Sept. 5, 1967 **G. G. KELLEY** **3,340,425**

ION GENERATOR HAVING BEAM STABILIZATION ACCELERATING ELECTRODES

Filed Aug. 31, 1966 3 Sheets-Sheet 1

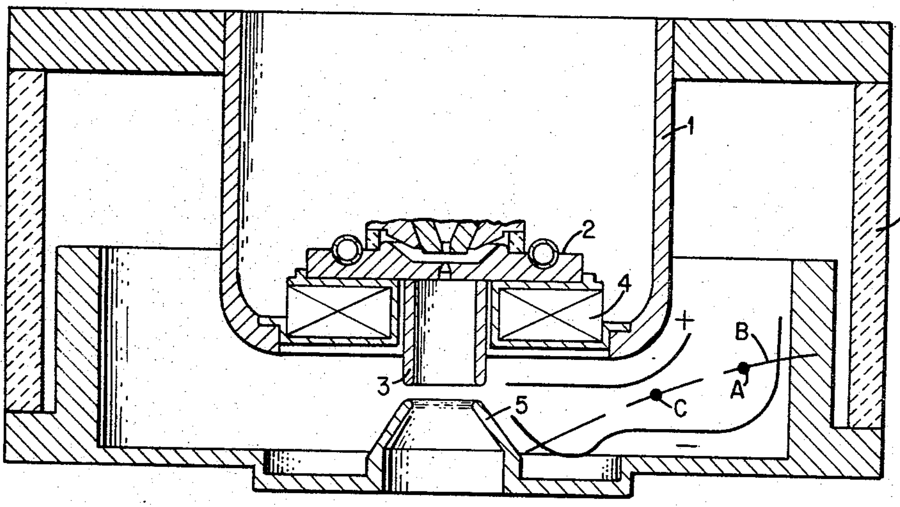

Fig. 1

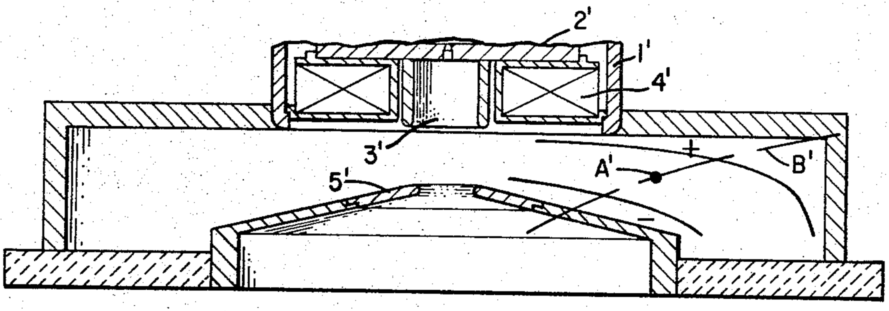

Fig. 2

INVENTOR.
George G. Kelley
BY
Roland A. Anderson
ATTORNEY.

