Sept. 27, 1966 TAKASHI TSUCHIMOTO 3,275,867

CHARGED PARTICLE GENERATOR

Filed Feb. 13, 1963

4 Sheets-Sheet 1

Fig. 1

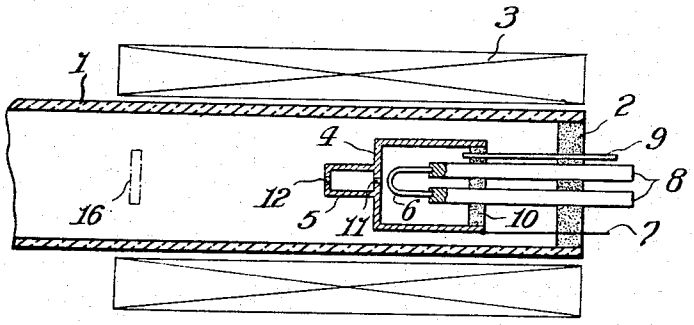
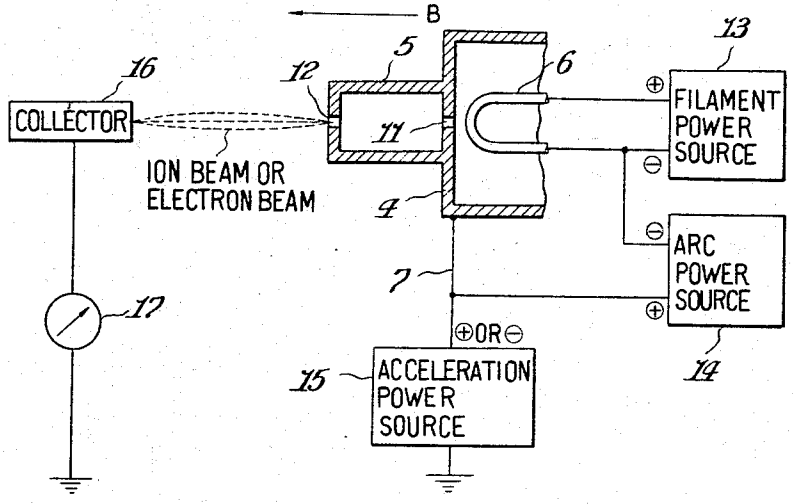


