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[72] Inventors Mario Rabinowitz
Menlo Park;
Edward L. Garwin, Los Altos Hills, Calif.
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[54] METHOD OF OPERATING AN ION-GETTER VACUUM PUMP WITH GUN AND GRID STRUCTURE ARRANGED FOR OPTIMUM IONIZATION AND SUBLIMATION
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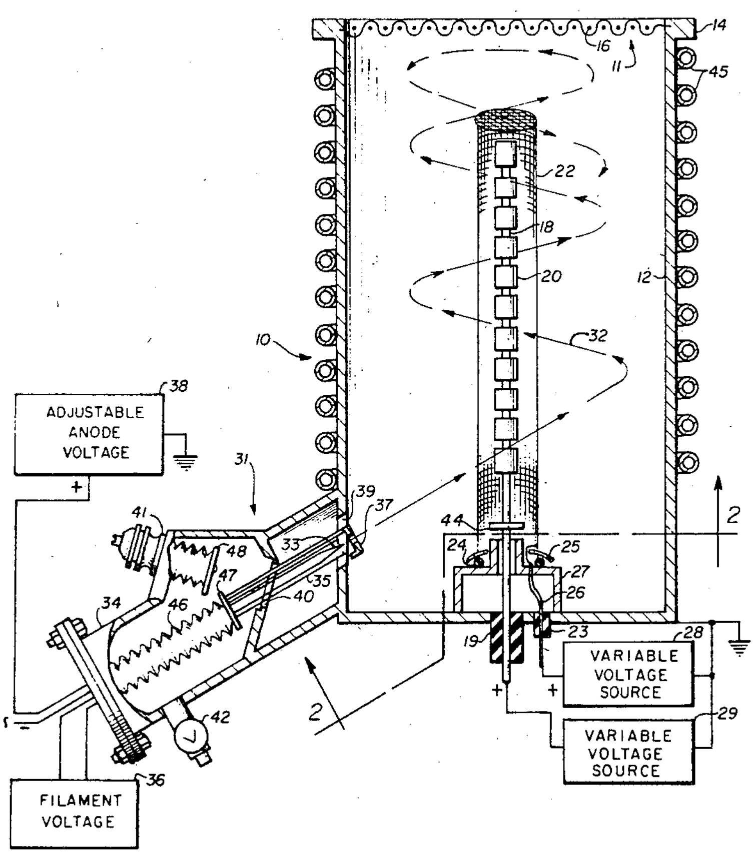
Primary Examiner—John Kominski
Assistant Examiner—Palmer C. Demeo
Attorney—Roland A. Anderson

ABSTRACT: Electrons injected between a cylindrical housing and a coaxial cylindrical grid at a predetermined angular momentum spiral over long paths around the grid for optimum ionization of gas molecules. A first electrostatic field is established between the housing and grid for accelerating ions to the housing and for establishing an optimum kinetic energy of the orbiting electrons. A second electrostatic field is independently established between the grid and a concentric titanium rod anode at an optimum intensity for accelerating spent electrons through the grid to bombard and sublimate the titanium for burying ions and combining with active gases.