Sept. 5, 1967 G. G. KELLEY **3,340,425**

ION GENERATOR HAVING BEAM STABILIZATION ACCELERATING ELECTRODES

Filed Aug. 31, 1966 3 Sheets-Sheet 2

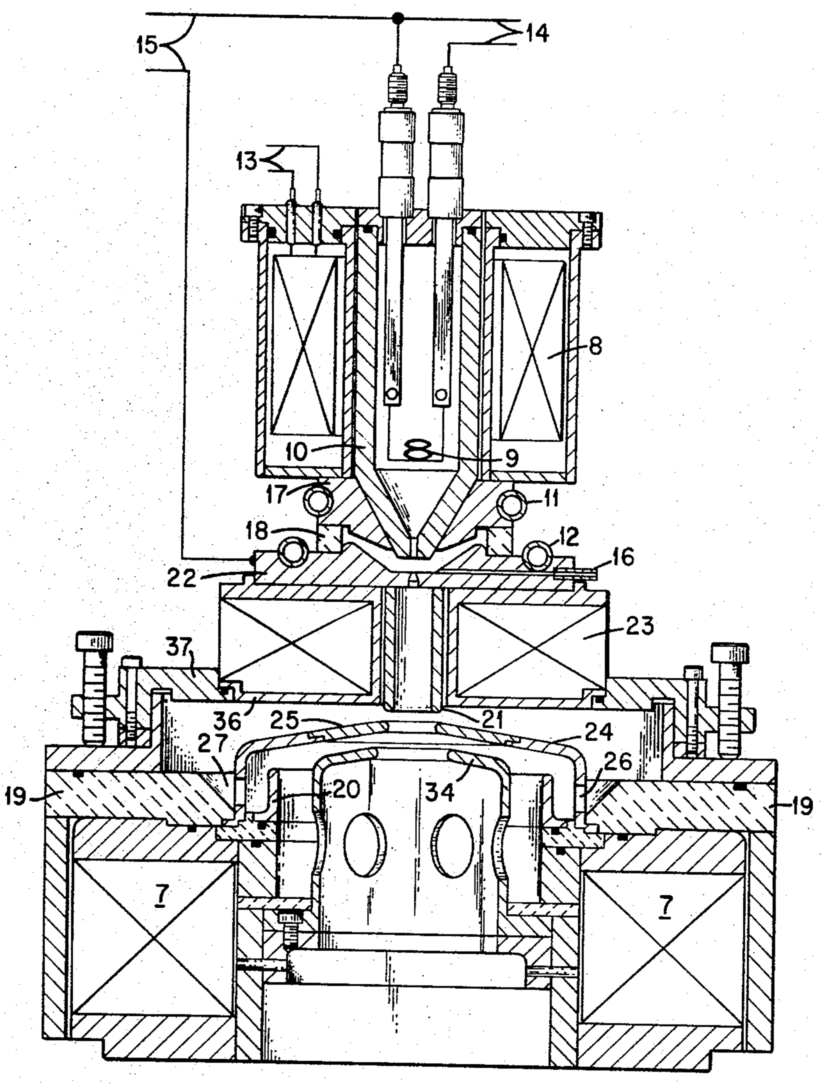

Fig. 3

INVENTOR.
George G. Kelley
BY
Roland A. Anderson
ATTORNEY.