Fig. 2



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Fig. 3

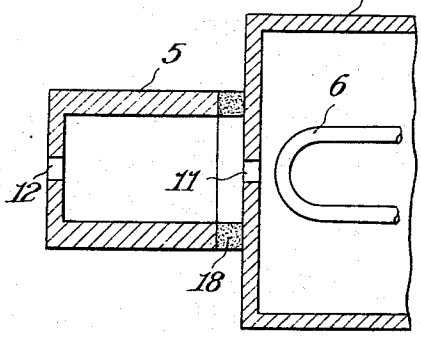


Fig. 4

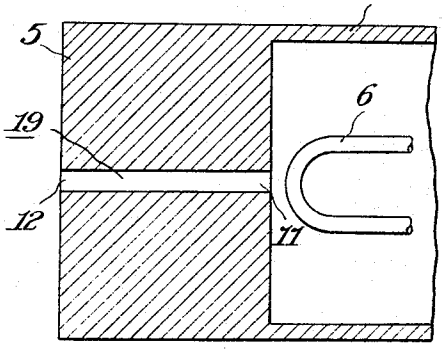


Fig. 5

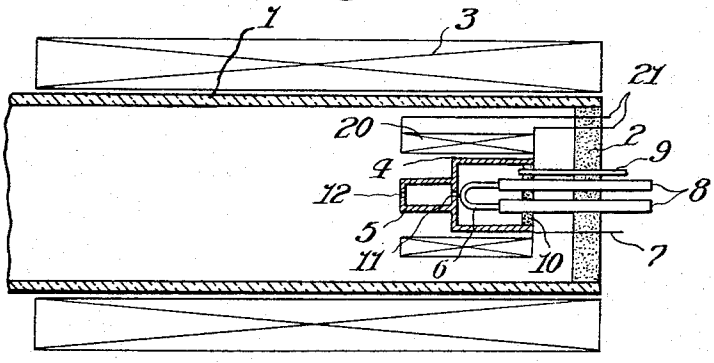
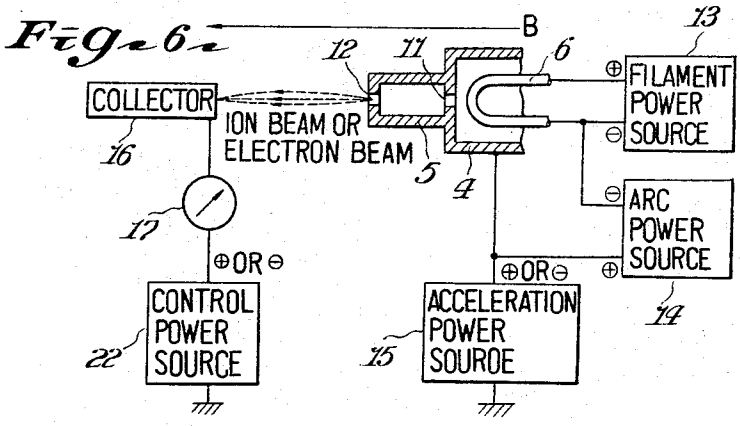


