United States Patent

Akahori et al.

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[54] ELECTRON BEAM GENERATOR FOR ELECTRON MICROSCOPE OR THE LIKE APPARATUS

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[52] **U.S. Cl.** .....**250/49.5 A**, 313/84, 313/282, 313/DIG. 1

[51] **Int. Cl.**.....**H01j 37/26**

[58] **Field of Search**.....313/DIG. 1, 313, 84, 282; 250/49.5 R, 49.5 A

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[57] **ABSTRACT**

An electron beam generator for electron microscopes or the like apparatus comprising an electron gun, an anode placed in a position opposite to the electron gun, and an electron gun chamber containing therein the electron gun and the anode, wherein either an electrical insulation layer is formed on the inner surface of the electron gun chamber or a cylinder of an electrically insulating material is provided to enclose the electron gun and the anode.

6 Claims, 11 Drawing Figures

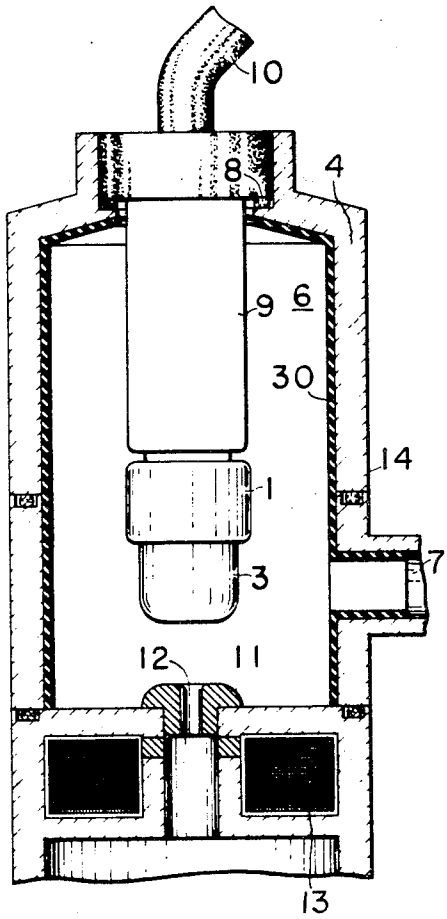
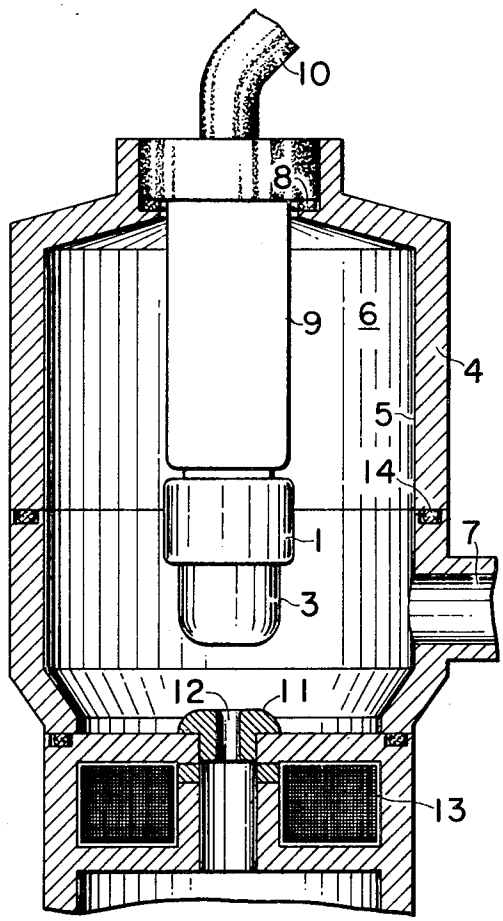


