Oct. 15, 1968 J. E. SWAIN ET AL 3,406,349

ION BEAM GENERATOR HAVING LASER-ACTIVATED ION SOURCE

Filed June 16, 1965 2 Sheets-Sheet 1

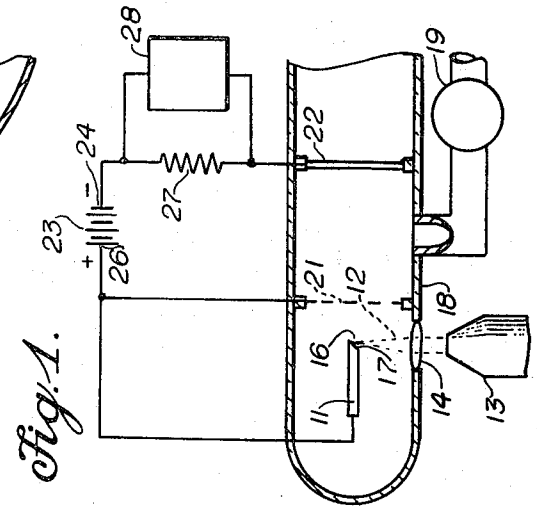


Fig. 1.

Fig. 2.

INVENTORS
JAMES E. SWAIN
JOHN B. TRUHER

BY

ATTORNEY

Oct. 15, 1968 J. E. SWAIN ET AL 3,406,349

ION BEAM GENERATOR HAVING LASER-ACTIVATED ION SOURCE

Filed June 16, 1965 2 Sheets-Sheet 2

Fig. 3.

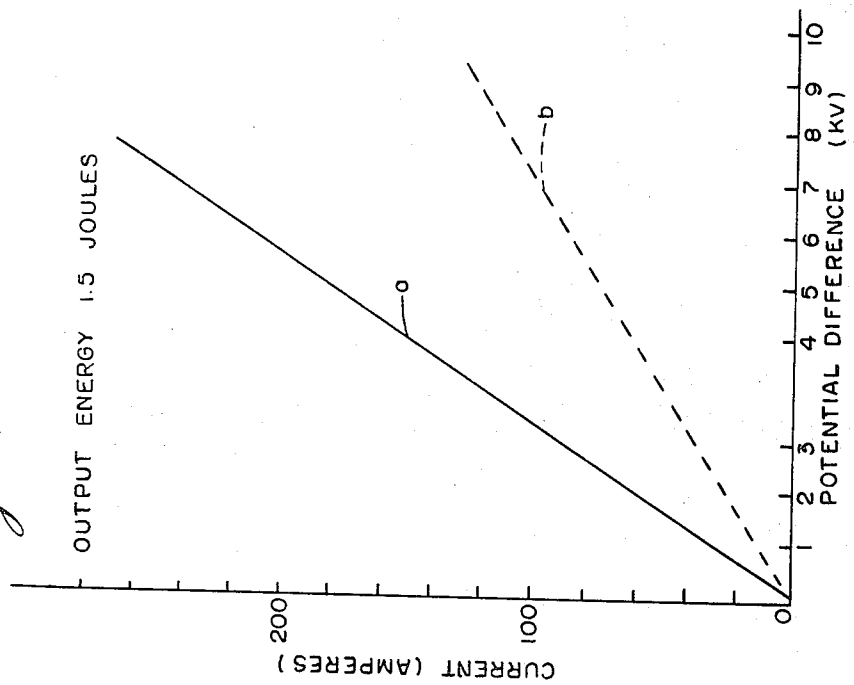
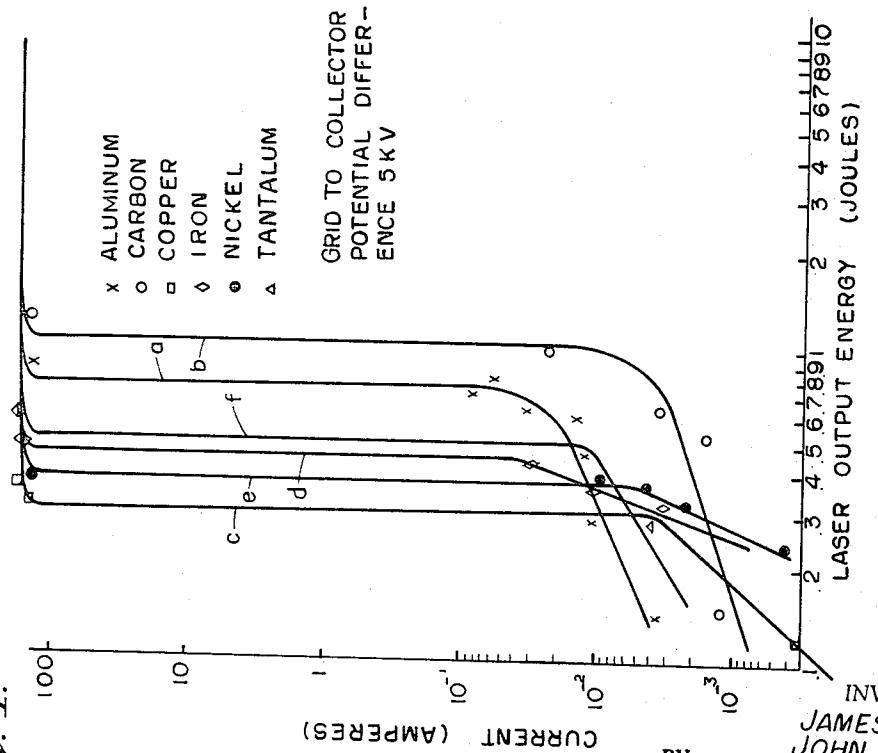