Fig. 6



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Fig. 7

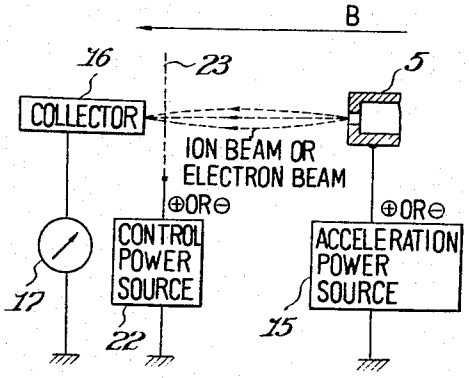


Fig. 8

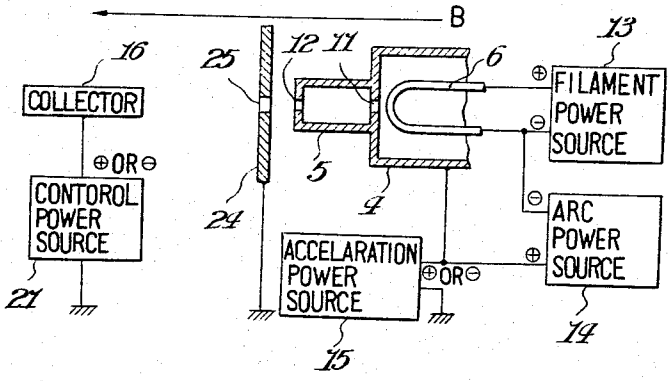


Fig. 10

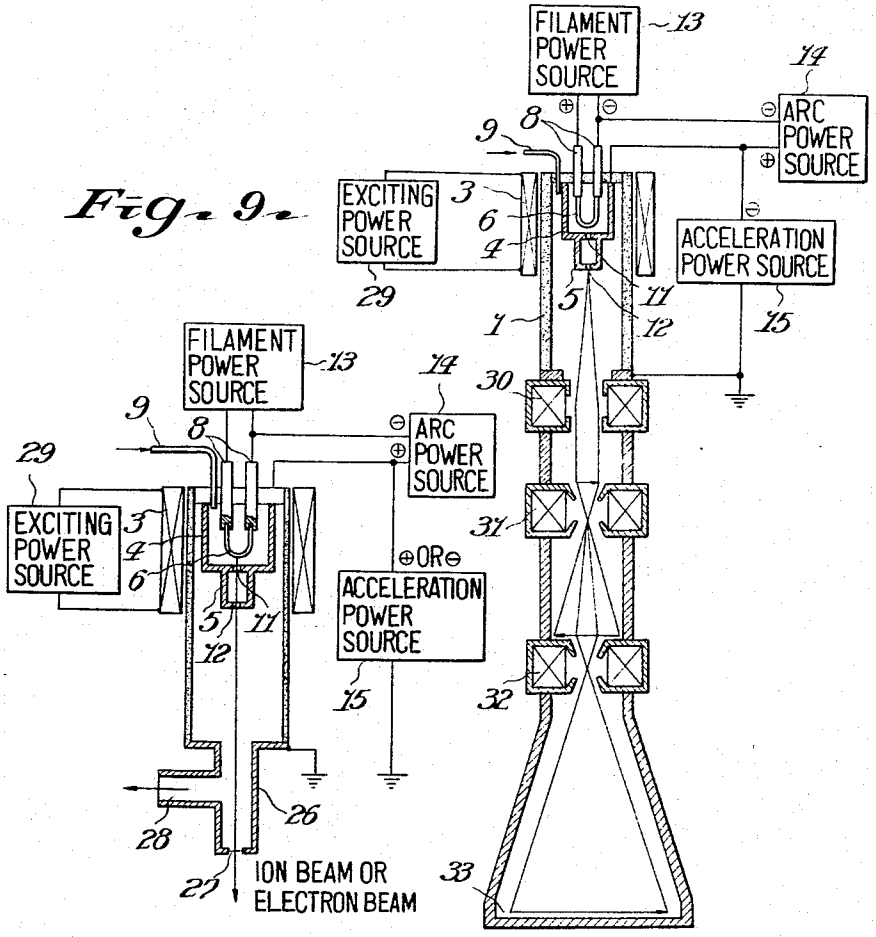

FILAMENT POWER SOURCE
13
14
ARC POWER SOURCE
9
8
EXCITING POWER SOURCE
3
6
4
29
ACCELERATION POWER SOURCE
5
11
12
1
15
30
31
32
33
⊕OR⊖
ION BEAM OR ELECTRON BEAM
26
28
27

Fig. 9

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3,275,867

CHARGED PARTICLE GENERATOR

Takashi Tsuchimoto, Kodaira-shi, Japan, assignor to Kabushiki Kaisha Hitachi Seisakusho, Chiyoda-ku, Tokyo-to, Japan, a joint-stock company of Japan

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Claims priority, application Japan, Feb. 15, 1962, 37/5,207
3 Claims. (Cl. 313—63)

This invention relates to a charged particle generator for use in apparatus wherein charged particles are used, such as, for example, charged particle accelerators and electron microscopes.

In general, charged particle generators are broadly classified into two classes, namely, ion source and electron source, depending on whether the charged particles to be generated are ions or electrons. If, in such an apparatus as a charged particle accelerator, it were possible to accelerate both ions and electrons with a single device, such a feature would be extremely convenient and useful. Heretofore, attempts have been made to provide such a feature by installing, in such an apparatus, both an ion and an electron which are composed of respectively separate systems, but an arrangement whereby, with a single generating device, both ions and electrons can be generated has never been successfully carried into practice, as far as I am aware.

It is an object of the present invention to provide a new and original charged particle generator wherein, by means of a single generating device, both ions and electrons can be generated.

It is another object of this invention to provide a charged particle generator as stated above of simple construction adaptable to minaturization and of simple operation.

With the foregoing and other objects in view, the invention resides in the novel arrangement and combination of parts and in the details of construction hereinafter described and claimed, it being understood that changes in the precise embodiment of the invention herein disclosed may be made within the scope of what is claimed without departing from the spirit of the invention.

Therefore, further and more specific objects and advantages of the invention will be readily apparent from the following description taken from the accompanying drawing in which:

FIG. 1 is a view partly in side elevation and partly in vertical section, showing one embodiment of the charged particle generator according to the present invention;

FIG. 2 is a schematic diagram, partly in block-diagram form, showing one example of electrical connection of the generator shown in FIG. 1;

FIGS. 3 and 4 are enlarged, side elevational views, in vertical section, respectively showing the principal parts of other embodiments of the generator of the invention;

FIG. 5 is a view partly in side elevation and partly in vertical section, showing still another embodiment of the invention;

FIGS. 6, 7, and 8 are schematic diagrams, partly in block-diagram form, respectively showing the constructions and examples of electrical connections for the principal parts of still other embodiments of the generator of the invention;

FIG. 9 is a schematic diagram, partly in block-diagram form, showing one example of a charged particle accelerator provided with the generator of the invention; and

FIG. 10 is a schematic diagram, partly in block-diagram form, showing one example of an electron microscope provided with the generator of the invention.

