may also be cooled in any conventional manner, this being not illustrated on the drawing.

The ion source according to the invention may be modified so that the space between anode and nozzle, such as the anode chamber 10 in Fig. 1, is kept at a higher pressure than the space between nozzle and cathode, such as the cathode chamber 20 in Fig. 1. Such modification differs from those described with reference to Figs. 1 to 4 essentially only by exchanging the electrodes.

According to another modification of the invention, one of the two electrodes may be designed as a nozzle. In this case the entire space between the two electrodes is kept at a considerably higher pressure than the space beyond the nozzle. For some cases of application it may be desirable to condense or concentrate the plasma beam behind the nozzle or nozzles. This can be done in known manner by magnetic devices. A simple way of providing such a device in apparatus according to Figs. 1 to 4 is to make the particular electrodes of magnetizable material and to provide them with a magnetizing winding so that the electrodes also serve as magnetic poles.

The embodiments of Figs. 5 and 6 are largely similar to the one described with reference to Fig. 1, corresponding components being denoted by the same reference numerals respectively. It will therefore suffice to describe only the essential differences.

According to Fig. 5 the bottom plate 71 of the cathode chamber is electrically connected with the anode terminal 17 and carries an insert 72 which forms the arc anode and is provided with a narrow nozzle orifice through which the cathode chamber 20 communicates with the anode chamber 10.

In the device illustrated in Fig. 6 the arc cathode 1 is provided with an annular core 74 of magnetizable iron which carries a magnetic excitation coil 75 to be energized from terminals 76. The top plate 77 and the cylinder 78 as well as the bottom plate 79 that form the cathode chamber are all made of magnetizable material; and the bottom plate 79, carrying the same nozzle insert as described with reference to Fig. 1, is equipped with another magnetic excitation coil 80 connected to current-supply terminal 81. When the coils 75 and 80 are energized by direct current, the cathode 1 and the insert 6 operate as magnet poles and produce a plasma-concentrating field. The magnetic field distribution is most favorable if the field intensity has a maximum within the nozzle orifice as is approximately the case in a device according to Fig. 6.

As mentioned above, an ion source according to the invention produces a flow of plasma of extremely high velocity and high ion density. This has the following advantages:

Behind the plasma nozzle, the ions can be extracted in the direction of the plasma beam and can be further accelerated as a beam or jet. Due to the high-velocity flow of the plasma, the supply and replenishment of ions to the probe is no longer limited by the diffusion velocity

of the ions as is the case with the ion sources heretofore available. The extraction of the ions perpendicularly to the plasma beam and radial-symmetrically to the beam axis as described with reference to Fig. 2 is of advantage for some cases of application. An apparatus according to Fig. 2 in which the plasma beam directly enters into the pre-vacuum tube has the further advantage that the excessive amount of gas is directly and almost completely eliminated without affecting the high vacuum. This permits large diameters of the pulling channel of the probe. Furthermore, because of the high temperature of the plasma beam, the molecule-ion proportion is negligibly small relative to the atom-ion proportion since the molecules almost completely disintegrate at the occurring high temperatures.

It will be obvious to those skilled in the art, upon a study of this disclosure, that my invention permits of various modifications as regards the design and arrangement of the individual components and that it may be embodied in devices other than those specifically illustrated and described, without departing from the essential features of my invention and within the scope of the claims annexed hereto.

I claim:

1. An apparatus for supplying a current of ion plasma, comprising a discharge vessel and a gaseous atmosphere therein, a high temperature arc gap device having an arc cathode and an arc anode spaced from each other, means dividing said vessel into cathode and anode chambers in which said cathode and said anode are located respectively, said means having on the arc gap axis a restricted nozzle orifice through which said chambers communicate with each other for flow of plasma, evacuating conduit means communicating with the anode chamber whereby, during operation, the cathode chamber has a higher pressure than the anode chamber, the gas in the cathode chamber being at at least 10,000° C. and at least several atmospheres pressure, and a high-potential probe electrode disposed near said arc gap device for extracting ions from the arc, the probe being connected to a vacuum source for removal of plasma.

