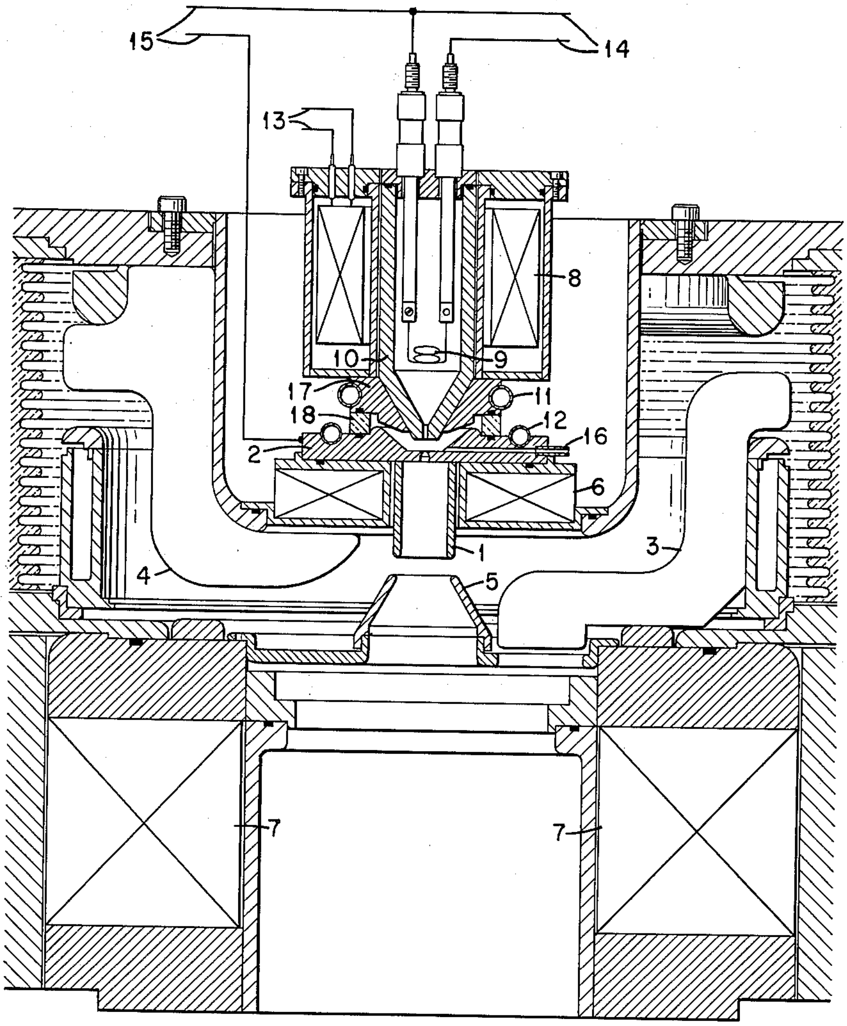
March 1, 1966 G. G. KELLEY ETAL 3,238,414

HIGH OUTPUT DUOPLASMATRON-TYPE ION SOURCE

Filed July 28, 1965



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3,238,414
Patented Mar. 1, 1966

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HIGH OUTPUT DUOPLASMATRON-TYPE ION SOURCE

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Filed July 28, 1965, Ser. No. 475,617
10 Claims. (Cl. 315—111)

This invention relates to an improved duoplasmatron-type ion source in which substantially higher and continuous output currents of high beam quality are provided than is possible with existing ion sources.

Duoplasmatron-type ion sources are utilized in several research programs at various government laboratories. For example, such ion sources are used for the injection of ions into various of the controlled thermonuclear reactor devices and for various accelerator systems. The ion source of the present invention is an improvement over the ion source described in AEC Report ORNL–2926, pp. 60–63, dated June 1, 1960. The ion source described in the above report provided a larger ion current than that provided with prior ion sources such as the von Ardenne ion source set forth in U.S. Patent No. 2,975,277 issued Mar. 14, 1961, for example. However, the output and "quality" of the ion beam achieved with the ion source of the above report were less than desired. The term "quality" refers to the physical shape of the beam at a target where the reciprocal of quality is proportional to the product of the beam diameter times the included angle of the beam. The better the quality, the more concentrated will be the beam at distant points of focus. Another persistent problem that limited the output and quality of prior ion sources was a matter of instabilities in certain energy ranges that resulted in severe sparking in a region between the ion source anode and the extracting electrode.

With a knowledge of the limitations of prior ion sources as discussed above, it is a primary object of the present invention to provide an improved ion source in which the output and quality of the ion beam therefrom are substantially increased over that achieved with prior ion sources.