Throughout the drawings, like parts are designated by like reference numerals and letters.

Referring to FIG. 1, the charged particle generator embodying the invention has a vacuum chamber **1** in the form of a hollow cylinder made of a non-magnetic material, which is preferably also an electrically insulating material at the same time, such as, for example, glass. This vacuum chamber **1** is closed at one end thereof by a vacuum cover plate **2** made of an insulating material and is encompassed concentrically about its external, peripheral portion at the same end by a beam focusing coil **3**. The vacuum chamber **1** contains within its interior, near the same end thereof, a coaxially disposed arc box **4** made of a non-magnetic and electrically conductive material such as, for example, graphite. A plasma box **5** similarly made of graphite is secured coaxially to the arc box **4**. A filament **6** made of a high melting-point metal such as, for example, tungsten or tantalum, is coaxially disposed within the arc box **4** and is connected to and supported by filament heating current conductors **8**. An arc voltage line **7** is connected to the conductive part of the arc box **4**, which is closed at its end facing the aforesaid end of the chamber **1** by an insulator circular plate **10**. A gas inlet pipe **9** is provided to supply gas to the interior of the arc box **4**. The arc box **4** is provided with an arc discharge hole **11** centrally disposed in the end wall of the said arc box **4** forming a partition between the box **4** and the adjoining plasma box **5**, which is provided, at its other end or downstream end, with a beam outlet hole **12**. The aforementioned focusing coil **3** is so adapted as to create an axial magnetic field B within the vacuum chamber **1**. The interior of the vacuum chamber **1** is maintained at a high vacuum of the order of 10^{-6} mm. Hg by a vacuum pump system (not shown).

One example of the electrical circuit of the charged particle generator of the present invention of the above-described construction is indicated in FIG. 2. The essential components of this circuit, other than the afore-described parts, are a filament power source **13** connected to the aforementioned filament **6**, an arc power source **14** connected between one terminal of the filament **6** and arc voltage line **7**, an acceleration power source **15** connected between the arc voltage line **7** and ground (earth), a collector **16** disposed within the vacuum chamber **1** and in the axial magnetic field B, and an ammeter **17** for measuring the beam current projected onto the said collector **16**.

Through the use of the charged particle generator of this invention of the constructional arrangement described above and illustrated in FIGS. 1 and 2, the generation of ion and electron beams is accomplished in the following manner. First, gas for discharge is introduced from the outside through the gas inlet pipe **9** into the interior of the arc box **4**, this gas for discharge being suitably selected in accordance with the kind of ions to be generated. For example, in order to obtain hydrogen ions, hydrogen gas is used, and in order to obtain argon ions, argon gas is used. By suitably regulating the flow rate at which this gas for discharge is introduced, the interior of the arc

box 4 which is within the vacuum chamber 1 evacuated at a high vacuum of the order of 10^{-6} mm. Hg and which is communicated with this vacuum chamber 1 by way of the holes 11 and 12 of capillary dimensions, is maintained at a pressure of the order of 5×10^{-3} mm. Hg at which relatively stable, low-voltage arc discharge is readily obtained. Under this condition, an arc voltage is impressed, with a polarity as indicated in FIG. 2, between the arc box 4 and the filament 6 by the arc power source 14; the filament is heated by the filament power source 13; and, in addition, the axial magnetic field is created by exciting the focusing coil 3 by means of an exciting power source (not shown), whereupon a low-voltage arc discharge is generated between the filament 6 within the arc box 4 and the arc box 4, and the gas for discharge is ionized.

The performance of the generator of this invention connected as shown in FIG. 2 can be illustrated by the following example of experimental result. Under the conditions of a filament voltage of 4 volts, a filament current of 300 amperes, with hydrogen gas used as the gas for discharge at a pressure of 5×10^{-3} mm. Hg, and an axial magnetic field intensity of 2,500 gausses, it was possible to cause, at will, the generation of a stable arc discharge between the range of 5 through 20 amperes, inclusive of arc discharge current by regulating the arc voltage.

