Oct. 29, 1968 C. ETIEVANT ET AL 3,408,519

ION SOURCE WITH SPACED ELECTRODE IONIZING PITS

Filed Aug. 8, 1966

4 Sheets-Sheet 1

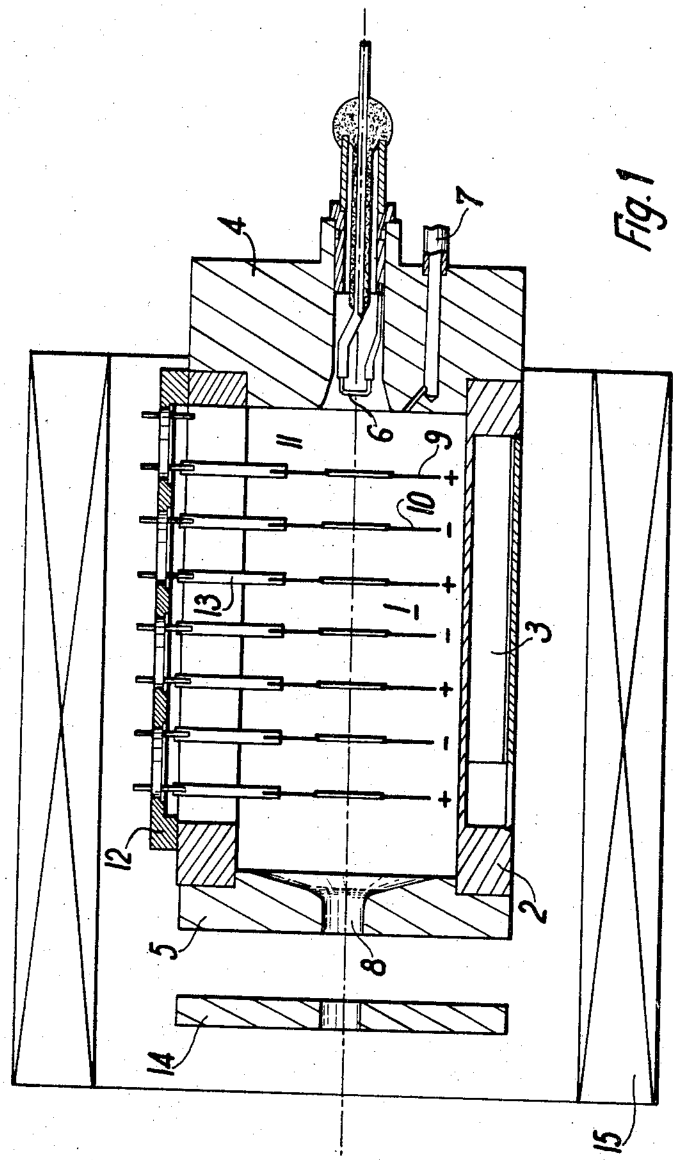


Fig. 1

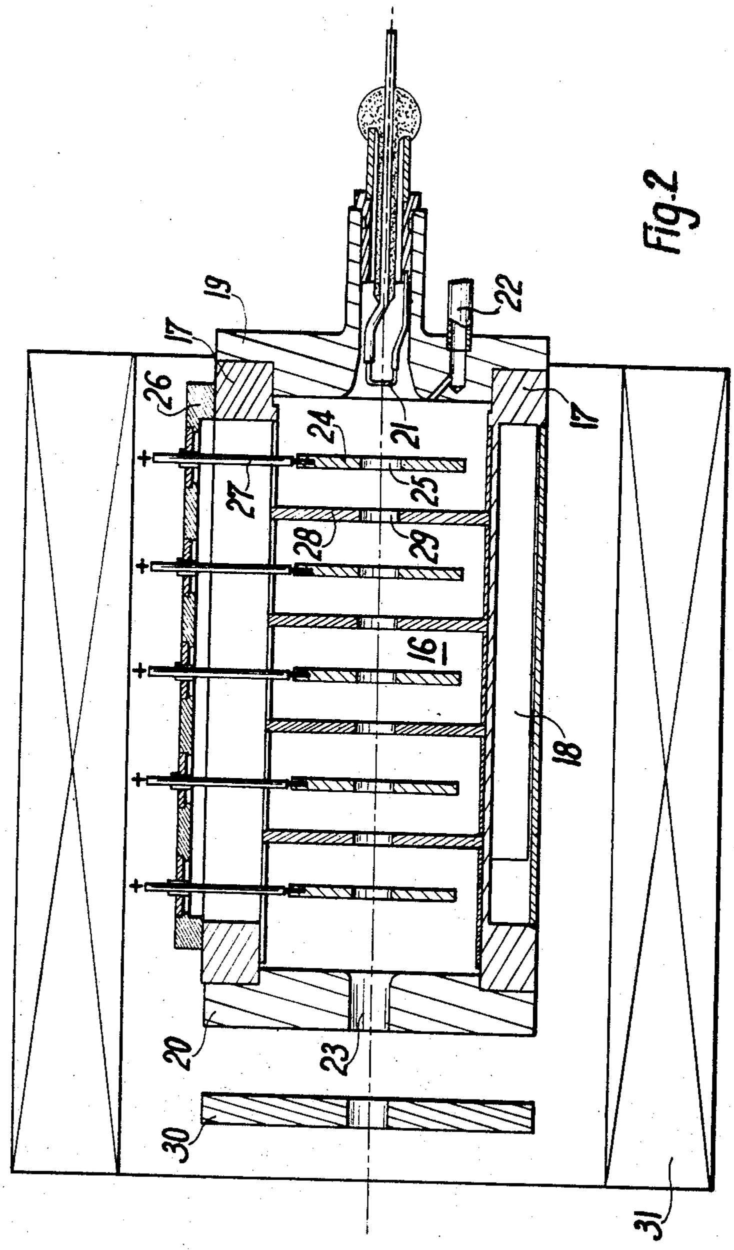


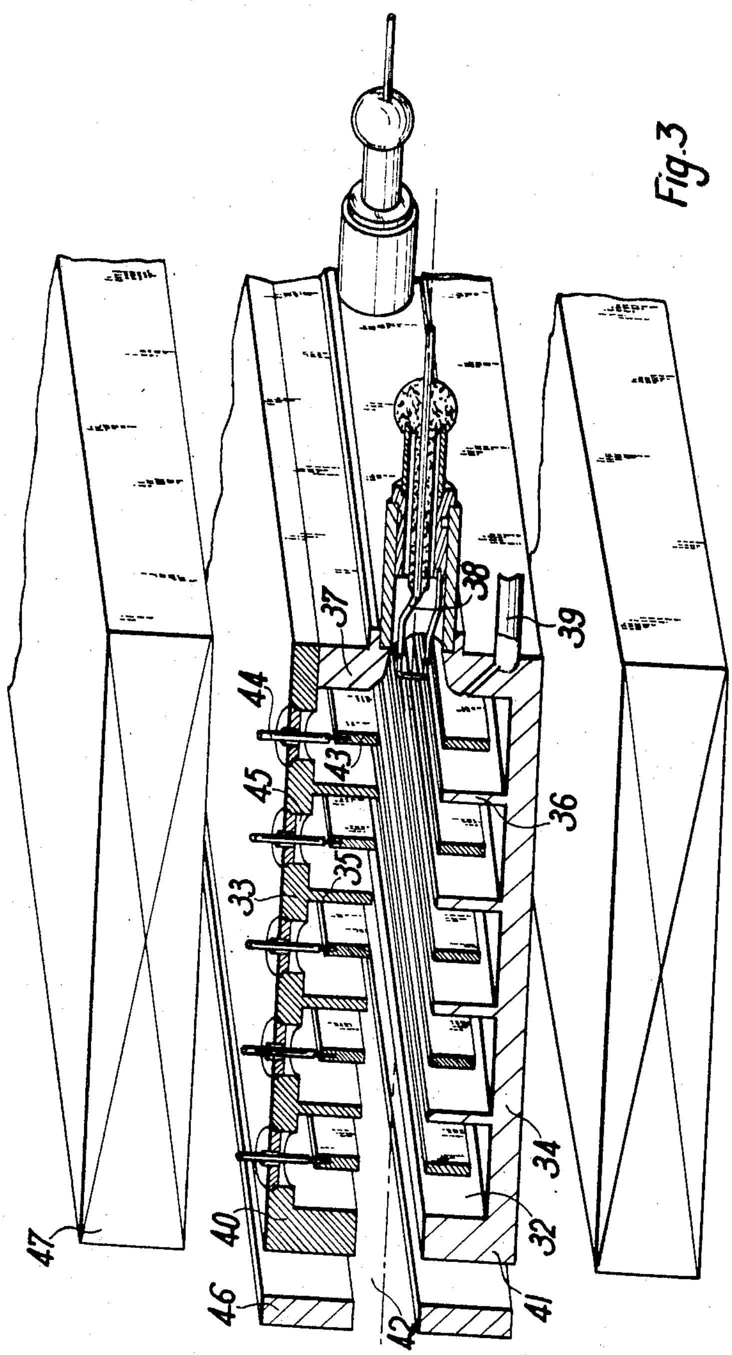
Fig. 2

Oct. 29, 1968 C. ETIEVANT ET AL 3,408,519

ION SOURCE WITH SPACED ELECTRODE IONIZING PITS

Filed Aug. 8, 1966

4 Sheets-Sheet 3



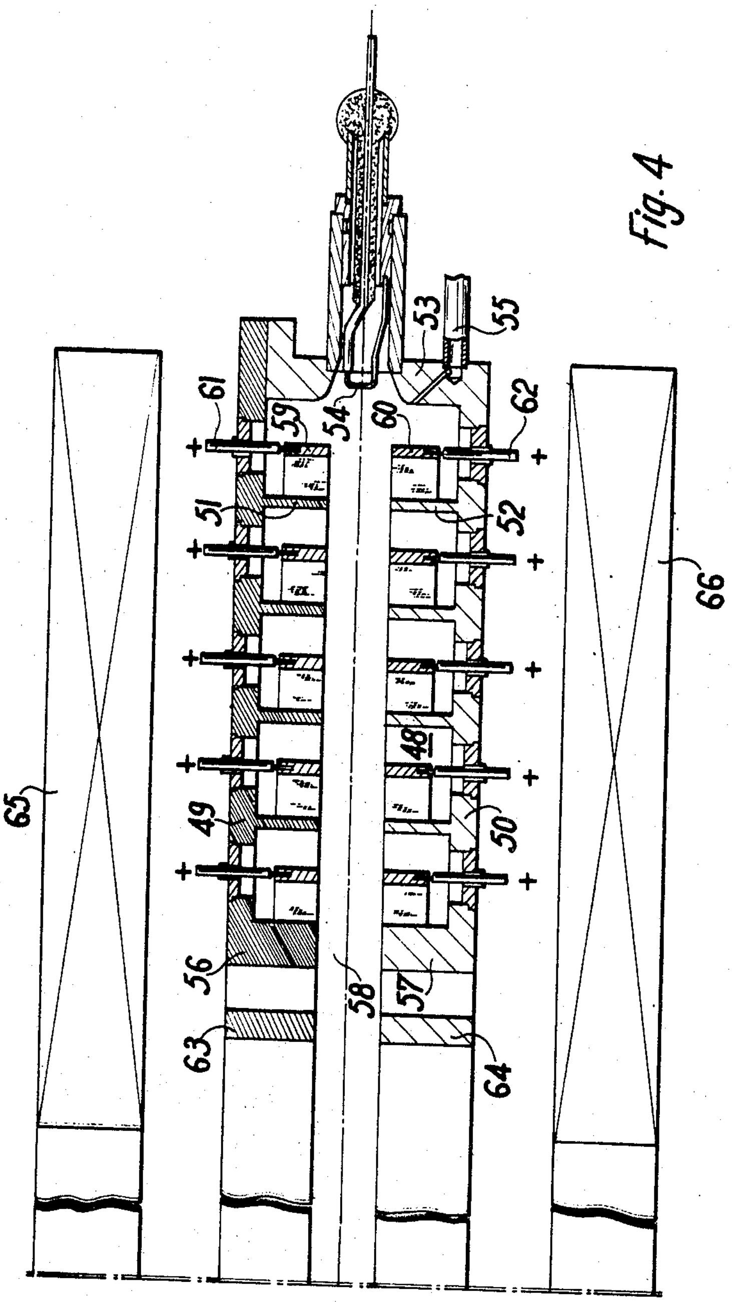


Fig. 4
53
55
61
59
54
60
62
51
52
66
48
65
49
50
56
58
57
63
64
+

United States Patent Office

3,408,519

Patented Oct. 29, 1968

3,408,519

ION SOURCE WITH SPACED ELECTRODE IONIZING PITS

Claude Etievant, Versailles, Pierre Hubert, Sceaux, and Mariano Perulli, Sucy en Brie, France, assignors to Commissariat a l'Energie Atomique, Paris, France

Filed Aug. 8, 1966, Ser. No. 571,109
Claims priority, application France, Aug. 20, 1965, 29,045
6 Claims. (Cl. 313—63)

ABSTRACT OF THE DISCLOSURE

An ion source in a vacuum chamber has between the cathode and the extraction aperture a succession of electrodes each with an aperture and of alternate D.C. potentials. Each electrode forms an ionizing pit with the ions of a given sign being expelled to the pits on either side of a given electrode.