Fig. 4.



INVENTORS
JAMES E. SWAIN
JOHN B. TRUHER
BY
Edmund A. Anderson
ATTORNEY

United States Patent Office 3,406,349 Patented Oct. 15, 1968

3,406,349

ION BEAM GENERATOR HAVING LASER-ACTIVATED ION SOURCE

James E. Swain, Livermore, and John B. Truher, Redwood City, Calif., assignors to the United States of America as represented by the United States Atomic Energy Commission

Filed June 16, 1965, Ser. No. 464,589
7 Claims. (Cl. 328—233)

ABSTRACT OF THE DISCLOSURE

An ion source and accelerator for producing ion beams of energies up to several m.e.v. and up to hundreds of amperes, comprising a target of a material to be ionized disposed in the light beam path of a laser, means for concentrating the light beam to impinge the target surface with an energy sufficient to ionize the target material and produce a plasma, electrode means for extracting the desired ions from the plasma produced by the light beam impinging said target, and electrostatic accelerator means for producing an electric field to accelerate the ions.

The present invention relates to charged particle beam generators, and more particularly, to an ion beam generator having an ion source employing a laser for production of ions and especially adapted for use in combination with electrostatic ion accelerators.

In its broad aspect, the present invention provides an ion source capable of generating heavy, i.e., high atomic or molecular weight, ions for use in an ion gun, which is particularly suited for use in electrostatic ion beam accelerators. In its specific use, the present laser beam ion generator is adapted to a Van de Graaf generator, to furnish a beam of heavy ions of improved intensities, e.g., at least 300 amperes. Generally the apparatus of the present invention forms a plasma including as its major constituent a selected ion species, by directing a laser light beam on a target body of feed material including molecules of the selected ion species. The ionizing action of the impinging laser beam liberates the molecules to form the plasma by evaporation and/or erosion of the surface of the target. The desired ions are then electrostatically extracted from the plasma and accelerated.

A primary advantage provided by the present ion beam generator is the increased intensity, i.e., current density of the ion beam which may be generated thereby. A primary factor which determines the relative rate at which the ions are produced, i.e., the ion beam current density which is produced is the power level of the light beam impinging on the feed body. Any laser preferably delivering a kilowatt or more of power is suitable for use in the ion source of the present invention and the light output of the laser device is directly determinative of the ion output current levels that may be achieved.