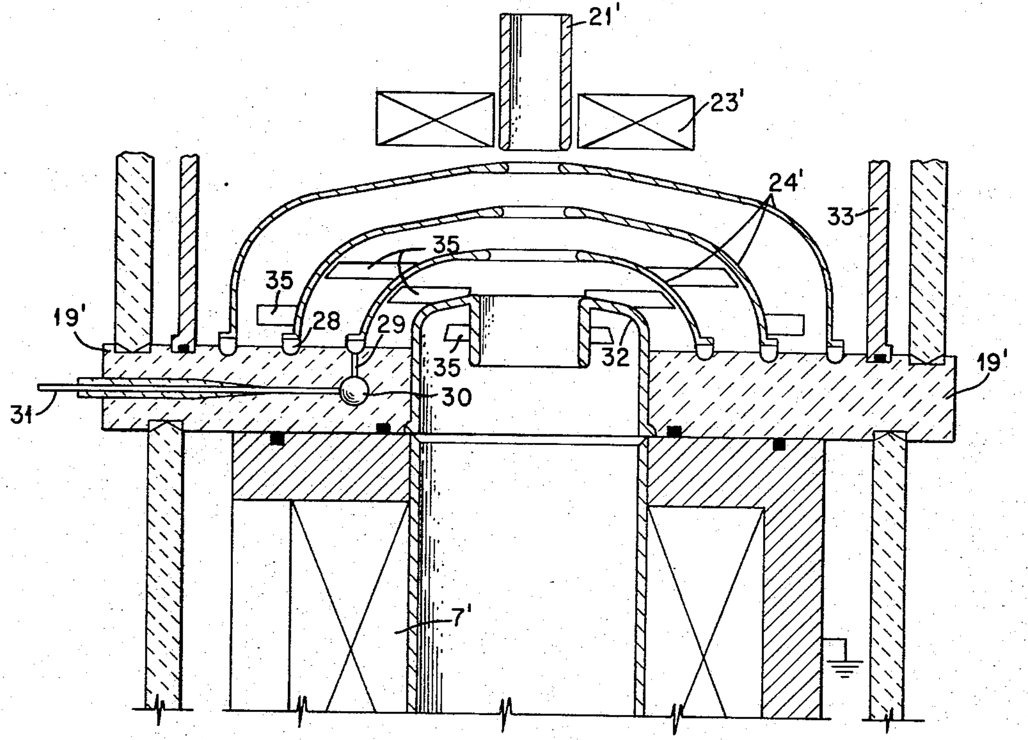

Fig. 4

INVENTOR.
George G. Kelley
BY
Roland A. Anderson
ATTORNEY.

United States Patent Office

3,340,425
Patented Sept. 5, 1967

3,340,425

ION GENERATOR HAVING BEAM STABILIZATION ACCELERATING ELECTRODES

George G. Kelley, Kingston, Tenn., assignor to the United States of America as represented by the United States Atomic Energy Commission

Filed Aug. 31, 1966, Ser. No. 576,791
6 Claims. (Cl. 315—111)

ABSTRACT OF THE DISCLOSURE

An ion generator has an inverted cup-shaped accelerating electrode positioned from a flat plate encompassing an anode plasma expansion cup of the ion generator such that in the ion accelerating region there is no point of maximum potential along a magnetic field line and electron oscillation cannot occur and, thus, the electrons are drawn out of the region as they are formed to thereby permit operation of the ion generator at higher accelerating voltages and higher magnetic fields while at the same time providing an ion beam that is well focused, of good quality, and with an increased output.

The invention described herein was made in the course of, or under, a contract with the U.S. Atomic Energy Commission.

Ion accelerators are utilized in several research programs at various government laboratories. For example, such ion accelerators are used for the injection of ions into various of the controlled thermonuclear reactor devices and for various accelerator systems. The ion accelerator of the present invention is an improvement over the ion accelerator region of the ion source described in U.S. Patent No. 3,238,414, issued Mar. 1, 1966, to George G. Kelley et al. The use of electron dump fins in the region between the anode and the extracting electrode in the above prior patent to minimize the severe sparking in that region caused by oscillating electrons which caused such sparking in ion accelerators prior to that patent, the use of a plasma epxansion cup as part of the anode structure in that patent, and providing a solenoid focusing magnet in conjunction with a smaller solenoidal magnet encompassing the above plasma expansion cup in that patent to provide a magnetic field nearly zero at the exit of the cup all contributed to providing an output ion beam with a substantial improvement in quantity and quality thereof as compared to prior devices. The term "quality" is defined in the above prior patent, to which reference is made.

The device of the above prior patent, although substantially better than those available therefore, was still inadequate in the sense that, when operated at 100 kv., the focusing magnetic field must be less than that desired in order to provide for optimum focusing of the ion beam; otherwise, sparking is excessive even with the use of the electron dump fins when attempts are made to increase the strength of the magnetic field above that which is necessary for efficient operation and focusing of the ion beam. This problem is accentuated further when even higher voltages are desired such as for high voltage (600 kv.) acceleration of the ion beam from the device.

With a knowledge of the limitations of the prior ion accelerators, as discussed above, it is the object of the present invention to provide an improved ion accelerator wherein the ion accelerating electrodes thereof may be operated at higher voltages and the focusing magnetic fields may be more intense than heretofore possible, while at the same time providing an ion beam that is well focused, of good quality, and that has an improved output.

This and other objects and advantages of the present invention will become apparent upon a consideration of

the following detailed specification and the accompanying drawings, wherein:

FIG. 1 is a partial sectional view of the device of the above prior patent illustrating the relationship between the equipotential planes and magnetic flux lines of the accelerating region thereof;

FIG. 2 is a partial sectional view of an ion source embodying the present invention illustrating the relationship between the equipotential planes and magnetic flux lines of the accelerating region thereof;

FIG. 3 is a cross-sectional view of a complete ion source employing the present invention; and

FIG. 4 is a partial sectional view of an ion source wherein the present invention is utilized in a multi-accelerating electrode design.