FIG. 1

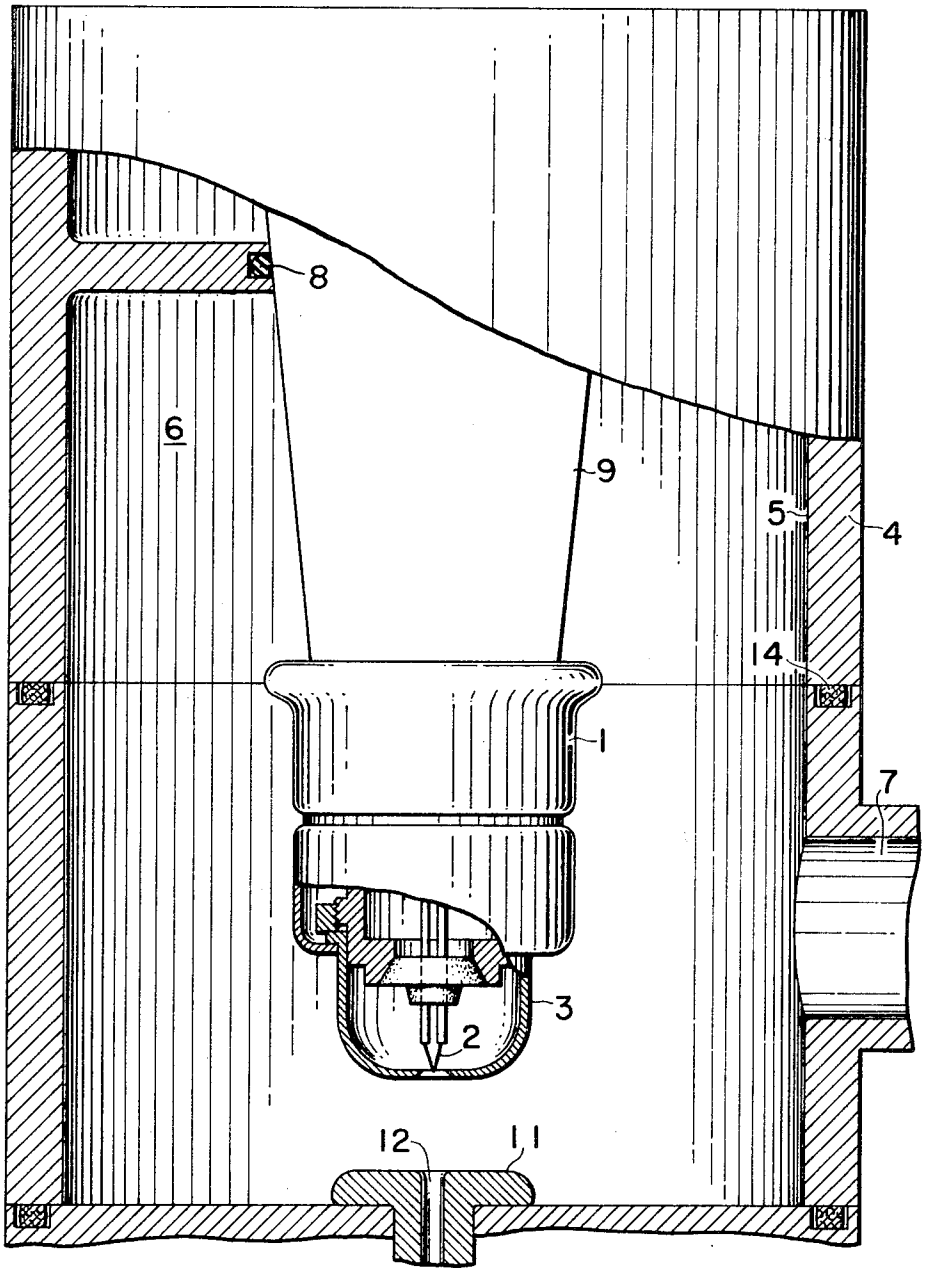


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FIG. 2



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FIG. 3

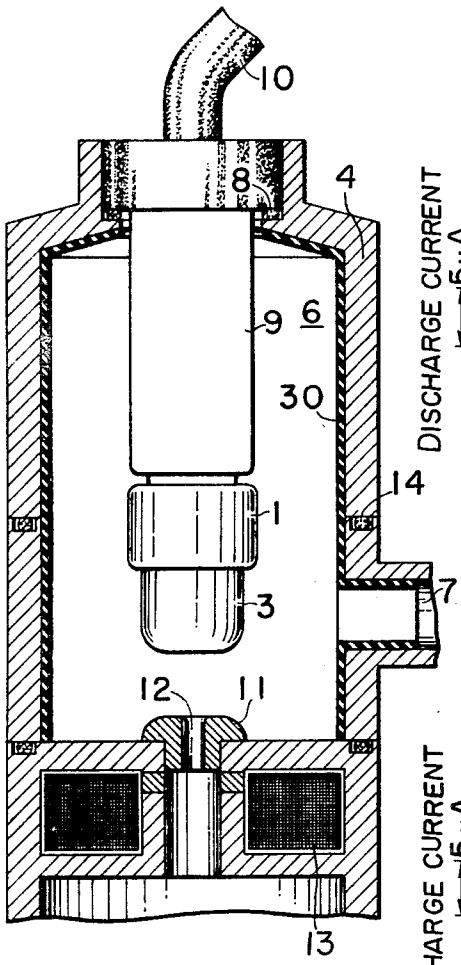


FIG. 4a

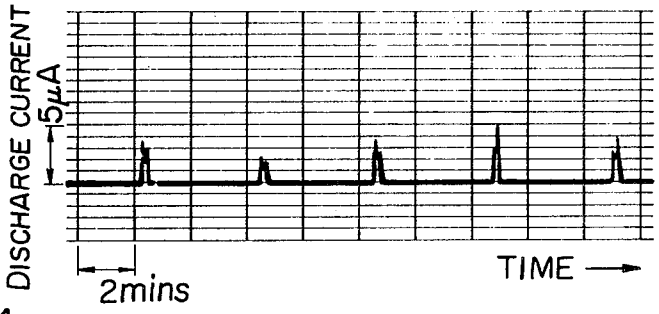
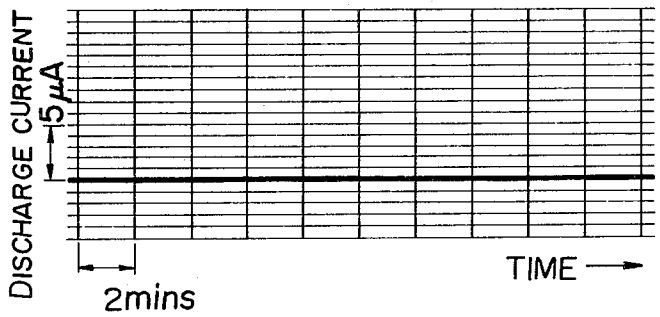