This invention relates to an ion source with a low rate of flow of neutral gas. A large number of known ion sources comprise a chamber into which neutral gas is injected and then ionised by an electrical discharge effect. A magnetic field confines the resulting plasma and thus increases the degree of ionisation of the plasma; one or more electrodes brought to negative potentials with respect to the chamber extract the ions via a small-section aperture formed in the wall of the chamber and accelerate them. These known ion sources differ from one another as regards the type of electrical discharge and the way the electrical discharge is generated. According to a first embodiment, an electric arc is generated by application of a voltage at two electrodes; in the Penning type discharge, the electrons emitted by a cathode are repelled by a negative plate and oscillate for a long time in the gaseous medium before reaching an anode; the magnetron type of discharge occurs under the action of a continuous electrical field and a magnetic field at right-angles to one another. Finally, the gas may be subjected to the action of a high-frequency electrical field.

In the above-described ion sources, the pressure of the neutral gas is about 1 Pascal or 14.7×10^{-5} lbs. per square inch. Neutral molecules flowing via the extraction aperture are obstructive because the life of the plasmas produced with these sources is greatly limited by charge exchange processes.

The attempt has been made to reduce the neutral gas density outside these sources by evacuating the unionised fraction of the gas by means of high-speed pumping systems but such a method requires bulky and expensive pumping installations.

This invention relates to an ion source with a low rate of flow of neutral gas without these disadvantages and using a novel type of electrical discharge. More precisely, the invention relates to an ion source comprising a vacuum chamber having an axis of revolution or a plane of symmetry and provided with neutral gas injection means and containing an electron-emitter cathode and an extraction aperture disposed on the same axis or in the same plane, said ion source being characterised in that it comprises firstly a succession of electrodes disposed inside its vacuum chamber between the cathode and the extraction aperture and perpendicularly to the axis of revolution or the plane of symmetry of the chamber, said electrodes each being formed with an aperture centered on said axis or having their axis situated on said plane and brought to alternate D.C. potentials, and secondly, means for producing a magnetic field extending along the axis of revolution or in the plane of symmetry.

According to a preferred embodiment of the invention, all or some of the said electrodes partition the chamber into chambers which intercommunicate via apertures formed in the electrodes, the first chamber containing the cathode and neutral gas inlet and the last cathode leading to the extraction aperture, the cross-section of the latter then being at least equal to that of the apertures formed in the electrodes, said section being small with respect to the section of the vacuum chamber.

Various exemplified embodiments of an ion source according to the invention will now be described with reference to the accompanying drawings. The embodiment details described in connection with these examples must be considered as forming part of the invention, although any equivalent means can be used without departing from the scope thereof.