The above object has been accomplished in the present invention by providing a rearrangement of the accelerating electrodes in the accelerating region of the prior device such that there is no point of maximum potential along a magnettic field line, and electron oscillation cannot occur and thus the electrons are drawn out of the region as they are formed to thereby prevent accumulation and uncontrolled discharge therefrom.

In the drawings, FIG. 1 illustrates the relationship between equipotential planes, shown as solid lines, and magnetic field lines, only one of which is shown as a dashed line, in the accelerating region of the ion source device of the above prior patent. It should be noted that the relative positions of components, and the shape of the equipotential planes and magnetic field line are not necessarily exact; however, there is a point of maximum electrical potential that exists along the field lines, as shown. Thus, an electron generated at point A moves along the field line B since there is a more positive potential at point C. The electron then oscillates along the flux line near the point C. Other electrons that are generated along the flux line B as well as electrons that are generated along other flux lines, not shown, will oscillate in the same manner and permit electron buildup which ultimately results in an undesirable electrical discharge or discharges especially at higher accelerating voltages and magnetic fields even with the use of the electron dump fins, not shown, since the fins do not remove all of the oscillating electrons at the higher operating values of accelerating voltages and magnetic fields.

If, however, an accelerating gap is provided, as in the present invention, such that there are no points of maximum potential along magnetic field lines, electron oscillation cannot occur and thus the electrons are drawn out of the accelerating region as they are formed to thereby prevent accumulation and uncontrolled discharges. Such a gap design is shown in FIG. 2. Here the equipotential planes and magnetic field lines produce the desired conditions. Thus, an electron at point A′ can move along magnetic field line B′, influenced by the potential gradient, without encountering a point of maximum potential prior to reaching the positive potential electrode. With such a gap design as shown in FIG. 2, it has been determined that there is no need for electron dump fins in the accelerating region and the ion accelerator can be operated at higher accelerating voltages and magnetic focusing fields than heretofore possible to produce a stable, well focused ion beam.

In FIG. 1 and FIG. 2, only the components of the accelerating region are shown, such as the source housings 1, 1′; the anodes 2, 2′; the plasma expansion cups 3, 3′; the solenoidal magnets 4, 4′; and the accelerating electrodes 5, 5′.

FIG. 3 illustrates the actual construction of an ion source embodying the present invention. The components 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 21, 22, and 23 of FIG. 3 are substantially the same and function in the same manner as the corresponding components in the above-mentioned prior Patent No. 3,238,414. The accelerating region of FIG. 3, however, is different from that utilized in the above patent and corresponds to that described above for FIG. 2. For example, a base plate **36** of the source unit rests in a recess of an extensive flat plate **37** so that together they form a flat electrode of the accelerating system. A second electrode **24**, in the form of an inverted shallow dish, is positioned in proper relationship to give the desired potential gradient with respect to the cup **21**. The ion aperture of the electrode **24** is defined by a graphite insert **25** so as to withstand operating temperatures. The walls of the dish-like electrode **24** are supported from a flat insulator **19**. The plate **37** is also supported from this insulator. A third electrode **34**, in the form of an inverted cup, is provided as shown such that the electrodes **24** and **34** provide an accel-decel combination that traps electrons between these electrodes and the magnetic lens **7** and allows space charge neutralization in this region. It should be noted that the electrodes **24** and **34** have the same relative configuration with respect to the flat electrode formed by members **36**, **37** whether the device of FIG. 3 is operated in a vertical position, as shown, or is operated in any other position such as on its side or upside down, for example.

The exact shape of the electrode **24** is not critical except that the resultant equipotential planes which are formed permit proper electron drain and that no portion of the insulator **19** can "see" any of the ion beam exiting from the cup **21** or through the aperture in the insert **25** of the electrode **24**. Several apertures **26** are provided in the side walls of the electrode **24** in alignment with slits **27** in the insulator **19** to improve the pumping by vacuum equipment, not shown. Thus, a baffle **20** is provided to block the direct line of sight from an ion beam to the aforementioned insulator **19**.