FIG. 4b



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FIG. 5

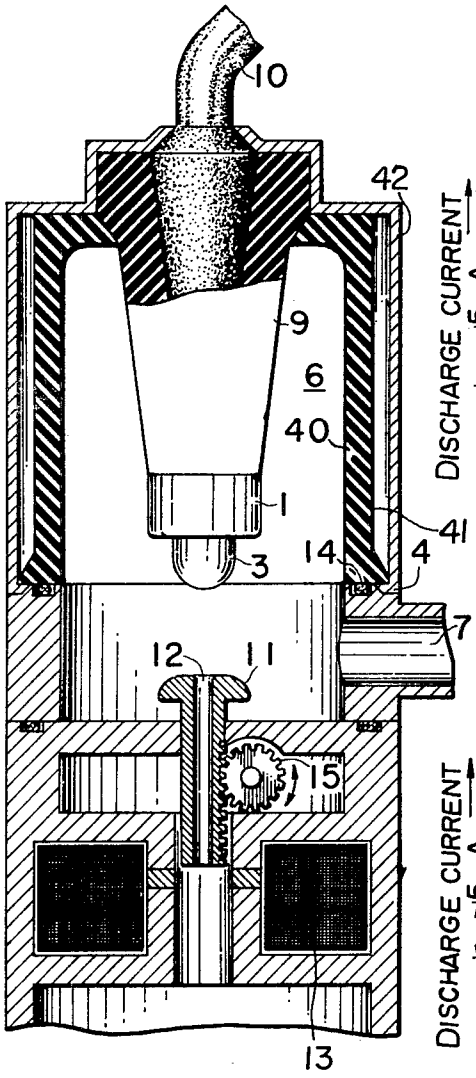


FIG. 6a

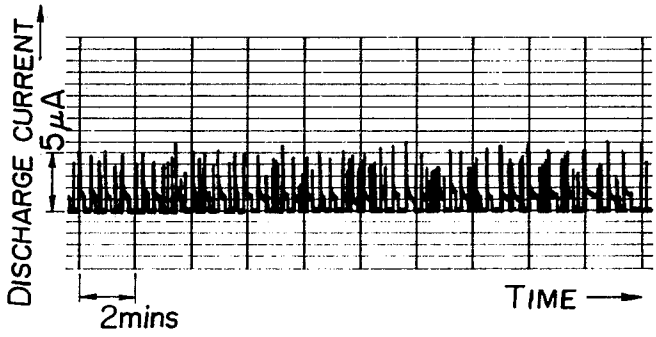
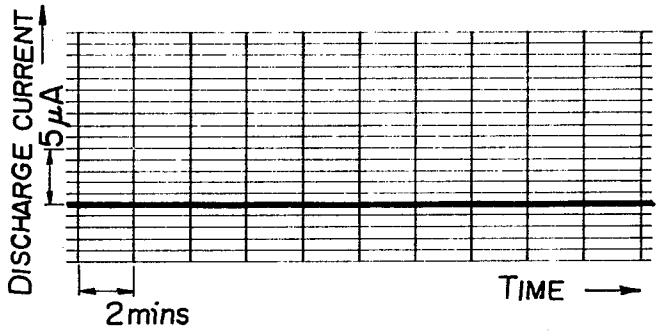