Only those elements required for an understanding of the invention have been illustrated in the drawings.

FIGURE 1 is a diagrammatic axial section of a first source comprising a chamber in the form of a cylinder of revolution, according to the invention;

FIGURE 2 shows a second source of a chamber in the form of a cylinder of revolution, according to the invention, again in axial section;

FIGURE 3 is a perspective view of a parallelepipedic flat-beam chamber according to the invention; and

FIGURE 4 is a section of an annular-chamber source according to the invention.

Referring to FIGURE 1, a cylindrical chamber **1** whose wall **2** has a cooling circuit **3** is bounded at the ends by flanges **4** and **5**. At its centre, flange **4** bears a cathode **6** consisting of a filament heated by an electrical source (not shown); a conduit **7** for the injection of neutral gas also extends through the flange **4**. The flange **5** has an axial extraction aperture **8**. Four positive electrodes, e.g. **9**, and three negative electrodes, e.g. **10**, interposed between the positive electrodes and all having a circular shape and each being formed with an axial circular aperture, e.g. **11**, are rigidly secured to a connecting lug **12**; they are electrically insulated from the wall **2** by insulating passages, e.g. **13**, and are connected to the terminals of a high-D.C. generator (not shown), the positive electrodes being connected to the positive terminal and the negative electrodes to the negative terminal. Outside chamber **1** and near flange **5** is an optical system for the extraction and acceleration of the beam, and this is denoted by electrode **14**. The system is placed inside a coil **15** which is coaxial with the chamber and which creates a magnetic field directed along the source axis.

In the embodiment shown in FIGURE 2, a cylindrical metal chamber **16** whose wall **17** has a cooling circuit **18** is bounded at the ends by flanges **19** and **20**. Flange **19** bears an axial cathode **21** consisting of a filament heated by an electrical source (not shown). A conduit **22** for the injection of neutral gas also extends through said flange **19**. Flange **20** has an axial extraction aperture **23**. Five positive electrodes, e.g. **24**, each formed with an axial circular aperture, e.g. **25**, are secured to a connecting lug **26**; they are electrically insulated from the wall **17** by insulating passages, e.g. **27**, and are connected to a high-voltage generator (not shown). Four negative electrodes, e.g. **28**, formed with an axial aperture, e.g. **29**, of the same cross-section as **25**, are supported by the wall **17** and hence are at the earth potential of the source; they are each disposed at the middle of the gaps separating two successive positive electrodes. Outside the chamber **16** and near the flange **20** is an optical system for extraction and acceleration of the beam, this system being denoted by electrode **30**. The system is disposed inside an axial coil **31** which produces a magnetic field directed along the axis of the source.

Referring to FIGURE 3, a parallelepipedic chamber

32 is bounded by a top wall 33, a bottom wall 34 and two lateral partitions (not shown) disposed at the front and rear of the figure. Wall 33 has four half-electrodes, e.g. 35. Wall 34 has four negative half-electrodes, e.g. 36, which are identical to the half-electrodes 35 and are disposed symmetrically thereto with respect to the horizontal plane of symmetry of the parallelepiped; the vertical part 37 of wall 34 has a number of filament cathodes, e.g. 38, spaced uniformly over the depth of the chamber 32 and a conduit 39 for the injection of neutral gas. The two vertical parts 40 and 41 respectively of the walls 33 and 34 bound an aperture 42 of rectangular shaped elongated along the depth of the chamber. Five positive electrodes, e.g. 43, in the form of rectangles having an elongate rectangular aperture of the same cross-section as 42, are situated at the centre of the gaps formed by the negative half-electrodes, e.g. 35 and 36; they are electrically insulated from the walls 33 and 34 and from the lateral partitions and are connected to a high-voltage electric source (not shown) through the agency of insulating passages, e.g. 44, which extend through apertures 45 formed for this purpose in the top wall 33. An optical extraction system denoted by an electrode 46 formed with a rectangular aperture of the same cross-section as the aperture 42 is situated outside the chamber in register with the said aperture. A flat coil 47 producing a magnetic field directed in the horizontal plane of symmetry of the chamber 32 surrounds the latter.