As evidenced by the teachings of the prior art, the production and acceleration of beams of light ions is well known. Machines which yield electrons, protons, deuterons and α particles at relatively high amperages are numerous and extensively used, especially in nuclear reaction experiments. With the advent of heavy ion accelerators, such as, the Hilac (Heavy Ion Linear Accelerator) at Lawrence Radiation Laboratory, of the University of California, and the accelerator described in U.S. Patent No. 2,867,748, Jan. 1, 1959, Chester M. Van Atta, the mass range of atomic species useful for nuclear reaction experiments has been extended to about an atomic number of 10. If high energy ion beams of the heavier atomic species are desired, electrostatic type accelerators are the only accelerators thus far known to be available for their

generation. The electrostatic accelerator, notably the Van de Graaf generator, has many advantages, primarily due to the simplicity and relatively low cost of the instrument. Also, the instrument may be used to accelerate light ions as well as heavy ions without basic changes. However, the most serious limitation of the electrostatic accelerators including the Van de Graaf is the low current intensities of the ion beams issuing therefrom, which ion currents are usually in the range of 100 milliamperes to about 1 ampere.

In contrast thereto, ion currents poduced by an electrostatic accelerator utilizing the ion source of the present invention can be up to at least more than two orders of magnitude greater. As a consequence the time required to produce nuclear reaction products in reasonable quantities can now be run in greatly diminished times which contributes to extraordinarily greater yields when isotopes of very short half life are the desired products. More important still, reactions which formerly were never carried out, because the time required was of impractical length, can now be performed in reasonably short periods. For example, various products having a short lifetime could never be made in reasonable quantities by the apparatus of the prior art because such products disintegrated more rapidly than they could be accumulated in amount sufficient even for experimental purposes.

Another advantage of the present ion beam generator is that only relatively small ion generating portions of the ion source need be positioned in the accelerator itself which facilitates its incorporation within various accelerator systems. The auxiliary equipment of the ion source, i.e., the laser light source, electrical power supplies and monitoring equipment, can be arranged externally, requiring only a light path be established between the laser source and feed material.

Accordingly, a primary object of the present invention is to provide an ion source capable of providing an ion current pulse output of up to or exceeding 300 amperes.

More particularly, an object of the present invention is to provide an ion source which is especially suited for use in conjunction with ion accelerators and more especially electrostatic accelerators.

Another object of the present invention is to provide an ion source capable of supplying heavy element ions at high current intensities, particularly atomic species having an atomic weight greater than ten.

A still further object of the present invention is to provide an improved Van de Graaf generator having a high current output of heavy ions.

Other objects and advantages will become apparent upon consideration of the following description taken in conjunction with the drawings, of which:

FIGURE 1 is a schematic representation of the ion source of the present invention;

FIGURE 2 is a cross-sectional view of a Van de Graaf generator, incorporating a laser beam ion generator in accordance with the invention;

FIGURE 3 is graphical representations illustrating the dependence of ion output current on the accelerating voltage used to extract the ions emitted from the target; and

FIGURE 4 is graphical representations illustrating the average ion current generated from various target materials, by a single laser beam light pulse.

Basically the ion source of the present invention comprises laser means, which is energized to generate a beam of coherent light and an emitter target body comprised of a material containing an element corresponding to a selected ionic species upon which the beam of coherent light is directed to vaporize and ionize said element. The ions created by the action of the laser beam form a plasma adjacent to the target. The invention further contemplates

means for extracting selected ions from the plasma and accelerate these ions along a defined path to provide a collimated ion beam.

More specifically, referring now to FIGURE 1, there is shown an emitter target **11**, which is comprised of a body of, preferably, solid material which contains, as high a concentration as possible of an atomic or isotopic species of which an ion beam is to be formed. In principle there is no significant limit to the species of ion which can be produced. The ion source of the invention will be particularly useful for producing ion beam pulses of elements and isotopes above atomic weight ten (10) since prior devices are not especially effective in the range. However, lower atomic weight ions can likewise be generated in the event an effective emitter target can be provided. Any material susceptible to vaporization and ionization by the lower beam should be suitable. It is not necessary that the material be solid. The emitter **11** may be, for example, a pool of liquid, such as mercury, if there are provided reasonable safeguards, such as baffles, to prevent undesirable splattering or the fluid might be absorbed into a porous ceramic or porous metal body on which a surface layer of the liquid is retained. The target **11** is disposed to receive a high intensity coherent beam of light **12**, directed from a laser light source **13**. The laser light source may be any conventional unit, preferably having an output of about one kilowatt or more. Since the number of ions emitted from the target is proportional to the laser output, other parameters being equal, the use of a relatively high-powered laser unit will, of course, be reflected in a marked increase in the ion output of the present ion source.