2. An apparatus for supplying a current of ion plasma, comprising a discharge vessel and a gaseous atmosphere therein, independently burning plasma producing high temperature arc gap means within said vessel for maintaining an arc in said atmosphere, means having a restricted orifice in the arc gap and dividing the vessel space into separate arc cathode and anode electrode chambers, one of said chambers having a gas pressure which is at least several atmospheres and is of a higher order of magnitude than the other chamber, and a high-potential probe electrode insulated from said arc gap means and disposed in one of said chambers close to said arc gap means for extracting ions from the arc, the probe forming a third chamber, and means connecting the latter to a high vacuum, the three chambers being connected so that the plasma travels from a plasma forming region of comparatively high pressure to a region of lower, pre-vacuum pressure comprising the other one of said arc electrode chambers, and thence through the third chamber to a region of high vacuum, for removal of plasma.

3. The apparatus of claim 2, the cathode and anode chambers being operated at pressures in the ratio of about 40 to .001.

4. The apparatus of claim 2, the pressures in the cathode and anode chambers differing by a factor of three to four powers of ten.

5. In an ion source according to claim 2, said anode chamber having the higher pressure.

6. An ion source according to claim 2, comprising magnet means having a magnetic field for concentrating the beam of plasma produced by the arc.

7. In an ion source according to claim 2, said arc gap means comprising cathode and anode electrodes of

magnetizable material, and magnetizing means mounted on said electrodes to produce a magnetic field for concentrating the beam of plasma produced by the arc.

8. In an ion source according to claim 2, said arc gap means comprising an arc electrode, a magnetizable core of annular shape coaxially mounted on said electrode, and a magnetizing coil on said core to produce a magnetic field for concentrating the beam of plasma produced by the arc.

9. In an ion source according to claim 2, said arc gap means, when in operation, having an arc-current intensity above the minimum required for substantially complete ionization of the plasma.

10. An apparatus for supplying a flow of ion plasma, comprising a discharge vessel and a gaseous atmosphere therein, independently burning plasma producing high temperature arc gap means within said vessel for maintaining an arc in said atmosphere, nozzle means having a nozzle orifice in the arc gap and dividing the vessel space into separate arc cathode and anode electrode chambers, the orifice serving for passage of plasma from the cathode chamber, the gas in the cathode chamber being at at least about 10,000° C., one of said chambers having conduit means for connection to a source of charge gas and the other chamber having conduit means for connection to a vacuum pump, said nozzle orifice having a cross section sufficiently narrow to maintain the pressure in one of said chambers three to four orders of magnitude higher than in the other chamber, said pressure in the one chamber being at least several atmospheres, and a high-potential probe electrode insulated from said arc gap means and disposed in one of said chambers close to said arc gap means for extracting ions from the arc, the probe forming a third chamber, and means connecting the latter to a high vacuum, the three chambers being connected so that the plasma travels from a plasma forming region of comparatively high pressure to a region of lower, pre-vacuum pressure comprising the other one of said arc electrode chambers, and thence through the third chamber to a region of high vacuum for evacuation to a point of use.

11. In an ion source according to claim 21, said nozzle means having coolant circulation ducts surrounding said nozzle orifice.

12. In an ion source according to claim 21, said nozzle orifice having substantially double-conical shape and having its axis coincident with the nozzle axis, said orifice having the narrowest cross section located intermediate the axial ends of the orifice so as to form a Laval-type nozzle.

13. An apparatus for supplying a current of ion plasma, comprising a discharge vessel and a gaseous atmosphere therein, a plasma producing high temperature arc gap device having a cathode and an anode spaced from each other in said vessel, partition means disposed between said anode and cathode and dividing the arc space in said vessel into separate arc cathode and anode electrode chambers, said partition means having a nozzle orifice located axially between said cathode and anode and forming a communication between said chambers, the orifice serving for passage of plasma from the cathode chamber, the gas in the cathode chamber being at at least about 10,000° C., one of said chambers having higher pressure than the other and being connected to a source of charge gas, the other having conduit means for connection to a source of vacuum, and a high-potential probe electrode insulated from said arc gap device and disposed in one of said chambers for extracting ions from the arc, the probe forming a third chamber, and means connecting the latter to a high vacuum, the three chambers being connected so that the plasma travels from a plasma forming region of comparatively high pressure to a region of lower, pre-vacuum pressure comprising the other one of said arc electrode chambers, and

thence through the third chamber to a region of high vacuum for evacuation to a point of use.