It is another object of the present invention to provide an ion source with substantially improved output and quality as in the preceding object and including means for substantially reducing the severe sparking caused by instabilities within the ion source that are inherent in such prior sources.

These and other objects and advantages of the present invention will become apparent upon a consideration of the following detailed specification and the accompanying drawing, wherein:

The single figure of the drawing is a sectional view of the ion source for accomplishing the above objects.

The above objects have been accomplished in the present invention by modifying the ion source described in the above-mentioned report which includes providing a plasma expansion cup as part of the anode structure to increase the quantity and quality of the extracted ion beam, providing electron dumps in the region between the anode and the extracting electrode to prevent oscillating electrons from forming undesirable and detrimental discharges or sparking, feeding gas into the region between the intermediate electrode and anode instead of into the cathode chamber as was done in prior ion sources, and providing a solenoid focusing magnet in conjunction with a smaller solenoidal magnet encompassing the above plasma expansion cup to provide a magnetic field nearly zero at the exit of the cup which further aids in producing an ion beam of very good quality and increased output. The use of the cup with a solenoid magnet placed about it, the use of the electron dumps and relocation of the gas feed provide an output which is about double to that achieved with the prior ion source.

Referring now to the drawing, a non-magnetic anode electrode 2 which may be copper, for example, is provided with a plasma expansion cup extension 1, and the anode 2 is provided with a centrally disposed aperture, as shown, for directing ions therethrough. A water cooling tube 12 is provided for cooling the anode 2. An electron emissive cathode 9 is mounted in axial alignment with the aperture in anode 2 and with a tapered collimating intermediate electrode member 10 disposed therebetween. The cathode 9 is connected to an adjustable source of filament supply (0–40 amperes), not shown, over leads 14. The intermediate electrode member 10 is cooled by a water line 11 which encompasses a heat transferring member 17 surrounding the tapered portion of member 10. Alternatively, the member 17 and member 10 may be fabricated into a unitary structure, if desired.

A conventional source magnet coil 8 encompasses the member 10, as shown, and serves its usual collimation function when used. The coil 8 is connected to an adjustable source of magnet supply (0–3 amperes), not shown, over leads 13. An adjustable arc supply voltage (0–200 volts), not shown, is connected over leads 15 between the cathode 9 and the anode 2. A source of gas, not shown, is fed at a controlled rate into the interior of the region between the member 10 and the anode 2 by means of a feed tube 16 with an 0.1-inch opening. Alternatively, gas may be fed into the cathode chamber 10 as in the prior ion sources, if desired, for better utilization of the feed gas. The intermediate electrode member 10 is connected to a source of supply, not shown, which is about 30 volts positive with respect to the cathode 9, for example.

Member 17 encompassing the lower end of member 10 is maintained in spaced relation to the anode electrode 2 by means of an annular insulating ring 18 to thus define an enclosed region where gas is fed thereinto through the gas feed tube 16.

An ion extracting electrode 5 is mounted in spaced relation to the end of the expansion cup 1 as shown in the drawing, and an adjustable source of accelerating voltage (0–100 kv.), not shown, is connected between the anode 2 and the electrode 5 in a conventional manner. A lens solenoid 7 provided with a current of 2400 amperes, for example, is provided below the extracting electrode 5 for the electromagnetic focusing of the ion beam therefrom to separate the beam components thereof in a conventional manner.

In order to provide a specialized shaping of the magnetic field near the anode, a solenoidal magnet 6 is provided adjacent to the anode 2 and encircling the plasma expansion cup 1. With this new coil 6, used in conjunction with the lens solenoid 7, the magnetic field can be made nearly zero at the exit from the cup 1. A significant improvement in beam quality and output has been achieved with the use of the coil 6 as compared to the prior ion source without such a coil. The coil 6 is connected to an adjustable source of supply (0–300 amperes), not shown.

When the feed gas is hydrogen, the beam components are H^+, H_2^+, and H_3^+. The desired beam component, which is space charge neutralized since the lens 7 acts as an electron trap, may be collected on a suitable target for analysis in a manner as described in AEC Report ORNL–3104, dated May 9, 1961, p. 75. When focusing of the ion beam components is not desired, the lens 7 and the coil 6 are not used, and the solenoid coil 8 is then used in a conventional manner.

Because of the geometry of the present device, as described above, electrons will oscillate along magnetic field lines and also precess around the axis of the ion source. Thus, high current operation was hampered by discharges resulting from the oscillating electrons. In order to substantially eliminate these undesirable discharges, a network of interlacing baffles or electron "dump fins" **3**, **4** are placed radially in the region between the anode cup **1** and the extracting eelctrode **5**. Three pairs of these fins located at 60° intervals are used, only two being shown in the drawing. The three pairs of electron dump fins were found to be adequate and resulted in a further improvement in beam quality and an increase in output.