FIG. 6b



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FIG. 7

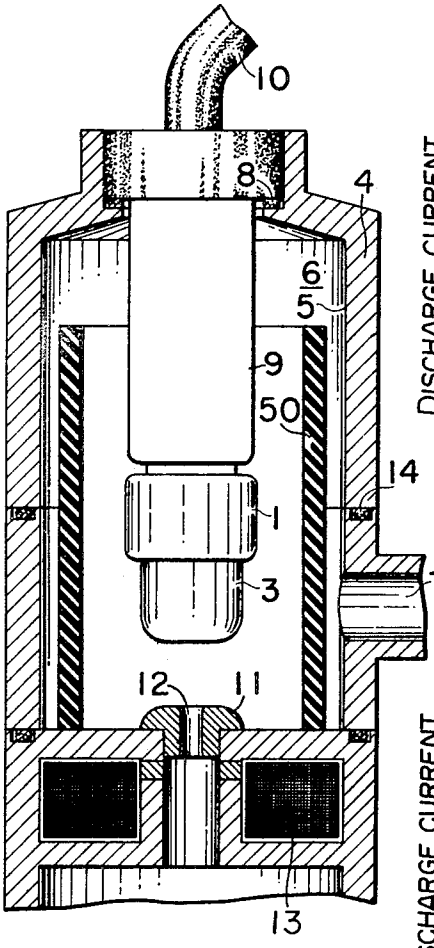


FIG. 8a

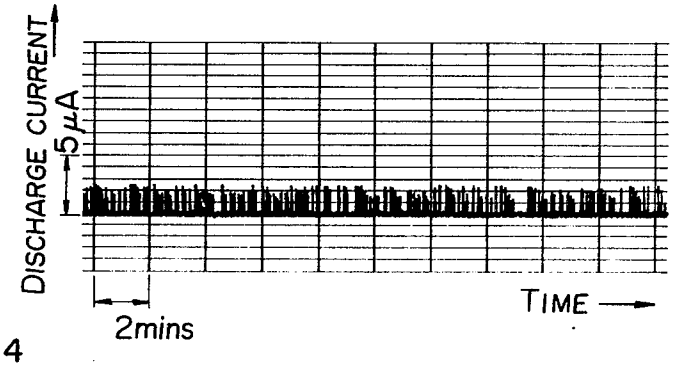
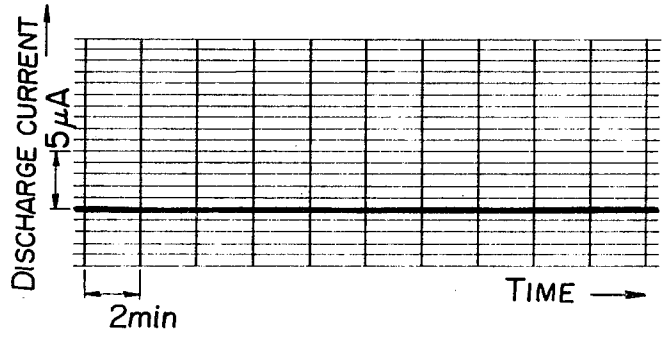


FIG. 8b



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ELECTRON BEAM GENERATOR FOR ELECTRON MICROSCOPE OR THE LIKE APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electron beam generator for an electron microscope or the like apparatus wherein the electron beam accelerating voltage is high and the generation of a highly stable electron beam is required. More particularly the present invention relates to an electron beam generator of this type which incorporates a means to prevent the occurrence of electrical discharges.

2. Description of the Prior Art

With the conventional electron beam generators for electron microscopes or the like apparatus in which the electron beam accelerating voltage is very high and at the same time the generation of a highly stable electron beam is required, one of the major causes of a lowering in the performance of such electron microscopes or the like has been the occurrence of a secondary fault to an electron beam generated from an electron source, such as a pulse discharge and a glow discharge due to the residual gas which would cause fluctuations in the electron beam accelerating voltage and a flickering with the irradiated electron beam spots.

For example, the electron source of these electron microscopes consists of an electron gun having a tungsten filament formed into a V-shape or the shape of a hairpin and a Wehnelt electrode of a cylindrical shape which surrounds the filament, is provided at its one end with a small aperture through which the electron beam is directed and is negatively biased with respect to the filament; and an anode which is at an equipotential level (ground potential) with respect to the microscope proper. The electron gun and the anode are usually housed within a gun chamber having a metallic pressuretight inner wall and evacuated to a high degree ranging from 1×10^{-4} to 10^{-6} torr. An exhaust pipe for removing air to produce a vacuum is mounted at a portion of the gun chamber wall and the gun chamber as evacuated may be separated from the portions of the microscope proper by means of an air lock. And, since an electron beam accelerating voltage of the order of 50 to 100 kv. or higher (this value may reach up to 1,000 kv. with extra high voltage electron microscopes) is applied between the Wehnelt electrode and the anode, in spite of the fact that the Wehnelt electrode and the filament are electrically insulated from the microscope proper, a very small discharge is induced between the cathode (for purposes of discussion, the filament and the Wehnel electrode, when generically referred to, will be hereinafter called as the cathode) and the anode and between the cathode and the gun chamber wall, and such very small discharge proves to be an obstacle to the provision of a stable electron beam.

The demands of the recent times have been toward an electron beam generator in which the electron beam accelerating voltage can be varied over a very wide range and which simultaneously satisfies a quality of being highly resolving. However, with the conventional electron beam generators for electron microscopes or the like apparatus, it has been impossible to attain such a stable electron beam for the following reasons:

1. Since the conventional electron guns for electron microscopes or the like have been so designed that their constructions including the distance between the cathode and the anode suit an electron source of the point source of light type, these electron guns are, for the applied accelerating voltages of 50 to 100 kv., near their allowable limits at which discharges are caused. Therefore, the degree of vacuum in the gun chamber exerts a very critical effect on the initiation of discharges. With the conventional electron beam generators, it is hard to realize a high degree of vacuum sufficient to meet the requirements of the previously stated trend toward the still higher accelerating voltages.