14. An apparatus for supplying a current of ions, comprising a discharge vessel and a gaseous atmosphere therein, a high temperature arc gap device having an arc cathode and an arc anode spaced from each other, means dividing said vessel into two separate chambers in which said cathode and said anode are located respectively, said means having on the arc gap axis a restricted orifice through which said chambers communicate with each other, one of said chambers having a higher pressure than the other, a probe electrode chamber having an ion intake opening communicating with the low-pressure chamber, the opening being substantially in alignment with the direction of spacing between said anode and cathode for extracting ions from the arc, said apparatus having a high-vacuum space connected to said probe electrode, the extracted ions passing from said low-pressure chamber through the probe chamber to said vacuum space.

15. In an ion source according to claim 14, said anode having an opening in coaxial relation to said direction of spacing, said probe electrode being disposed at the side of said anode facing away from said cathode, and said orifice and said probe opening being coaxially aligned, whereby the ions are extracted into said vacuum space in the direction of the beam of plasma passing through said orifice of said dividing means.

16. In an ion source according to claim 14, said probe electrode being disposed in radially symmetrical relation to said direction of spacing, and said vacuum space being located laterally of said probe electrode relative to said spacing, and said probe electrode orifice having a slit around the spacing direction, whereby the ions are extracted into said vacuum space in a direction perpendicular to said spacing direction.

17. In an ion source according to claim 14, said vessel having a pre-evacuating conduit communicating with said low-pressure chamber for maintaining a pre-vacuum pressure between said two orifices.

18. An apparatus for supplying ions, comprising a gaseous discharge vessel having two high temperature arc electrodes forming an arc discharge path in said vessel, two nozzle means having respective restricted nozzle orifices located on said path between said electrodes and providing communication between the two electrodes, said nozzle means providing an intermediate space between the two orifices thereof, an evacuating conduit communicating with said intermediate space to form a region of lower pressure, and a high-potential, high-vacuum connected, probe electrode chamber communicating with said region for extracting ions from the arc, there being a space formed between one of the arc electrodes and the entrance to said probe electrode chamber, the latter space being subjected to high-vacuum through said probe chamber, the probe electrode having a nozzle extending into said latter space, the three chambers being connected so that the plasma travels from a plasma forming region of comparatively high pressure of at least several atmospheres adjacent one of the electrodes to the said region of lower pressure, and thence through said latter space and through the probe electrode chamber to a region of high vacuum for supply to a point of use.

19. In an ion source according to claim 18, said two electrodes comprising a cathode in the chamber having the higher pressure and an anode in the other chamber; said cathode, anode, probe electrode and nozzle orifices being all coaxially aligned in the direction of said arc path; said anode and said probe electrode having central openings on the alignment axis.

20. In an ion source according to claim 18, one of said nozzle means being adjacent the lower-pressure chamber and consisting of insulating material.

21. An apparatus for supplying a plasma ion current, comprising a discharge vessel and a gaseous atmosphere

therein, a plasma forming high temperature arc gap means having an arc cathode and an annular conical arc anode spaced from and extending toward the cathode, means dividing said vessel into two separate chambers in which said cathode and said anode are located respectively, said dividing means having on the arc gap axis a restricted orifice through which said chambers communicate with each other, the cathode chambers having an inlet for source gas and having a higher pressure than the anode chamber, the pressure in the cathode chamber being at least several atmospheres, the gas therein being at least 10,000° C., an annular conical probe electrode extending toward and communicating with the anode chamber, the probe having an ion intake aperture substantially in coaxial alignment with the direction of spacing between said anode and cathode for extracting ions from the arc, said apparatus having a high-vacuum space connected to said probe electrode, the ions passing from said low-pressure anode chamber through the probe chamber to said vacuum space for supply to a point of use.