An optical lens **14** is positioned between laser **13** and emitter target **11** to intercept and concentrate the light beam **12** onto an appropriate surface of emitter **11**. It has been found, in practice, that the number of ions ejected from target **11** increases to a maximum if the laser beam **12** is focused at a focal point **16** somewhat outwardly of the surface of target **11**, rather than on the target surface **17** itself. Maximum ion production occurs if the focal point **16** is about ¼" away from the surface **17** of target **11**. Although a convex lens **14** is shown other optical focusing lenses or a metallic reflector lens system and an optical window may be substituted therefor. In a typical construction emitter **11** is disposed within the closed end region of an elongated tabular envelope **18**. Envelope **18** may be made of an insulator such as glass with lens **14** supported in a hermetic mount (not shown) or in an opaque envelope used in the same manner or provided with a light pervious window disposed externally to admit laser light beam **12**. The envelope is evacuated by a vacuum pump **19** coupled thereto. A filter grid **21** of spaced parallel conductors is disposed transversely across envelope **18** in spaced relation to emitter **11**, and accelerating grid electrode **22** is disposed in spaced parallel relation to grid **21** distally of emitter **11**. The grid **21** and electrode **22** may simply be supported by attachment to the glass or ceramic wall of the envelope **18**, or alternatively by stand-off insulators or the like. A direct current (D.C.) power supply **23** is arranged with the negative terminal **24** connected to accelerating electrode **22**. The positive terminal **26** of supply **23** is connected to emitter **11** and in common to filter grid **21** which is mounted in envelope **18** between target **11** and accelerating electrode **22** across the line of sight path therebetween at a distance of up to a few centimeters from accelerating electrode **22**. Filter grid **21** forms a boundary to the space between emitter **11** and grid **21** occupied by the plasma. Being positively charged with respect to electrode **22**, grid **21** attracts and collects electrons from within the plasma. Positive ions are extracted from the plasma by the negative potential between emitter **11** and electrode **22** to escape through the grid **21** by virtue of their higher momenta and are then accelerated toward electrode **22** by the negative electric field gradient established between electrode **22** and filter grid **21**. A parallelly connected resistor **27** and monitoring oscilloscope **28** serially connected between negative terminal **24** of supply **23** and electrode **22** afford means for measuring the ion current intercepted by electrode **22**, such ion current being proportional to the total generated ion current. The principal portion of the ion current passes unimpeded through the open end of envelope **18** and is available for use thereafter. The vacuum pressure to which envelope **18** is evacuated depends on the voltage impressed between grid **21** and electrode **22**. For a potential difference of a few thousand volts between grid **21** and electrode **22**, the pressure should be reduced to at least 10^{-6} mm. Hg.

As illustrated in FIGURE 1, electrode **22** furnishes the initial accelerating potential for the ions liberated from emitter **11**. Electrode **22** is generally apertured to allow the ions to pass through into a beam tube or the like affixed to the end of envelope **18** distal emitter **11**. However, a high accelerating voltage can be impressed on electrode **22** to accelerate the ions to energies useful for example, in bombardment experiments, or the study of nuclear characteristics of materials. If desired, a target may be disposed at or in front of electrode **22** in which case electrode **22** may be of solid discoidal construction and removably sealed to envelope **18**.

As noted supra, the region between grid **21** and electrode **22** preferably is maintained at a low pressure with a sufficiently large distance between these elements to prevent arcing therebetween. It has been found, however, that arcing or glow discharge between these electrodes produces ions having higher ionization states, e.g., doubly, triply, and more highly ionized ions. Hence, by adjusting conditions so that arcing will occur between grid **21** and electrode **22**, e.g., by increasing the voltage between these elements or decreasing the distance therebetween, ions of higher ionization states can be generated. Moreover, it is theorized that arcing also increases the intensity of the primary ion beam by causing the ionization of neutral atoms and molecules liberated from the target **11** by the laser light beam **12**.