2. The oil vapor that flows back into the gun chamber from the exhaust system as well as the moisture and oil that creep into the gun chamber through the exhaust pipe and the wall of the microscope proper are gasified and join with the residual gas floating in the gun chamber, thereby reducing the degree of vacuum in the chamber. Especially, a very high vacuum with the degree of vacuum ranging from 1×10^{-4} to 1×10^{-6} torr is maintained in the gun chamber so that while the moisture, oil or the like absorbed on the inner wall of the gun chamber may be discharged thus cleansing the chamber wall, the chamber wall will be turned into a highly adsorptive surface. Thus, when the vacuum in the gun chamber is broken during the replacement operation of the filament and the like exposing the interior of the chamber to the atmospheric pressure, a considerable amount of the steam in the air and other organic gases will adhere to the inner surface of the gun chamber.

3. The steam pressure of the oil usually employed with a rotary oil pump during the initial stage of an exhausting operation is of the order of 1×10^{-3} to 1×10^{-4} torr, which means that the oil tends to be readily gasified. And this oil vapor enters into the gun chamber and adheres to the highly adsorptive inner surface of the chamber wall as previously explained. Under these conditions, the inner surface of the chamber wall appears as if it is covered with thin layers of water and oil. Thus, admitting that the adsorbed moisture, oil and the like can be carried out and exhausted to a certain extent by an exhausting operation following the aforesaid initial exhausting stage, it is still unavoidable that a considerable amount of such substances are left within the chamber.

These various factors tend to reduce the degree of vacuum within the gun chamber, and the residual gas when ionized under a high voltage gives rise to electrical discharges between the cathode and the anode as well as between the cathode and the chamber wall.

Generally, electrical discharges within the gun chamber include two classes of discharges, i.e., the creeping discharge at the surface of the insulation of a porcelain insulator and the pulse discharge between the cathode and the anode. The discharges between these two electrodes are such that as they exceed the glow discharge region at a vacuum lower than 1×10^{3} torr, the discharges tend to decrease at vacua on the 1×10^{-4} torr level and increase again at vacua ranging from 1×10^{-5} to 1×10^{-6} torr.

Furthermore, since these pulse discharge and the creeping discharge at the surface of the insulation are caused in proportion to the electric field strength between the cathode and the anode and between the cathode and the gun chamber wall, the gun chamber has hitherto been expanded in proportion to the magnitude of the applied accelerating voltages to increase the distance between the cathode and the anode in an attempt to avoid these discharges.

However, this has inevitably resulted in increase in the creeping distance of the insulation for a porcelain insulator. Consequently, the trend toward larger gun chambers has been promoted still further thus requiring attendant improvements such as the increased capacity for exhaust systems and the increased diameter for exhaust pipes to reduce the pumping resistance. Thus, there has been an unavoidable inconvenience that the exhaust systems tend to be bulkier and heavier and the cost tends to be still higher.

SUMMARY OF THE INVENTION

The first object of the present invention is therefore to provide an improved electron beam generator for electron microscopes or the like apparatus.

Another object of the present invention is to provide an electron beam generator for electron microscopes or the like apparatus in which an accelerating voltage higher than utilized in the prior art generators may be applied and at the same time a highly stable electron beam may be produced.

Further object of the present invention is to provide an electron beam generator for electron microscopes or the like apparatus that can be made smaller and more compact than hitherto possible.

Still further object of the present invention is to provide an electron beam generator for electron microscopes or the like apparatus which is more efficient and more inexpensive to construct (or economical) as compared with the conventional generators.

The principal object of the present invention is to provide an electron beam generator for electron microscopes or the like apparatus wherein provision is made for preventing electrical discharges to give a stable electron beam even when a high electron beam accelerating voltage is applied.

These and other objects of the present invention will be apparent from the following description of the invention and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a partial longitudinal sectional view of an electron beam generator used with the conventional electron microscopes or the like apparatus.

FIG. **2** is a partial enlarged longitudinal sectional view showing mainly the electron gun portion of an electron beam generator used with the conventional electron microscopes or the like apparatus.

FIG. **3** is a partial longitudinal sectional view showing an embodiment of the electron beam generator according to the present invention.

FIG. **4***a* and FIG. **4***b* are graphs showing the conditions of the initiation of discharges to provide a comparison between the embodiment of the present invention illustrated in FIG. **3** and the conventional generators.

FIG. **5** is a partial longitudinal sectional view showing another embodiment of the electron beam generator according to the present invention.

FIG. **6***a* and FIG. **6***b* are graphs showing the conditions of the initiation of discharges to provide a comparison between another embodiment of the invention shown in FIG. **4** and the conventional generators.

FIG. **7** is a further embodiment of the electron beam generator according to the present invention.

FIG. **8***a* and FIG. **8***b* are graphs showing the conditions of the initiation of discharges to provide a comparison between the further embodiment of the invention shown in FIG. **5** and the conventional generators.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As previously explained, in an electron microscope or the like apparatus even a very small electrical discharge in the electron beam generator must be strictly avoided, since such a discharge may still cause fluctuations in the electron beam accelerating voltage and a flickering with the radiated electron beam spots, thus constituting one of the causes that lower the efficiency of the beam generator.