Referring to FIGURE 4, a chamber 48, having a horizontal plane of symmetry and a vertical axis and in the form of a ring of rectangular cross-section, is bounded by a top wall 49 and a bottom wall 50. Wall 49 has four annular negative half-electrodes, e.g. 51, and the wall 50 has four half-electrodes, e.g. 52, which are identical to the half-electrodes 51 and are disposed symmetrically thereto with respect to the plane of symmetry. The vertical part 53 of 50 has a number of cathodes, e.g. 54, spaced uniformly along the periphery of the chamber, and a conduit 55 for the injection of neutral gas. The two vertical symmetrical parts 56 and 57 respectively of the walls 49 and 50 define an annular aperture 58. A positive half-electrode, e.g. 59, is mounted in each of the gaps between two negative half-electrodes in the top part and a positive half-electrode, e.g. 60, is mounted in the bottom part, these half-electrodes being connected to a high-voltage electrical source (not shown) by insulating passages, e.g. 61 and 62, extending through the walls 49 and 50. An optical extraction system denoted by the annular half-electrodes 63 and 64 is mounted in register with aperture 58. Two flat coils 65 and 66 coaxial with chamber 48 generate a radial magnetic field in the latter.

The published work of one of the inventors has shown the possibility of producing very low-pressure discharges in a chamber containing electrodes which are brought to alternate D.C. potentials and subjected to the action of a magnetic field (P. Hubert, compte-rendu de la 5ème Conférence Internationale sur les phénomènes d'inoisation dans les gaz. Munich 1961—North Holland Publishing Company, page 687). Arcing curves were plotted on such a system and show that for a given pressure in the chamber there is a minimum magnetic field at which the voltage between successive electrodes corresponding to the start of the discharge drops abruptly and assumes a value of the order of one kilovolt. It has also been found that in the configuration investigated, fast electrons accumulate at the places which represent potential pits for them, under the effect of a mixed electrical and magnetic confinement. This configuration was obtained in the ion sources according to the invention. In the cylindrical source shown in FIGURE 1, the electrons emitted by the cathode 6 oscillate in the positive potential pit centered at the level of the first positive electrode 9; under the effect of the magnetic field generated by the coil 15 they take a very long path in the gaseous medium so that ionisation probabilities increase. The ions produced are

expelled from this region and accumulate in the negative potential pit centered at the level of the first negative electrode 10. During the oscillations in this pit, these ions ionise the residual gas and the resulting electrons are expelled to the two positive potential pits on either side of the negative potential pit in question. Any particle escaping from a pit thus necessarily drops into an adjacent pit of opposite polarity in which it produces a new residual gas ionisation process. The life of the particles is increased and an appreciable multiplication effect occurs which allows a dense plasma to be obtained. Also, the extraction aperture 8 is disposed after a positive potential pit which expels the ions. The latter are therefore automatically extracted. This effect is combined with the effect of the optical system 14 which strictly could be eliminated. The pressure of the neutral gas is very low because of the electrical configuration obtained.

In the cylindrical source shown in FIGURE 2, the rate of flow of neutral gas of the source was also reduced by using negative electrodes, e.g. 28, to partition the chamber into successive chambers between which there is a pressure gradient. Under conditions of continuous molecular flow, and since the cross-section of the aperture formed in the electrodes is small with respect to that of the body of the source, the pressures P in each chamber are linked by the repetition law $2P_{n+1}=P_{n+2}+P_n$, where n denotes the rank of the chamber counting from the extraction aperture. Since the latter has a cross-section equal to that of the central aperture of the electrodes and the pressure outside the source is very low with respect to the pressure in the first stage, the pressure in the stage of rank n is $P_n=nP_1$. There is therefore a decrease in pressures along the axis of the source and a higher pressure can be maintained in the chamber containing the electrode and the neutral gas inlet while the pressure near the extraction aperture is limited.