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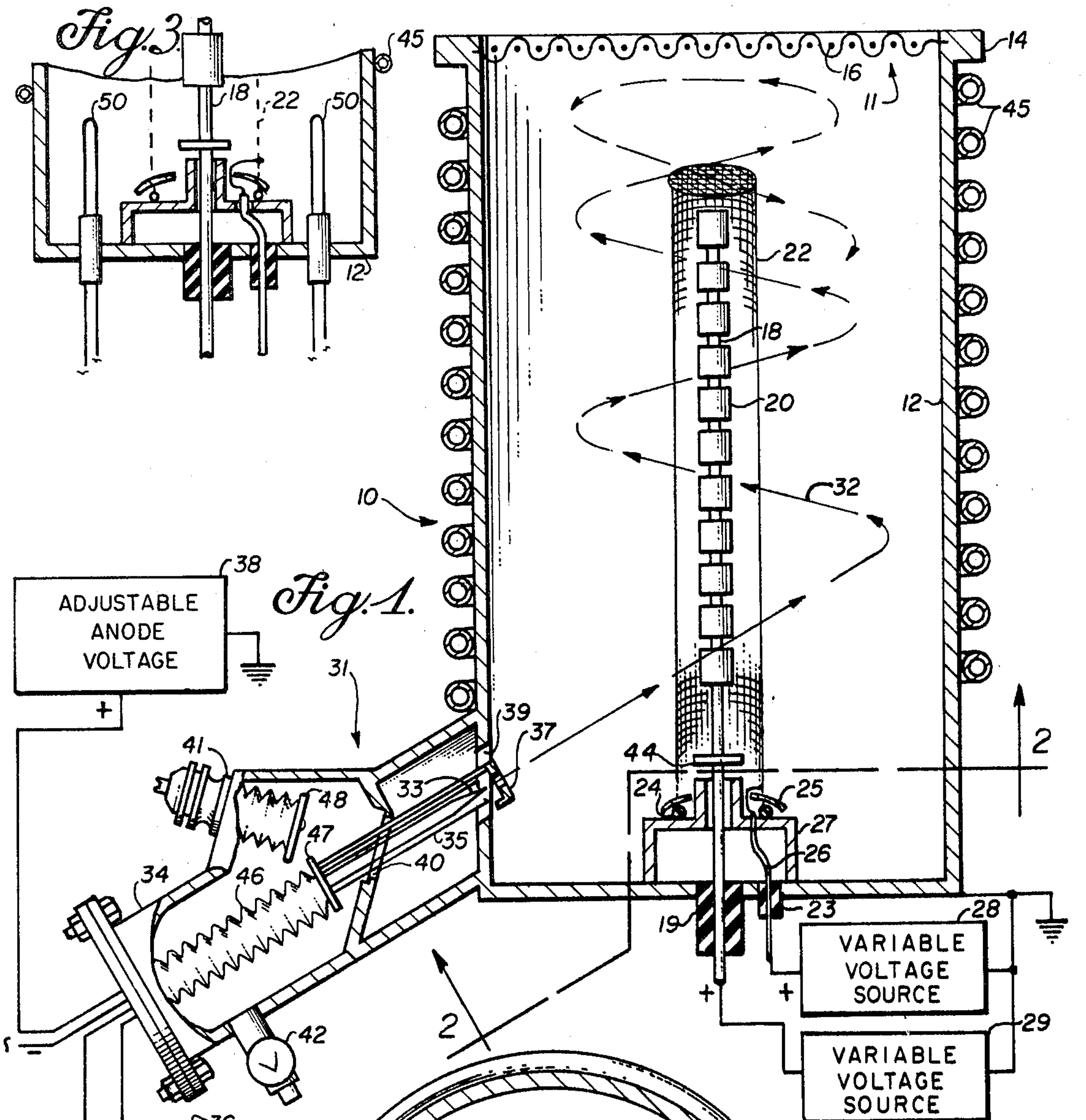

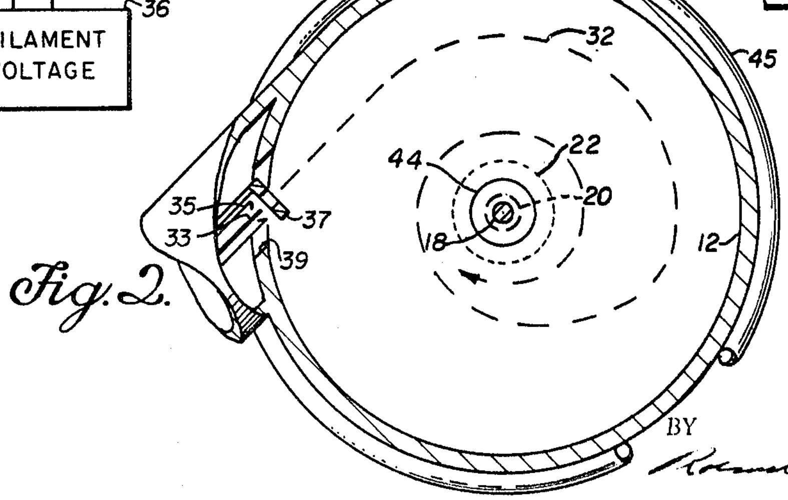

INVENTORS
MARIO RABINOWITZ
EDWARD L. GARWIN
BY
ATTORNEY

METHOD OF OPERATING AN ION-GETTER VACUUM PUMP WITH GUN AND GRID STRUCTURE ARRANGED FOR OPTIMUM IONIZATION AND SUBLIMATION

BACKGROUND OF THE INVENTION

The invention relates to ion-getter vacuum pumps, and more particularly, it relates to grid-controlled ion-getter vacuum pumps.