The conventional electron beam generator for electron microscopes or the like apparatus will now be outlined below with reference to FIGS. **1** and **2** in which numeral **1** designates an electron gun composed of a filament **2** and a cylindrically shaped Wehnelt electrode **3** which surrounds the filament and is negatively biased with respect to the filament. The electron gun is housed in a gun chamber **6** formed with a metallic wall **4** having a pressuretight inner wall surface **5**. The gun chamber **6** is provided at a portion thereof with an exhaust pipe **7** communicating with a vacuum pump (not shown) so that the chamber is always evacuated to a degree of vacuum ranging from 1×10^{-4} to 1×10^{-6} torr. A porcelain insulator **9** is mounted on the portion of the gun chamber through a packing **8** for sealing the chamber as evacuated and a high voltage is thus applied to the electron gun **1**, which high voltage is externally derived by means of a high-voltage feed cable **10** through the insulator **9**. Numeral **11** designates an anode disposed at the lower end of the gun chamber **6** opposite to the electron gun **1** and spaced away from the latter by a predetermined distance, and this anode is at an equipotential level with respect to the microscope proper (or at ground potential). Numeral **12** designates an aperture through which the electron beam passes, and numeral **13** designates an electron lens. Numeral **14** designates a packing for vacuum sealing so that the upper part of the gun chamber above the packing **14** may be opened when air must be admitted into the gun chamber for replacing the filament (the filament in the electron microscope or the like apparatus is used at elevated temperatures to attain a high brightness so that its life is of the order of 50 to 100 hours). It is to be noted that an air lock means (not shown) is provided so that even if the air is admitted into the gun chamber, vacuum in other portions of the microscope proper may be maintained.

With the arrangement described above, the application of a voltage between 50 to 200 kv. to the electron gun **1** causes the electrons emitted from the heated filament to be accelerated and converged through the electric fields by the Wehnelt electrode **3** and the anode **11**. The electrons are thus formed into an electron beam having a very small diameter, and this electron beam is then passed through the electron beam transit aperture **12** of the anode **11**. Then, the electron beam is focused by means of one or two electron lenses **13** into an electron beam having a very small diameter equal to or smaller than 1μ and the electron beam is now applied to an object. Under these circumstances, steam and oils and fats which have adhered to the inner surface **5** of the metallic chamber wall **4** of the gun chamber **6**, or the oil vapor flowing back into the chamber, prevent a desired degree of vacuum from being established in the chamber, thus causing the initiation of very small electrical discharges. Consequently, it has been a common practice to plate the inner wall surface **5** with chromium and then polish it to produce thereon a mirror finish which provides for a smooth surface. This requires much time and labor and at the same time the volume of the gun chamber must be increased in proportion to the magnitude of an applied accelerating voltage thus giving rise to an inconvenience that the production cost rises enormously.

On the contrary, according to the present invention the inner wall surface of the gun chamber is formed with an electrical insulation layer or the electron gun and the anode are enclosed by means of a cylindrical member consisting of an electrical insulation material so that electrical discharges such as a pulse discharge and a glow discharge may not be produced within the gun chamber.

The embodiments of the present invention will now be explained in detail below.

Now referring to FIG. **3**, the first embodiment of the present invention will be explained. In this figure, those elements which are designated by the same reference numerals as used in FIG. **1** indicate the identical components. A gun chamber **6** consists of a metallic chamber wall **4** of the same potential with an anode **11** and a thin layer **30** of a pressuretight electrical insulation material is applied to the inner surface of the chamber wall.

The material for the insulating layer **30** may consist of highly polymerized materials having pressure tightness and a hydrophobic property, for example, fluoric resins such as Teflon (trade name, $CF_2{=}CF_2$) and polyester resins such as Mylar (trade name) which are less adsorptive or permeable than metals to the moisture and oils and which comparatively easily discharge the adsorbed substances as compared with metals. The insulating layer **30** may also have different thickness depending on the kinds of material used, on the distance between the chamber wall and the electrode, and an appropriate thickness will be of the order of 0.5 to 3 mm. when these fluoric resins or polyester resins are to be used. If the insulating layer is thinner than this range of thickness, pinholes may easily be produced in the layer by very small electric discharges passing between the cathode and the anode. If thicker, this insulating layer of these highly polymerized organic materials produce gases during the initial stage of the exhausting operation and this lengthens the time required to attain the desired degree of vacuum. Since this generation of gas is believed to arise from the air entrapped in the layer when the organic material is applied to the wall surface or from the

residual volatile components in the organic material (including the unpolymerized substances), it is desirable to employ any coating methods which will completely remove these inclusitions.

Referring now to FIGS. 4*a* and 4*b*, the conditions of the generation of electrical discharges will be explained with respect to the present embodiment and the conventional generator.