The operation of the flat beam source shown in FIGURE 3 and the annular source shown in FIGURE 4 is the same as that of the cylindrical source shown in FIGURE 2, only the shape of the component parts being different. On the three sources described, of which the chamber is metal, only the negative electrodes provide partitioning, so that production is simplified. If the wall of the chamber is an insulator, there is no difficulty in providing as many successive chambers as there are electrodes.

For gas pressures which provide a considerable rate of ion flow of the source, the minimum value of the magnetic field providing the advantage of alternate potential discharge is very small with respect to the values used, so that arcing is practically always obtained under conditions of use. In the above-described sources, the magnetic field is uniform over the entire length but a field of varying intensity could be used and it is very advantageous to form a magnetic mirror near the cathode to enable the flux of the ions lost on the cathode to be reduced. This field can be produced either by coils or by permanent magnets.

Electron sources with a negative final electrode can also be produced on the same principle; the rate of flow of electrons of an emitting cathode can thus be appreciably multiplied.

A cylindrical source according to FIGURE 1 has been constructed with seven electrodes consisting of 2 mm. thick molybdenum discs having an outside diameter of 40 mm. disposed with 15 mm. spacing and formed with 15 mm. diameter apertures. The diameter of the extraction aperture was 4 mm. The cathode was a tungsten filament mounted on a stainless steel flange. The beam acceleration electrode was a molybdenum disc having a 30 mm. diameter aperture. The source operated in a magnetic field of 500–5000 gauss. The voltage between successive electrodes as 2500 to 5000 volts and the beam acceleration voltage varied from 1000 to 5000 volts. The discharge initiating pressure was less than 10^{-3} Pascal in hydrogen. The extracted ion beam intensity was 2 ma. for a pressure of $1.3.10^{-2}$ Pascal and 7 ma. for $6.5.10^{-2}$ Pascal. The corresponding neutral gas flow was

$$33.10^{-2}\ \text{l.} \times \text{Pascal} \times s^{-1}$$

A source as shown in FIGURE 2 gave similar results for an injected gas pressure of 10^{-1} Pascal, i.e. an output pressure of 2.10^{-2} Pascal. The apertures of the electrodes and the extraction aperture then had diameters of about 10 mm.

We claim:

1. An ion source comprising a vacuum chamber having at least one plane of symmetry and provided with neutral gas injection means and containing an electron-emitter cathode and an extraction aperture disposed in the same plane, said ion source comprising a succession of electrodes disposed inside its vacuum chamber between the cathode and the extraction aperture and perpendicularly to the plane of symmetry of the chamber, said electrodes each being formed with an aperture situated on said plane and brought to alternate D.C. potentials, and means for producing a magnetic field parallel to the plane of symmetry, each of said electrodes forming an ionizing pit, the ions of a given sign produced in a given electrode being expelled to the two pits on either side of the given electrode.

2. An ion source according to claim 1, wherein the chamber is in the form of a cylinder of revolution and the electrodes are circular plates formed with a circular aperture.

3. An ion source according to claim 1, wherein the chamber is of rectangular parallelepipedic shape and the electrodes are rectangular plates formed with a rectangular aperture.

4. An ion source according to claim 1, wherein the chamber is in the form of a ring of rectangular cross-section and each electrode consists of two identical cylinders whose axis coincides with the axis of revolution of the ring and is perpendicular to its plane of symmetry, the said two cylinders being spaced a small distance apart.

5. An ion source according to claim 1, wherein the electrodes partition the chamber into successive chambers which inter-communicate by apertures formed in the electrodes, the first chamber containing the cathode and neutral gas inlet and the last leading into the extraction aperture.

6. An ion source according to claim 5, wherein the extraction aperture cross-section is at least equal to that of the apertures formed in the electrodes, said section being small with respect to the cross-section of the vacuum chamber.

References Cited

UNITED STATES PATENTS

2,809,314	10/1957	Herb.	
3,182,220	5/1965	Gabor	313—63
3,274,436	9/1966	Reich	313—231 X

JAMES W. LAWRENCE, *Primary Examiner.*

R. F. HOSSFELD, *Assistant Examiner.*