The cathode **9** of FIG. 3 is connected to an adjustable source of filament supply (0–40 amperes), not shown, over leads **14**. The source magnet coil **8**, when used, is connected to an adjustable source of supply (0–3 amperes), not shown, over leads **13**, An adjustable arc supply voltage (0–300 volts), not shown, is connected over leads **15** between the cathode **9** and the anode **22**. 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. An adjustable source of accelerating voltage (0–100 kv.), not shown, is connected between the anode **22** and the electrode **24** in a conventional manner. The electrode **34** is connected to ground. The water cooling tubes **11** and **12** are provided to cool the intermediate electrode **10** and the anode **22**, respectively.

Gas from a gas source, not shown, is fed at a controlled rate into the chamber between the intermediate electrode **10** and the anode **22** by means of a feed tube **16** with an 0.1-inch opening. Alternatively, gas may be fed into the cathode chamber, if desired, for better utilization of the feed gas. The coil **23** encompassing the plasma expansion cup **21** is connected to an adjustable source of supply (0–300 amperes), not shown.

It should be noted that the device of FIG. 3 may be operated with or without current to the coil **8**, depending upon whether a focused or non-focused ion beam is desired from the device in the same manner as in the above-mentioned prior patent. However, in all operations, the current to the coil **23** is adjusted either alone or in combination with adjustment of the current to the coil **8** with the lens focusing coil **7** bucking the coil **23** to provide a magnetic field which is nearly zero at the exit from the plasma expansion cup **21** which in turn provides for the optimum ion current from the device.

The ion source is enclosed in a suitable enclosure and the enclosure is evacuated to a pressure of 5×10^{-8} mm. Hg, for example, in a conventional manner.

The device of FIG. 3 operates in the same manner as the device in the above-mentioned patent, except the accelerating region of the present device has been modified, as described above, over that used in the prior patent such that the relationship of magnetic field lines and equipotential planes substantially eliminates electron oscillations to a point where the undesirable electrical discharges are eliminated, and no electron dump fins are necessary or required. For example, the device of FIG. 3 has been operated at accelerating voltages up to 100 kv. and magnetic fields (as measured in the throat of the focusing coil **7** below the electrode **24**) up to 5K gauss without any electron discharge, which was impossible to achieve with the prior device of the above patent with such a magnetic field. Ion currents of up to a total of 900 ma. and a H^+ beam of up to 500 ma. have been obtained under these operating conditions and the ion beam was stable and well focused and of very good quality, thus providing a more concentrated beam at distant points of focus than heretofore possible because of the ability to utilize a more concentrated magnetic field as discussed above.

The device of FIG. 3 can be modified, if desired, to provide a centrally apertured target cathode between the anode **22** and the coil **23** and insulated therefrom with the expansion cup **21** affixed to the target cathode in the same manner as the device described in the report ORNL–3908, March 1966, pp. 103–104. The use of such a target cathode in the device of FIG. 3 provides an ion beam that is just as stable and well focused as the ion beam produced by FIG. 3 without the target cathode. Such a modified device with a target cathode is useful for producing a H_2^+ ion beam.

The device of FIG. 4 illustrates a modification of the device of FIG. 3, wherein the accelerating region thereof has been modified to provide a multi-electrode arrangement for ion acceleration. The components **7'**, **19'**, **21'**, and **23'** of FIG. 4 correspond to the same components **7**, **19**, **21**, and **23** of FIG. 3. The other components of the device of FIG. 4, which are not shown, are identical to those utilized for the device of FIG. 3.