Example

A Q-spoiled laser **13**, comprising a 6" x ½" Brewster angle ruby rod, pumped by two 6" linear Xenon flash lamps furnished a light pulse output of 0.2 joules in 70 nanoseconds. The light beam **12** was directed at a nickel target **11** and focused to a focal point **16** one-quarter inch from the target surface **17** by a lens **14** having a focal length of 1.25 inch. Voltage supply **23** established a potential difference of 3,000 volts between grid **21** and electrode **22**. Grid **21** was a 120 mesh 27% transmitting nickel grid. Electrode **22** was of solid construction to enable collection thereon of the entire nickel ion beam generated. The distance between grid **21** and emitter **11** was set at ½". The peak ion current incident on the electrode **22** was measured by means of a 100 (ohm) resistor **27** and oscilloscope **28** and found to be 14 amps per light pulse.

More extensive data were obtained with an un-Q-spoiled laser **13** having an output of 1.5 joules in the form of a light pulse of a duration of about 200 microseconds. The data are summarized in the graphs of FIGURES 3 and 4. FIGURE 3 illustrates the dependence of the peak current on the grid collector voltage at an output of 1.5 joules. Graph *a* indicates the total effective current including arcing and ion current components at electrode **22** under arcing conditions of operation, while graph *b* represents an estimate of the minimum ion current component incident thereon. The graphs *a–f* of FIGURE 4 show the total peak current incident on electrode **22** for a variety of target materials, i.e., aluminum, carbon, copper, iron, nickel, and tantalum. The potential difference between the grid **21** and electrode **22** was maintained at 5 kv. The ion current component

of the total current is at least 40%. A typical installation wherein an ion source in accord with the invention is illustrated in FIGURE 2. In FIGURE 2 is shown in cross section a portion of the potential spheres of a Van de Graaf generator. The accelerator depicted is of the type wherein positively and negatively charged spheres form an electric field therebetween to accelerate an ion beam. As will be apparent from the discussion below, the inventive principle applies equally well to a single potential sphere Van de Graaf accelerator where the ions are accelerated by the electric field between the potential sphere and ground. A more detailed description of Van de Graaf generators as well as other electrostatic generators is found in Chapter 4 of "Applied Nuclear Physics," Pollar and Davidson, 2nd Edition, John Wiley and Sons, New York, N.Y., 1951. For present purposes Van de Graaf generators may be basically provided as follows:

A first potential sphere **31** in FIGURE 2 is mounted at one end of a tubular support **32**. A conventional belt charge transfer mechanism is mounted with tubular support **32** and transfers positive charge from charge inducing means (not shown) as in conventional practice to sphere **31** via insulating belt **33**. Brush collectors **34** pick up the positive charge from the belt **33** and conduct it to sphere **31**. Simultaneously, the negative charge is removed from sphere **31** by spray point **36** which is conductively communicated between the inside surface of sphere **31** and that portion of belt **33** from which the positive charge is to be removed. Positively charged member **37** attracts electrons from the sphere **31** to the spray point **36**, wherefrom they are removed by the moving belt **33**. A second potential sphere **38** is mounted in spaced relation to the first sphere **31** and is charged to an opposite polarity in a manner similar to sphere **31**, by conventional means (not shown). It is noted, however, that sphere **38** can be referenced to ground potential or eliminated entirely. For the acceleration of positive ions sphere **31** need only be referenced to a negative potential source and a corona discharge established between such source and sphere **31**.

Accelerating tube **39** defines an elongated evacuated volume **41** through which the ion beam from an ion source is directed to be accelerated. A first end **42** of accelerating tube **39** is hermetically joined to sphere **31**. Similarly, the other end **42** of accelerating tube **39** is hermetically joined to sphere **38**. The surface of each sphere, **31** and **38**, in hermetic communication with the interior volume **41** of tube **39** define respectively apertures **44** and **46** to provide communication of the interior **41** of accelerator tube **39** with the respective interiors of spheres **31** and **38**.

To establish a uniform voltage gradient between spheres **31** and **38**, doughnut-shaped conductors **47** are mounted at regular intervals about tubular member **39** in coaxial relation thereto. The doughnut-shaped conductors **47** provide the uniform potential gradient between the spheres **31** and **38** by providing a conducting path for a corona discharge from one sphere to the other, e.g., from sphere **31** to sphere **38**. In order to confine the ions near the center of the tubular member **39**, drift tube **48** is electrically connected to each doughnut-shaped conductor **47**. The cylindrical conductors **48** are coaxially aligned in spaced apart relation within tube **39**. The confinement and acceleration of the particles directed through tube **39** is accomplished by the action of the electric field existing in gaps **49** between adjacent tubular conductors **48**.