Another modification which resulted in an increase in output and less current drain on the arc power supply was changing the gas feed from the cathode chamber to the region between the intermediate electrode and anode. The total ion output is increased by at least 100 ma. and the arc current at the same time can be reduced by about 10 amperes. However, when high gas efficiency is important, the gas is fed into the cathode region as in the prior art. The ion source is enclosed in a suitable enclosure and the enclosure is evacuated by means of oil diffusion pumps with liquid nitrogen traps and by means of titanium getter pumps, not shown, to a pressure of 5×10^{-8} mm. Hg, for example, in a conventional manner.

In the operation of the ion source of the present invention, for any given current through the source coil **8**, there is a current for the coil **6** that provides an optimum ion current and minimum beam divergence. It should be noted that the maximum output with no current through the coil **8** is at least as high as other optimized combinations. Thus, the ion source of the present invention can be and preferably is operated without using the conventional source coil **8**. Since the present ion source may also be used to provide an ion beam which is not focused, the coil **8** is then used alone without using the coils **6** and **7**, when such a beam is desired as mentioned above. However, in all operations the current to the coil **6** is adjusted either alone or in combination with adjustment of the current to the coil **8** with the lens coil **7** bucking the coil **6** to provide a magnetic field which is nearly zero at the exit from the plasma expansion cup **1** which in turn provides for the optimum ion current from the ion source. With no current to the coil **8**, the excitation of coil **6** is about 10,000 ampere-turns, for example, and the arc current is about 15 amperes, for example. Ion beams of very high quality and as large as 450 ma. of H^+ ions (at 70 kev.), through an aperture 2 cm. in diameter placed 100 cm. below the source, are obtained in the operation of the ion source of the present invention. Currents of 1 ampere are obtainable at a lower quality. It should be noted that the present ion source produces a substantially high output current that is continuous and steady. Such high output currents have not been achieved previously except possibly with pulsed ion sources. These parameters represent performance which is considerably better in several respects than that achieved with prior ion sources. For example, the above achieved continuous output of 450 ma. is about double that obtainable with prior ion sources such as described in the above-mentioned AEC report, ORNL-2926. It should be noted that the best ion beam is always produced when the solenoids **6** and **7** are bucking rather aiding each other. However, an adequate ion beam is produced when these solenoids are aiding each other.

It has been determined that, when the coil **6** is used without using the coil **8** in the operation of the present device, comparable results are obtained if the normally magnetic intermediate electrode **10** is replaced with a nonmagnetic electrode such as copper, for example. The very efficient operation using such a copper intermediate electrode is contrary to what is predicted on the basis of conventional duoplasmatron theory which depends on a high gradient magnetic constriction of the discharge arc. Thus, in the above arrangement, the coil **6** provides a magnetic field for electron trapping, but the discharge is constricted only by the canal in the intermediate copper electrode. By using copper for the intermediate electrode, additional heat transfer can be accomplished and increased flexibility is provided in the operation of the source.

In the ion source of the present invention, as described above, the size of the plasma expansion cup **1** is not critical. However, for every size of anode cup there is a corresponding optimum length that allows the plasma from the source to fill the cup but prevents large plasma losses to the cup walls. For example, the cup **1** may have an inside diameter and length, respectively, of ⅝ inch and 1¼ inches, ⅞ inch and 1¾ inches, 1¼ inches and 2½ inches, 1½ inches and 2½ inches, and 2 inches and 3 inches. It has been determined that the optimum ion beam at 60 kev. can be extracted from the present ion source when the anode cup is 1¾ inches long with a ⅞-inch inside diameter and with the cup's lower surface being ⅛ inch below the lower surface of the coil **6** and 6 inches above the center of the magnetic lens **7**. With the above geometry, the spacing between the cup **1** and the extractor electrode **5** is about 0.3 inch and the anode aperture is 0.070 inch, for example.

Total hydrogen beams up to 900 ma. can be obtained with the present ion source, as described above, and 450 ma. H^+ ions at 70 kev. At 60 kev., a current of 385 ma. of H^+ can be obtained from a total beam of 700 ma. using the present ion source. Thus, it can be seen that the ion source described above is very efficient in producing H^+ beams.

As mentioned above, the solenoid lens **7** is used for focusing an ion species from the source. When it is desired to obtain an intense H_2^+ beam from the above ion source, this is accomplished by enlarging the anode aperture from 0.070 inch to 0.750 inch. With such a modification a 135-ma. 600-kv. H_2^+ beam can be produced with a total extracted beam of 270 ma. This output is about 50% greater than that achievable with prior ion sources.

The present invention has been described by way of illustration rather than by way of limitation and it should be apparent that it is equally applicable in fields other than those described.