Ion-getter vacuum pumps are operated by introducing electrons into the pump at an energy level that creates ions upon collision with gas molecules. The gas ions thus produced are accelerated by electric fields in the pump to impinge and penetrate into receptive pump surfaces. Simultaneously getter material (e.g., Ti, Ta) is sublimated or otherwise deposited on these surfaces so that the buried ions are further covered. The fresh deposit of getter material also reacts with chemically active gases (e.g., O_2 and N_2) without requiring ion formation. Thus, an ion-getter pump is operated by removing molecules from the gaseous state and putting them into the solid state.

One way of continuously supplying gettering material is to bombard the material to its sublimation temperature with the electrons that are used to ionize the gas. This has the advantage that the getter material may be thermally isolated easily as compared to resistive heating of the gettering material with its resultant thermal outgassing of electrical leads and nearby parts such as insulators and supporting structures. However, in known arrangements in which the electron bombardment method of sublimation is used, a conflict arises as to the strength of electric field to be used in the pump. A relatively low electrostatic field is required to give the injected electrons long paths before they are intercepted at an electrode. Long paths increase the probability of electron collisions with the gas molecules. A low field also permits the orbiting electrons to have an average kinetic energy corresponding to the maximum ionization cross section of the gas, thereby increasing the probability that the electrons will ionize the gas molecules when they collide. In conflict with the advantages of a low electrostatic field, a high field is required to impart sufficient energy to the electrons to heat the gettering material to its sublimation temperature. However, a high electrostatic field tends to reduce the amount of ionization by shortening the electron paths and imparting a much higher than optimum average kinetic energy to the electrons.

Another problem found in filament electron source type of ion-getter pumps is the need to periodically replace the filament without introduction of gas into the pump or vacuum system.

SUMMARY OF THE INVENTION

In brief, the present invention pertains to an ion-getter vacuum pump having a housing into which electrons are injected at a circumferential point to travel long orbital spiraling paths with optimum average kinetic energy for ionizing gas molecules within the housing. Upon losing sufficient angular momentum, such as by collision with gas molecules, the electrons are accelerated through a grid to impinge upon a centrally located anode which has getter material mounted upon it. The major part of the electron paths is under the influence of a relatively low electrostatic field between the grid and the pump housing. Upon reaching and passing through the grid, the electrons come under the influence of a relatively high electrostatic field between the grid and central anode that imparts sufficient energy to the electrons to raise the gettering material to its sublimation temperature upon striking it, thereby causing the material to sublime upon the inner surface of the pump housing for removal of gas molecules within the housing.

Since the two electrostatic fields influence the electrons independently, the fields may be adjusted separately to give optimum results in their respective areas without adversely influencing the other area. Therefore, the field between the pump housing and the grid may be independently adjusted for maximum ionization of the gas molecules, while the field between the grid and central anode may be adjusted independently to provide the optimum sublimation rate.

Although various methods of electron injection may be used in conjunction with the aforementioned grid structure, we disclose a unique external electron gun which may be isolated from the housing by means of a valve. Thus the filament can easily be replaced without exposing the pump or vacuum system to external gas. This increases the useful lifetime of such a pump. With a small, relatively inexpensive valve, the electron gun can be isolated to change filaments, allowing the main body of the pump and the rest of the vacuum system to remain evacuated. Otherwise, the whole vacuum system would be exposed to atmospheric pressure, or a very large expensive valve would be required to isolate the system from the pump during filament replacement. Such an arrangement is impractical not only because of the expense and space consumption of a large valve, but also because it is undesirable to expose the pump to atmospheric pressure.

It is an object of the invention to ionize gases with maximum efficiency in an ion-getter vacuum pump with a stream of electrons and to also independently control the sublimation temperature of gettering material with the same electron stream.

Another object is to decouple accelerating fields of differing strengths in an ion-getter vacuum pump.

Another object is to independently adjust the accelerating forces on a stream of electrons during traversal by the electrons of an ionization region and subsequently a sublimation region in an ion-getter vacuum pump.

Another object is to simultaneously produce electrostatic fields that result in independent optimum ionization and sublimation within an ion-getter vacuum pump.

Another object is to efficiently and inexpensively replace the filament of an ion-getter pump without affecting the vacuum within the pump.

Another object is to increase the useful operating lifetime of an ion-getter pump.