The regions **51** and **52** defined by the respective spheres **31** and **38** are at the potential to which the respective sphere is raised. The ion source of the invention is disposed within the field free region **51**. More particularly, the charged particle source comprises emitter target material **53** which furnishes selected ions for the formation of the ion beam. In one embodiment, target **53** is in the form of a thin wire, which is stored on a spool **54** carried, e.g., by bearing mounts (not shown) and advanced on command by friction spools **56** provided with motor or manual drive means (not shown) as the tip **57** of the wire is eroded away to form plasma by a laser light beam **58** that is directed to impinge thereon.

When sphere **31** is of a design not required to be evacuated, laser target **53** and friction drive spools **56** are hermetically enclosed in a tubular vessel **59** similar to envelope **18** which is closed at one end **61** and hermetically joined to the inner surface of potential sphere **31** at the opposite end **62** in axially aligned relation to aperture **44**, as by direct connection or by flanged joint (not shown) to thereby communicate with interior volume **41** of accelerating tube **39**. Accelerating tube **39** and tubular vessel **59** are then evacuated jointly by pumps (not shown).

Towards generating charged particles, a laser light source **63** mounted externally to sphere **31**, generates a laser light beam **58** which is directed through an open space within support column **32** to impinge on target **53**. For example, column **32** is provided with a light pervious window **66** at some distance outside sphere **31** and a prism **67** mounted adjacent thereto in the open space of column **32** to reflectively direct the light beam **58** toward the emitter tip **57**. A lens **68** mounted in the wall of vessel **59** in the path of light beam **58** concentrates the light beam onto target tip **57** where it causes the emission of ions and electrons with finite velocities from the target surface. For optimum results, the lens **68** is positioned to have its focal point at a distance of about ¼" from the surface of target **53**.

The emitted ions and electrons form a moving plasma **69** proximate the surface of target **53**, the plasma **69** moving away from the target surface. Towards forming a beam of ions, a filter grid **70** is mounted in spaced relation to target **53** in path of the moving plasma **69**. As noted hereinbefore, the electrons of plasma **69** are separated from the positive ions which are to be formed into an ion beam by charging both target **53** and grid **70** positively. More particularly, a potential generator **71** has a positive terminal **73** connected to target **53** and grid **70**, and a second less positive terminal **72** to an accelerating electrode **74**. Power supply **71** shown schematically in FIGURE 2 is disposed outside the main portion of the Van de Graaf generator and furnishes a multi-kev. potential difference between positive terminal **73** and terminal **72**. The wire connections are made through the interior of the support column **32** to target **53**, grid **70**, electrode **74**.

A grid mesh, highly transmissive accelerating electrode **74** is preferably of a convex construction and is disposed to point its distended central position toward the grid **70**. The high current ion beam has a tendency to diverge rapidly due to the mutual repulsion of the charged particles. This tendency to diverge is counteracted by the axially converging electric field generated by the convex shape of the accelerating electrode **74**. Accelerating electrode **74** serves the further purpose of accelerating the positive ions which pass through grid **70** towards accelerating tube **39**. The beam is further concentrated and focused by a focusing electrode **76** disposed between the accelerating electrode **74** and aperture **44** and electrically connected to the negative terminal **77** of potential generator **71**. The voltage delivered to focusing electrode **76** is negative with respect to accelerating electrode **74** and positive with respect to potential sphere **31**.

In operation, the ions liberated from target **53** by laser beam **64** are formed into an ion beam and preaccelerated through the full potential difference between the grid **70** and potential sphere **31**. The preaccelerated ion beam enters through aperture **44** into accelerator tube **39** and is accelerated through the full potential difference between the potential spheres **31** and **38**, the accelerated beam is then directed to impinge upon a target **78** disposed at the end of the tube **39**. Although target **78** is shown in FIGURE 2 as being disposed at aperture **46** of sphere **38**, it could be positioned inside sphere **38** or at any point along tube **39**.

It is to be understood that the present ion source is also

adaptable to be used in Van de Graaf generators having a single potential sphere. In such devices the support column **33** generally serves to house the beam tube as well as the belt charging mechanism. Or, as is the case in machines having a potential sphere comprised of two joined spherical shapes, belt charging mechanism transfers the charge to one section of the joined spheres within the support tube provided therefor, while the beam tube is integral with the support for the other half of the joined spheres.