FIG. 4*a* illustrates the occurrence of very small electrical discharges when the gun chamber **6** (inside diameter = 96 mm., maximum accelerating voltage = 50 kv.) composed of a mild steel chamber wall **4** with a chromium-plated inner wall surface was left in a 60 to 70 percent atmosphere for several hours and then the chamber was evacuated to a vacuum range 1×10^{-4} to 1×10^{-6} torr. Thereafter, an electron beam accelerating voltage of 75 kv. was applied. The occurrence of a very small discharge of the order of 2 to 5μ A. was repeated at nearly 4-minute intervals.

FIG. 4*b* shows the case when an accelerating voltage of 75 kv. was applied under the same conditions and with a gun chamber of the same construction as in FIG. 4*a*, excepting that a Teflon coating **30** of 0.5-mm. thickness was applied to the inner wall surface of the gun chamber. In this case, no electrical discharge took place over several hours.

It will be seen from the foregoing that the application of a thin layer of highly polymerized organic material such as fluoric, polyester and epoxy resins to the inner wall surface of the gun chamber **6** reduce the adsorption of the moisture and oils and fats which tend to cause electrical discharges. Thus, the working and polishing operations of the inner wall of the gun chamber are eliminated and this effect, coupled with synergistic insulating effects of the electrical insulating layer, provides an electron beam generator with a quite limited occurrence of very small electrical discharges.

In the embodiment described above, the coating applied to the inner wall of the gun chamber uses highly polymerized organic material. It will be seen, however, that an inorganic electrical insulating layer may be formed in place of such organic layer, the usable inorganic material including alumina porcelain, magnesia porcelain, glassy material, etc., and those inorganic insulating materials which are as pressuretight as possible, i.e., so-called hard porcelains are most suited for the purposes. In this case, the larger the thickness of the layer is, the more effectively the electrical discharges will be prevented, if the problem of the limits in the insulating layer forming techniques or economical limits are put aside.

Referring now to FIG. 5, the second embodiment of the present invention will be explained below. In this figure, the components designated by the same reference numerals as used in FIG. 1 are identical with the corresponding components shown in FIG. 1. Numeral **40** designates a cylindrical sheath of a pressuretight inorganic electrically insulating material, such as a hard porcelain containing more than 80 percent alumina (Al_2O_3). This cylindrical sheath has a smoothed surface and it is integral with a porcelain insulator **9** (composed of electrically insulating material such as a ceramics) in a vacuum-sealing manner and form the chamber wall of a gun chamber **6**. The cylindrical sheath is also connected to other metallic portions of the microscope proper through a packing **14** for vacuum seal. Here, the outer portion of the gun chamber **6** is exposed to the atmosphere. Thus, in order to prevent any electrification, that portion of the chamber which is exposed to air, i.e., an outer surface **41** of the chamber wall **40** may be metallized by spraying a conductive paint to it, or the outer surface of the cylindrical sheath **40** may be covered with a metallic outer wall member **42** which is equipotential with an anode **12**, and then connected to ground. In this case, the metallic outer wall **42** merely functions as a grounding conductor for preventing electrification. Numeral **15** designates a device for raising and lowering the anode and the device externally raises or lowers the anode **11** in proportion to the magnitude of an applied accelerating voltage so as to adjust the distance between the anode and the cathode.

With the construction as shown in FIG. 5, the present embodiment permits the cylindrical sheath **40** to be located close enough to the gun chamber **6**. In other words, the vacuum distance between the chamber wall **40** of the gun chamber **6** and the cathode may be shortened and at the same time the height of the gun chamber is reduced since the creeping distance at the insulation surface of the porcelain insulator **9** as viewed from the cathode is extended. The entire volume of the gun chamber may also be reduced. As a result, the evacuating capacity of the exhausting system may be fully utilized and the degree of vacuum in the chamber may be readily raised to thereby prevent the very small electrical discharges.

Now referring to FIGS. 6*a* and 6*b*, the occurrence of electrical discharges both in the present embodiment and the conventional generator will be explained hereunder. FIG. 6*a* shows the condition of the occurrence of discharges in a mild steel gun chamber (internal diameter = 120 mm. ϕ, insulation creeping distance = 70 mm., degree of vacuum = 1×10^{-4} to 1×10^{-6} torr) having a chromium-plated inner wall surface. The electron beam accelerating voltage applied was 100 kv. The very small electrical discharges of the order of 2.5 to 6μ occurred in succession.

FIG. 6*b* shows the case when an accelerating voltage of 100 kv. was applied under the same conditions as in FIG. 6*a* and with the gun chamber (internal diameter = 120 mm. ϕ, insulator creeping distance = 165 mm., degree of vacuum 1×10^{-4} to 1×10^{-6} torr)—the chamber being composed of the chamber wall in the form of a cylindrical sheath made of a sintered alumina, 10 mm. thick, integrally formed with the insulator (composed of a sintered alumina) in a vacuumtight manner. The result showed that the occurrence of very small electrical discharge was completely prevented.

In this case, the creeping distance at the insulation is increased so that with the same accelerating voltage the gun chamber may be made smaller as compared with the conventional generators.

On the other hand, if the gun chamber has the same volume as that of the conventional generator, a much higher accelerating voltage may be applied.