What is claimed is:

1. In an ion source in an evacuated enclosure, said source being provided with a heated electron emissive filament electrode, a cooled anode electrode provided with an ion extraction centrally disposed aperture spaced from and in axial alignment with said filament electrode, a cooled intermediate ion collimating electrode disposed between said filament electrode and one side of said anode electrode and being spaced from and in axial alignment with said anode electrode and filament electrode, said intermediate electrode also enclosing said filament electrode, an ion extracting electrode disposed on the other side of said anode electrode in spaced relation and axially aligned therewith, an adjustable power supply connected to said filament electrode, an adjustable source of operating power connected across said anode electrode and filament electrode for establishing an arc discharge therebetween, an adjustable source of accelerating voltage connected across said anode electrode and extracting electrode, and an electromagnetic source solenoid disposed about said filament electrode with a source of magnet power supply connected to said solenoid, the improvement comprising a plasma expansion cup affixed to said anode electrode in axial alignment with said anode aperture and being positioned in the space between said anode electrode and extracting electrode with a spacing gap being provided between said cup and extracting electrode, an electromagnetic solenoid coil encompassing said plasma expansion cup, adjustable power supply means connected to said solenoid coil to provide a selected magnetic field, means for feeding gas at a controlled rate into the space between said intermediate electrode and said anode electrode, a plurality of radially disposed and interlacing electron dump fins posi-

tioned in the vicinity of said gap between said expansion cup and extracting electrode, an electromagnetic solenoid lens axially aligned with said electrodes and positioned beyond said extracting electrode for focusing the ion beam from said extracting electrode and providing space charge neutralization of the focused ion beam, means for energizing said solenoid lens such that its magnetic field bucks the magnetic field provided by said solenoid coil encompassing said cup, and means for adjusting said power supplies to said source solenoid and to said solenoid coil to provide a near-zero magnetic field at the exit of said expansion cup, thereby providing a high quality ion beam from said ion source with at least a twofold increase in output current density.

2. The ion source set forth in claim **1**, wherein said source solenoid is disconnected.

3. The ion source set forth in claim **2**, wherein said intermediate electrode is fabricated from copper.

4. The ion source set forth in claim **3**, wherein three pairs of said electron dump fins are provided, said fins being located at 60° intervals.

5. The ion source set forth in claim **3**, wherein said feed gas is hydrogen, said solenoid lens effecting the separation of the hydrogen ion beam from said extracting electrode into a beam of H^+ ions, a beam of H_2^+ ions, and a beam of H_3^+ ions, said H^+ ion beam having a continuous current density of 450 ma. at 70 kev.

6. An improved ion source including an evacuated enclosure for housing said source, said ion source comprising a heated electron emissive filament cathode, a cooled copper anode provided with an ion extraction centrally disposed aperture spaced from and in axial alignment with said cathode, a cooled intermediate ion collimating electrode disposed between said cathode and one side of said anode in axial alignment and spaced relation thereto, said intermediate electrode also enclosing said cathode, a hollow plasma expansion cup affixed to the other side of said anode in axial alignment with said anode aperture, an electromagnetic solenoid coil encompassing said cup, an

ion extracting electrode mounted in axial alignment with and in spaced relation to the end of said cup, a plurality of radially disposed and interlacing electron dump fins positioned in the vicinity of the space between said cup and extracting electrode, an adjustable source of operating voltage connected between said anode and cathode to provide an arc discharge therebetween, means for feeding gas at a controlled rate into said arc discharge, an adjustable power supply means connected to said solenoid coil, an adjustable source of current supply connected to said cathode, an electromagnetic solenoid lens axially aligned with and positioned beyond said extracting electrode for focusing the ion beam from said extracting electrode and providing space charge neutralization of the focused ion beam, means for energizing said solenoid lens such that its magnetic field bucks the magnetic field provided by said cup solenoid coil, and an adjustable source of accelerating voltage connected across said anode and extracting electrode, said power supply means connected to said solenoid coil being adjusted to provide a magnetic field nearly zero at the exit of said plasma expansion cup, thereby producing an ion beam of high quality and substantially improved output with a minimum of beam divergence.

7. The ion source set forth in claim **6**, wherein three pairs of said electron dump fins are provided, said fins being located at 60° intervals, and said feed gas is hydrogen.

8. The ion source set forth in claim **7**, wherein said intermediate electrode is fabricated from copper.

9. The ion source set forth in claim **8**, wherein said feed gas is fed into the cathode chamber provided by said intermediate electrode which encloses said cathode.

10. The ion source set forth in claim **8**, wherein said feed gas is fed into the space between said intermediate electrode and said anode.

No references cited.

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