To adapt the present invention to use in conjunction with electrostatic accelerators of the type having a charged plate rather than a closed spherical shell as a high voltage terminal, the most negative terminal of the power source employed in forming the ion beam must be connected directly to the high voltage terminal of the accelerator. At the same time care must be taken that points connected to the positive terminal do not exceed the maximum supportable voltage, since these points are at a higher potential than the high voltage accelerator terminal itself.

Throughout the description the problem of separating one particular ionic species from a beam composed of a plurality of positive ion species has not been dealt with. Often it is not necessary to single out one ionic species, as for example in experiments where the desirable product is easily separated from by-products formed from other accompanying ions. For those reactions or experiments, however, where the purity of the ion beam is of importance, the beam may be split by well known techniques, e.g., in accordance with the teachings of the mass spectroscopy art by passing the ion beam through a magnetic field perpendicular to the field lines thereof. In view of the numerous possible embodiments of the present invention which will be apparent from the teachings of the invention, we pray the present invention be limited only by the following claims.

What is claimed is:

1. Apparatus for generating and accelerating a high intensity ion beam current, comprising,

(a) an evacuated accelerating chamber, said accelerating chamber adapted to be directionally permeated by a high intensity first electric field,

(b) an emitter body including a target element disposed in said accelerating chamber in coextensive alignment with said first electric field,

(c) enclosure means circumscribing said target body in spaced relation thereto, said enclosure means defining a hermetically sealed region communicating with the interior defined by said accelerating chamber in coextensive alignment with said first electric field, said enclosure means defining window passive to light in juxtaposed relation to said target body,

(d) laser light source having an output of at least one kilowatt to furnish an energetic beam of coherent photons,

(e) optical means for focusing said beam of photons onto a point proximate the surface of said emitter means, effective to impinge upon said surface a beam of photons of an energy density sufficient to vaporize and ionize said elemental species,

(f) a conductive grid disposed transverse to the principal axis of said enclosure means in spaced relation to said target body,

(g) an accelerating electrode having a structure passive to said ions disposed transverse to the first electric field in said accelerating chamber in spaced relation to and on the side said grid distal said target body; and

(h) a voltage source having a first and second output terminal, said first terminal positive with respect to said second terminal, said first output terminal being electrically connected to said target body and said grid, said second terminal being connected to said accelerating electrode to thereby establish a second electrostatic field to accelerate said ions of said element from said plasma along a path between said target and said accelerating electrode, said first electric field in said accelerating chamber being established by a first charged conductive shell terminal, said accelerating chamber being joined at a first end to said shell and extending radially away therefrom, said shell further defining an aperture within the region where said accelerating chamber and shell are joined, said aperture being axially aligned with said accelerating chamber, said target body, grid, and accelerating electrode disposed within the volume defined by said shell in axial alignment with said aperture.

2. Apparatus of claim **1** further defined in that accelerating electrode has a convexly curved structure, said electrode being disposed with its outer portions flaring uniformly and axially away from said grid.

3. Apparatus of claim **1** in which said first charged conductive terminal is spherical and said apparatus includes a second conductive spherical shell charged opposite said first spherical shell, said conductive spherical shell being joined to said accelerating chamber at the end thereof distal said first spherical shell.

4. Apparatus of claim **3** further defined in that said second spherical shell defines an aperture aligned with said second electric field established between said first and second spherical shells to provide communication between the volume defined by said accelerating chamber and a portion of interior of said sphere, said portion of the interior of said sphere being adapted to be evacuated and contain a beam target in transverse relation to said second electric field.

5. The apparatus of claim **1**, further defined in that the distance between said surface of said emitter and said point upon which said beam of photons is focused is approximately ¼ inch.

6. The apparatus of claim **1**, further defined in that said emitter is comprised of a high Z metal, and in that said laser has an output energy between about .2 and .3 joules.

7. The apparatus of claim **1** wherein said conductive shell terminal is spherical.

References Cited

UNITED STATES PATENTS

3,294,970	12/1966	Jenckel.	
3,360,733	12/1967	Vali et al.	328—233

ROBERT SEGAL, *Primary Examiner.*