The plasma box 5 has the function of maintaining a stable arc discharge even when the pressure of the gas for discharge decreases. That is, the low-voltage arc discharge created between the arc box 4 and the filament 6 passes through the arc discharge hole 11, extending into the interior space of the plasma box 5, and here, also, the gas for discharge is ionized. The ions so produced pass through the arc discharge hole and advance toward the filament 6 to cause the discharge to continue and be stabilized.

Next, in order to obtain either the desired ions or electrons as a beam, it is sufficient merely to impress on the arc box 4 and plasma box 5 an acceleration voltage which is positive or negative with respect to ground (earth) potential by means of the acceleration power source 15 as indicated in FIG. 2. More explicitly, impressing a positive acceleration voltage produces a stream of ions of positive charge, and, conversely, impressing a negative acceleration voltage produces a stream of electrons of negative charge, the said stream in either case being released through the beam release hole 12, focused by the intense axial magnetic field B created by the focusing coil 3, and accelerated toward the collector 16 which is at ground (earth) potential. This accelerated beam of ions or electrons so produced flows into the collector 16 and proceeds by way of the ammeter 17 to ground (earth) potential.

In the charged particle generator of this invention of the above-described compositional arrangement, since the switching between ion generation and electron generation can be accomplished in a simple manner by merely changing the polarity of the acceleration voltage to be impressed on the arc box 4 and the plasma box 5, the operation is simple, and, at the same time, there are other advantages such as the possibility of selecting, at will, the energy of either an ion beam or an electron beam to be used by adjusting the said acceleration voltage. Furthermore, since the beam is fully focused by the existence of the intense axial magnetic field B, complicated electrode systems such as pull-out type electrodes or focusing electrodes are unnecessary, this feature being another important advantage of the present invention.

The performance of the above-described generator according to this invention may be further illustrated by the following example of experimental result. With the use of tantalum wire of 3-mm. diameter for the filament 6, and under the further conditions of a filament heating current of 300 amperes, an arc discharge current of 10 amperes, a magnetic field of 2500 gausses, a gas for discharge consisting of hydrogen gas at a pressure of 5×10^{-3} mm. Hg, and a beam discharge hole 12 of 5-mm. diameter, an ion (proton) beam current of 100 milliamperes was obtained with an acceleration voltage of +400 volts, and an electron beam current of over 1 ampere was obtained with an acceleration voltage of −400 volts.

Thus, the charged particle generator of this invention is highly suitable for obtaining a high-current, charged particle beam of relatively low energy. With further increase in the intensity of the axial magnetic field B, the plasma density within the plasma box 5 increases, and a beam of even higher current is obtained. For example, while with an axial magnetic field B of the order of 2400 gausses an ion beam of only approximately 10 milliamperes can be obtained, when the axial magnetic field B is increased to 20,000 gausses, but the various other conditions are unchanged, it is possible to obtain an ion current of 500 milliamperes or higher. In addition to this method of increasing the plasma density within the plasma box 5, there is the method of increasing the arc discharge current, whereby the output of the charged particles increases substantially as the square of the arc discharge current.

Furthermore, while in the embodiment indicated in FIG. 2 the collector 16 disposed in the axial magnetic field B is connected by way of the ammeter 17 to ground (earth) potential, it is also possible to cause the ion beam or electron beam current to vary over a wide range also by using a control power source 22 as shown in FIG. 6 so that a positive or negative voltage, with respect to the ground (earth) potential, can be impressed on the collector 16 and thereby adjusting the collector voltage. The effectiveness of this method has been experimentally confirmed.

It has been found, further, that beam control of remarkable effectiveness similar to that described above can be achieved also by positioning a control grid 23, for example, of mesh form, upstream from the collector 16 as indicated in FIG. 7 and impressing thereon a control voltage by means of a control power source 22. The term "control grid" used herein is, of course, not limited to mesh-form devices but includes also other devices capable of passing a beam, such as a plate electrode having one aperture or a plurality of apertures.

Because of its remarkable beam current control as described above, the generator of the present invention has the further advantage of being capable of effecting beam current control with a much higher degree of stability than is possible in the case of known electron acceleration devices and the like wherein beam current control is accomplished by varying the filament heating current or the Wehnelt voltage.