In FIG. 4, a plurality of centrally apertured accelerating electrodes **24'** are provided between the cup **21'** and a grounded electrode **32**. The metallic member **33** is electrically connected to the anode, not shown, or to the target cathode, not shown, when such a cathode is utilized. Each of the electrodes **24'** is connected to respective sources of high voltage, only one of such connections being shown, by means of a respective terminal **28**, a lead **29**, a connector **30**, and a lead **31**. The member **33** is connected to a 600-kv. source of potential, and the outer, middle, and inner electrodes **24'** are connected to 450–kv., 300–kv., and 150–kv. sources of potential, respectively. A plurality of pumping slots **35** are provided to facilitate the evacuation of the accelerating region. Thus, the electrodes **24'** of the ion source of FIG. 4 are each shaped to provide the desired relationship of equipotential planes to the magnetic field, and the arch of each prevents "line of sight" between the ion beam and any portion of the common supporting insulator **19'**.

The device of FIG. 4 has all of the advantages of the device of FIG. 3, and is useful as a high energy ion injector for controlled thermonuclear reactor devices and for various accelerator systems.

This invention has been shown and described with a duoplasmatron-type ion source by way of illustration rather than limitation and it should be apparent that it is equally applicable with other sources of ions and in fields other than those described.

What is claimed is:

1. In an ion source device in an evacuated enclosure, said device 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, an electromagnetic source solenoid disposed about said filament electrode with a source of magnet power supply connected thereto, 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, an electromagnetic solenoid coil encompassing said plasma expansion cup, an adjustable power supply means connected to said solenoid coil to provide a selected magnetic field, means for feeding gas at a selected, controlled rate into the space between said intermediate electrode and said anode 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, means for energizing said solenoid lens such that its magnetic field bucks the magnetic field provided by said solenoid coil encompassing said expansion 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, the improvement wherein there are provided (1) an extensive flat plate, (2) a base plate supporting said plasma cup solenoid coil, said base plate being mounted in a recess of said extensive flat plate such that said plates together form a flat electrode of the accelerating system, said ion extracting electrode being in the shape of an inverted shallow dish with respect to said flat electrode, and (3) a flat insulator supporting the side walls of said dish-like extracting electrode, said insulator also supporting said extensive flat plate, said shallow-dish extracting electrode being so designed in relation to said flat electrode such that there is no point of maximum potential along a magnetic field line, and (4) a centrally apertured, grounded electrode positioned between said extracting electrode and said solenoid lens, whereby electrons are drawn out of the region as they are formed to thereby prevent electron

accumulation, electron oscillations and uncontrolled discharges, thus allowing said device to produce a well focused ion beam at relatively large values of accelerating voltages and magnetic fields.

2. The device set forth in claim **1**, wherein said adjustable source of accelerating voltage is of a selected value in the range from 0–100 kv., and the magnetic field in the throat of said focusing solenoid lens is of a selected value up to 5 kilogauss.

3. The device set forth in claim **1**, wherein a plurality of additional ion extracting electrodes are provided in the acceleration region of said device, said additional extracting electrodes also being in the shape of inverted shallow dishes with respect to said flat electrode and being in spaced relation to each other and to said first ion extracting electrode, all of said extracting electrodes being so designed in relation to each other and to said flat electrode such that there is no point of maximum potential along any magnetic field line, and a plurality of selected high voltage sources connected to respective ones of said extracting electrodes to provide a plurality of respective accelerating steps in said accelerating region.

4. The device set forth in claim **3**, wherein at least three extracting electrodes are provided, said flat electrod being connected to a high voltage source of about 600 kv., said high voltage sources connected to said respective extracting electrodes being respectively about 450 kv., 300 kv., and 150 kv., said centrally apertured, grounded electrode positioned between the last of said extracting electrodes and said solenoid lens.

5. The device set forth in claim **2**, wherein a centrally apertured, target cathode is positioned between said anode and plasma expansion cup with said cup being affixed to said target cathode.

6. The device set forth in claim **3**, wherein a centrally apertured, target cathode is positioned between said anode and plasma expansion cup with said cup being affixed to said target cathode.

References Cited

UNITED STATES PATENTS

3,238,414	3/1966	Kelley ----------	313—230 X

FOREIGN PATENTS

835,118	5/1960	Great Britain.

JAMES W. LAWRENCE, *Primary Examiner.*

STANLEY D. SCHLOSSER, *Examiner.*