Referring now to FIG. 7, the third embodiment of the present invention will be explained. In this figure, those components which are designated by the same reference numerals as used in FIG. 1 indicate that they are the same as the corresponding components shown in FIG. 1.

Within a gun chamber having a mild steel chamber wall **4** with a chromium-plated inner wall surface **5**, a hollow cylindrical member **50** of an electrically insulating material such as glass and ceramics is disposed between the electron gun **1** and the chamber wall **4** surrounding the electron gun **1** and an anode **11**.

The insulating cylinder **50** has a very high dielectric breakdown strength as compared with the degree of vacuum (1×10^{-4} to 1×10^{-6} torr), the field strength between the cathode and the chamber wall **4** is relieved so that the magnitude of an applied voltage at which very small electrical discharges will be caused is also increased.

Referring to FIGS. 8*a* and 8*b*, the conditions of the occurrence of electrical discharges both in the present invention and the conventional generator will be explained below.

FIG. 8*a* illustrates the situation when an accelerating voltage of 100 kv. was applied in the gun chamber **6** (internal diameter = 96 mm., degree of vacuum = 1×10^{-4} to 1×10^{-6} torr) having the mild steel chamber **4** with the chromium-plated inner wall surface **5**. The very small electrical discharges of the order of 1 to 2.5μ A. occurred frequently in succession.

FIG. 8*b* illustrates the situation under the same conditions and with the same gun chamber **6** as in the case of FIG. 8*a*, excepting that the ceramic insulating cylinder **50** of 5-mm. thickness was disposed to surround the electron gun **1** and the anode **11**. As will be seen from the figure, no very small electrical discharges took place. In order to eliminate the electrical discharges in the case of FIG. 8*a*, the internal diameter of

the gun chamber must be at least 140 mm. ϕ if the insulating cylinder **50** were not used. Thus, if the applied voltage is kept constant, the generator according to the present invention will be made much smaller as compared with the conventional generators.

The effect of the insulating cylinder **50** is synergistic in that molecules of the residual gas floating in a vacuum in the chamber are prevented from being ionized to flutter between the cathode and the chamber wall **4** and cause electrical discharges and that the dielectric strength of the cylinder itself serves to prevent electrical discharges. Thus, a still higher voltage may be applied if the thickness of the cylinder is increased in proportion to the magnitude of applied voltages. In this case, it will be needless to say that the distance between the cathode and the anode and the creeping distance at the insulation of the insulator **9** must also be increased in proportion to the magnitude of applied voltages. Although the embodiment shown in FIG. **7** has been explained as using the insulating cylindrical member made of a ceramic material, this cylinder may be replaced with fiber-reinforced plastics, thermosetting plastic material (having sufficient mechanical strength and withstand voltage) or a laminated tube.

We claim:

1. An electron beam generator for electron microscopes or the like apparatus comprising an electron gun consisting of a cathode for emitting thermions and a control electrode for controlling said thermions, said electrode being biased negatively with respect to said cathode; high-voltage feed means electrically insulated from said apparatus for applying a high voltage to said electron gun; an anode disposed at a position opposite to and spaced away from said electron gun by a predetermined distance, said anode being connected to ground potential; and a gun chamber provided with a vacuum seal for housing said electron gun, high-voltage feed means and anode, said gun chamber being composed of a metallic wall which is at an equipotential with said anode, wherein said gun chamber is provided with means formed of a solid smooth-surfaced hydrophobic electrical insulation for preventing electrical discharges between the wall of said gun chamber and said two electrodes, said insulation means surrounding said two electrodes and being spaced away from said two electrodes by a predetermined distance.

2. An electron beam generator for electron microscopes or the like apparatus according to claim **1**, characterized in that said means for preventing electrical discharges consists of a smooth-surfaced hydrophobic electrical insulation layer having good electrically insulating and heat-resisting properties formed on the inner surface of said metallic wall, and said layer is substantially free from volatile substances.

3. An electron beam generator for electron microscopes or the like apparatus according to claim **2** characterized in that the electrical insulation layer formed on the inner wall surface of said gun chamber consists of a material selected from polyester and epoxy resins having good electrically insulating and heat-resisting properties.

4. An electron beam generator for electron microscopes or the like apparatus according to claim **2** characterized in that the electrical insulation layer formed on the inner wall surface of said gun chamber consists of a material selected from sintered alumina and magnesia materials and glass.

5. An electron beam generator for electron microscopes or the like apparatus according to claim **1** wherein said means formed of a solid electrical insulation for preventing electrical discharges is an element of cylindrical shape disposed between said electron gun and said chamber wall and surrounding said two electrodes.

6. An electron beam generator for electron microscopes or the like apparatus according to claim **5** wherein said cylindrical insulation element consists of a material selected from a group consisting of sintered alumina and magnesia materials, glass and highly polymerized material.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,636,346 Dated January 18, 1972

Inventor(s) Hiroshi Akahori, et al

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

First page of patent, priority data, which reads:

"Mar. 17, 1968"

should read:

--Mar. 17, 1969--.

Signed and sealed this 29th day of May 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

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