FIG. 3 shows another embodiment of the charged particle generator according to this invention, in which the arc box 4 and the plasma box 5 are electrically insulated from each other by an insulating material 18. With this construction, by impressing different voltages on the arc box 4 and the plasma box 5, and providing means to adjust these voltages separately, control of the plasma is facilitated. Furthermore, effective results can be attained by separating the arc discharge hole 12 from the arc box 4 and the plasma box 5 and providing individual adjustment of their potentials.

Still another embodiment of the generator of the present invention is shown in FIG. 4. In this embodiment, the arc discharge hole 11 and the beam release hole 12 are formed as end portions of a long hole 19 formed through the plasma box 5 along its center axis, whereby a high-density plasma compressed into a narrow shape within the interior space of the said long hole 19 is generated. By such an arrangement, not only is the construction simplified, but the vacuum conductance throughout the long hole 19 becomes the minimum in the case wherein the diameter of the beam discharge hole 12 is made constant. Accordingly, it becomes difficult for the gas for discharge to leak through the long hole 19 to the

high-vacuum side, and there is little possibility of dropping of the degree of vacuum of the high-vacuum side. Furthermore, by this arrangement, it is possible to lessen the detrimental effects on the vacuum conductance of the arc discharge hole **11** and the arc discharge characteristics caused by the gradual deformation and enlargement of the said arc dicharge hole **11** due to erosion, with passage of time, of the arc electrode parts provided with the said arc discharge hole because of arc discharging.

FIG. 5 shows still another embodiment of the invention wherein, in addition to the focusing coil **3** shown in FIG. 1, an auxiliary coil **20** is provided within the vacuum chamber **1** so as to encompass the arc box **4** and the plasma box **5** in a disposition which is coaxial therewith. When this auxiliary coil **20** is energized through lead wires **21** by an outside power source (not shown), an intense, axial, auxiliary magnetic field, which is superimposed on the axial magnetic field created by the main coil **3**, is generated in the interior of the arc box **4** and the plasma box **5**, and it is possible to increase the plasma density irrespective of the intensity of the magnetic field due to the main coil **3**. It is also possible, of course, to provide a magnetic field by means of only the auxiliary coil **20** when the magnetic field due to the main coil **3** is of zero intensity, that is, when the main coil **3** is nonexistent. It will be obvious, furthermore, that the means for creating these axial magnetic fields is not limited to hollow cylindrical coils, permanent magnets being also usable for this purpose. The requisite condition is that a uniform, axial magnetic field be formed.

In still another embodiment of this invention, as shown in FIG. 8, a ground (earth) electrode **24** having a beam exit hole **25** is provided between the plasma box **5** and the collector **16**, preferable at a position near the plasma box **5** (for example, at a position at a distance of from a few millimeters to 20 millimeters from the plasma box **5**). The apparatus is so adapted that only an accelerating field exists in the space on the upstream side (plasma box side) of the said electrode **24**, and only a control field exists in the space on the downstream side (collector side) thereof. By this arrangement, in the case when the control field due to the control power source **22** does not exist, the velocity of the accelerated ion stream or electron stream after passing through the beam exit hole **24** becomes constant, and differences in energy due to differences in position are eliminated. Accordingly, beam control when the control field is imposed can be accomplished in an easy, positive, and accurate manner.

In order to indicate still more fully the significant usefulness of the charged particle generator of the present invention and the manner of its application, two particular examples of its application are described in detail hereinbelow.

One example of such application to a charged particle accelerator is shown in FIG. 9. In this application, the vacuum chamber **1** of the charged particle generator of this invention shown in FIG. 1 is formed from a nonmagnetic, electrically-insulating material and is extended to form an acceleration tube. At the downstream end (lower end as viewed in FIG. 9) of this acceleration tube, there is coaxially connected an acceleration tube extension **26** which has an aperture **27** axially disposed at its downstream end and is provided with an evacuation pipe **28** connected to its side. The charged particle generating part of the apparatus is substantially the same as the generator described hereinbefore in conjunction with FIGS. 1 and 2, and the focusing coil **3** is energized by an exciting power source **29**.