22. An apparatus for supplying ions, comprising a discharge vessel and a gaseous atmosphere therein, a plasma forming high temperature arc gap means having an arc cathode and an annular conical arc anode spaced from and extending toward the cathode, means dividing said vessel into two separate chambers in which said cathode and said anode are located respectively, said dividing means having on the arc gap axis a restricted orifice through which said chambers communicate with each other, the cathode chamber having an inlet for source gas and having a higher pressure than the anode chamber, the orifice serving for passage of plasma from the cathode chamber, the gas in the cathode chamber being at at least 10,000° C. and at at least several atmospheres pressure, an annular conical probe electrode extending toward and communicating with the anode chamber, the probe having an ion intake aperture substantially in coaxial alignment with the direction of spacing between said anode and cathode for extracting ions from the arc, said apparatus having a high vacuum space connected to said probe electrode, the ions passing from said low-pressure anode chamber through the probe chamber to said vacuum space, for supply to a point of use, said arc gap means comprising cathode and anode electrodes of magnetizable material, and magnetizing means mounted on said electrodes to produce a magnetic field for concentrating the beam of plasma produced by the arc.

23. An apparatus for supplying a plasma ion current, comprising a discharge vessel and a gaseous atmosphere therein, a plasma forming high temperature arc gap device having an arc cathode and an annular conical arc anode spaced from and extending toward the cathode, means dividing said vessel into two separate chambers in which said cathode and said anode are located respectively, said dividing means having on the arc gap axis a restricted tapering orifice through which said chambers communicate with each other, the cathode chamber having an inlet for source gas and having a higher pressure than the anode chamber, the orifice serving for passage of plasma from the cathode chamber, the gas in the cathode chamber being at at least 10,000° C. and at at least several atmospheres pressure, an annular conical probe electrode chamber extending toward and communicating with the low-pressure anode chamber for extracting ions from the arc, said anode chamber having a communicating conduit for connection to pre-vacuum means, said apparatus having a high-vacuum space connected to said probe electrode, the ions passing from said low-pressure chamber through the probe to said high-vacuum space, for supply to a point of use the tapering orifice, the anode, the arc gap axis and the probe chamber being in axial alignment.

24. An apparatus for supplying ions, comprising a ves-

sel, a conduit for introduction of source gas into said vessel into a region of comparatively higher pressure of at least several atmospheres, plasma producing high temperature arc gap means in the vessel, the arc gap means comprising two electrodes across which the arc is formed, one of the electrodes being in the said higher pressure region, a high potential probe, insulated from the arc gap means, to extract ions, a high vacuum conduit connected to the probe, the apparatus providing a restricted passage for flow of ions from said region of higher pressure to said probe, said vessel having a low pressure chamber ahead of the probe and subsequent to the other one of the electrodes, with respect to the plasma flow direction, said chamber having a conduit for connection to a vacuum source for removal of plasma, said region and said chamber differing in pressure by a factor of three to four powers of ten.

25. An apparatus for supplying a flow of ion plasma, comprising a discharge vessel and a gaseous atmosphere therein, independently burning plasma producing high temperature arc gap means within said vessel for maintaining an arc in said atmosphere, nozzle means having a nozzle orifice in the arc gap and dividing the vessel space into separate arc cathode and anode electrode chambers, the orifice serving for passage of plasma from the cathode chamber, the gas in the cathode chamber being at at least about 10,000° C., one of said chambers having conduit means for connection to a source of charge gas and the other chamber having conduit means for connection to a vacuum pump, said nozzle orifice having a cross section sufficiently narrow to maintain the pres-

sure in one of said chambers three to four orders of magnitude higher than in the other chamber, said pressure in the one chamber being at least several atmospheres, and a high-potential probe electrode insulated from said arc gap means and disposed in one of said chambers close to said arc gap means for extracting ions from the arc, the probe forming a third chamber, and means connecting the latter to a high vacuum, the three chambers being connected so that the plasma travels from a plasma forming region of comparatively high pressure to a region of lower, pre-vacuum pressure comprising the other one of said arc electrode chambers, and thence through the third chamber to a region of high vacuum for evacuation to a point of use, the pressures in the cathode and anode chambers differing by a factor of at least forty to one.

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