In the operation of the accelerator of the above construction, a gas for discharge such as, for example, hydrogen gas, is introduced through the gas inlet pipe **9** into the arc box **4**, and the filament power source **13**, the arc power source **14**, and the exciting power source **29** are caused to operate so as to cause the generation in the

plasma box **5** of a discharge plasma which is concentrated to a high density. Then, when a high acceleration voltage, that is, a high voltage relative to ground (earth) is impressed by means of the acceleration power source **15** on the plasma box **5**, positive ions in the case of positive acceleration voltage, and negative ions or electrons in the case of negative acceleration voltage, are released through the beam release hole **12**, are accelerated through the vacuum chamber **1** toward the ground (earth) potential, and are released into the outside atmosphere through the aperture **27**. The characteristics of the charged particles to be accelerated can be selected at will by suitably selecting the kind of gas for discharge to be introduced into the arc box **4** and the polarity of the acceleration voltage.

FIG. 10 indicates one example of application of the charged particle generator of this invention as the electron beam source of an electron microscope. The downstream end (lower end as viewed in FIG. 10) of the vacuum chamber **1** of the generator of this invention, which is substantially the same as the embodiment hereinbefore described with reference to FIGS. 1 and 2, is connected to the electron beam source end of the microscope structure, which has, in sequental order from the said electron beam source end, a condenser lens **30**, an objective lends **31**, a projector lens **32**, and a camera box **33**. The acceleration power source **15** is adapted to impart to the plasma box **5** a negative voltage relative to ground (earth). For the gas for discharge, a gas such as, for example, hydrogen gas is used, and electrons are derived from the discharge plasma generated in the plasma box **5** and are accelerated. The accelerated electron beam so produced is used within the microscope structure to form an electron line image of the sample or specimen being examined.

By the use of the charged particle generator of the present invention of the above-described constructional arrangement, it is possible, by means of a single generator to generate both positively and negatively charged particle beams, that is, both an ion beam and an electron beam. Moreover, the operation of switching between this ion generation and electron generation, consisting of merely changing the polarity of the acceleration voltage, is extremely simple. In construction, also, the generator of this invention is simpler than a conventional combination of an ion source and a electron source and is adaptable to miniaturization. The present invention provides, furthermore, a charged particle generator having numerous other advantages such as its capability of producing in a stable manner a charged particle beam of high current with any desired energy, whereby the generator of this invention is highly effective for application as a charged particle source of various apparatuses such as a charged particle accelerator.

Although the present invention has been described in conjunction with preferred embodiments thereof, it is to be understood that modifications and variations may be resorted to therein without departing from the spirit and scope of the invention, as those skilled in the device will readily understand, and such modifications and variations are within the purview and scope of the invention and appended claims.

What is claimed is:

1. A charged particle generator comprising means defining a vacuum chamber, means for creating an axial magnetic field within said vacuum chamber, means defining an arc discharge box, means for supplying gas into said arc discharge box, a plasma chamber contiguous to said arc discharge box, said plasma chamber having a small opening therein adjacent said arc discharge box to provide communication between the arc discharge box and chamber respectively, said plasma chamber having an outlet opening to provide communication between the interior of the plasma chamber and said vacuum chamber, said arc discharge box and said plasma chamber

being located within said vacuum chamber so as to create therethroughout from within the interior of said arc discharge box and within said axial magnetic field a low voltage arc discharge plasma and means for impressing an accelerating voltage relative to ground on said arc discharge box to release charged particles within said plasma from said plasma box through the said outlet opening.

2. A charged particle generator as claimed in claim 1 and further including a collector within said vacuum chamber and disposed within the beam path of said charged particles and within the said axial magnetic field and means for impressing a control voltage relative to ground on said collector to control the release rate of said charged particles.

3. A charged particle generator as claimed in claim 1 and further including a collector and a control grid in the beam path of said charged particles within said vacuum chamber and within said axial magnetic field and means for impressing a control voltage relative to ground on said control grid to control the release rate of said charged particles.

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DAVID J. GALVIN, *Primary Examiner.*

GEORGE N. WESTBY, *Examiner.*

D. E. SRAGOW, *Assistant Examiner.*