Other objects and advantageous features of the invention will be apparent in a description of specific embodiments thereof, given by way of example only, to enable one skilled in the art to readily practice the invention, and described hereinafter with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a cross-sectional view of an ion-getter vacuum pump incorporating the novel grid structure and electron gun according to the invention.

FIG. 2 is a cross-sectional view of the ion-getter vacuum pump of FIG. 1 taken along lines 2–2.

FIG. 3 is a cross-sectional view of a portion of a vacuum pump having two internal hot filament cathodes as electron sources.

DESCRIPTION OF AN EMBODIMENT

Referring to the drawing for a description of an embodiment of the invention, there is shown in FIG. 1 a cross section of an ion-getter vacuum pump **10**, comprising a vacuum-tight cylindrical housing **12**. An end **11** of the housing **12** is open for communication with a vacuum chamber (not shown) from which gas is to be pumped. The open end **11** is provided with a flange **14** for suitable connection to the vacuum chamber.

Electrons are injected into the interior space of the cylindrical housing **12** by means of an electron gun **31** which is mounted in one end of the housing. The gun **31** is angled with respect to the central axis of the housing so that the electrons are injected in a tangential direction that has an axial component. This is desirable for efficiently directing a large number of electrons in long spiraling paths. However, the axial component is not necessary as more fully discussed hereinafter. A representative angle of the gun with respect to the axis of the housing is indicated in FIG. 1, whereas the tangency of the gun with respect to the housing is indicated in FIG. 2. The electron gun **31** is comprised of a hot filament cathode 33 connected to a voltage source 36 and is removably mounted in a gun housing 34. A focusing cup 35 is negatively biased and focuses electrons emitted from the filament 33. An accelerating anode 37 having a central aperture is mounted at the injection end of the gun and is connected to an adjustable voltage source 38 to inject a proper electron current into the pump. The electrons are injected by the gun into the housing between a cylindrical grid 22 and the housing 12. An electrostatic field is maintained between the housing and grid by means of a variable DC voltage source 28 with the grid biased positively with respect to the housing. At each end of the housing, the field contains axial components directed toward the opposite end. Electrons moving into an end of the housing are thereby given an impetus in the axial direction toward the opposite end, causing them to spiral back and forth around the grid 22 along orbital spiraling paths such as path 32. The electrons therefore spiral continuously around the grid until angular momentum is lost by field asymmetries or by collision with gas molecules.

A grid 16 may be mounted across the end 11 in electrical connection with the housing 12. The grid 16 permits movement of neutral gas particles from the vacuum chamber to the interior of the pump housing. Since the grid 16 presents a surface that is electrically continuous with the pump housing it produces a reflection of the electrons the same as that produced as they approach the housing. By various methods, such as adjusting the filament bias, the electrons may be injected with a total energy that is intermediate the potential energy of the housing and the cylindrical grid 22. At this intermediate energy level the electrons will not have sufficient energy to reach the housing or escape from the pump field even in the absence of the grid 16. In the absence of grid 16, the excursion of an electron will be further up before it reaches an equipotential where all of its axial kinetic energy is converted into potential energy; whereupon it will be reflected back down into the pump.

An anode electrode 18 is mounted along the central axis of the housing 12 but is electrically isolated therefrom by means of an insulating bushing 19. The anode 18 includes gettering material in the form of cylindrical slugs 20 of titanium, for example, that are suitably attached to the electrode along its length. The cylindrical grid 22 is mounted concentrically with the housing 12 and electrode 18 on an insulating mounting 24, which electrically isolates the grid from the rest of the pump. A shadow shield 44 prevents deposition of gettering material on bushing 19. Another shadow shield 25 surrounds the insulating mounting 24 to prevent deposit of vaporized gettering material on the mounting. A lead 26 extends through an insulating bushing 23 in the pump housing and connects the grid 22 to the positive terminal of the variable DC voltage source 28, which has its negative terminal connected to the pump housing 12. A cylindrical shield 27 serves both to shield the insulators 19 and 23 from vaporized gettering material as well as to support the insulating mounting 24. A second adjustable DC voltage source 29 has its positive terminal connected to the lower end of the anode electrode 18 and its negative terminal connected to the pump housing.

In operation of the pump 10, a first electrostatic field with radial and axial components and essentially no azimuthal components is established between the cylindrical grid 22 and the cylindrical housing 12 with the voltage source 28. Electrons are injected into the pump with sufficient initial angular momentum that they cannot fall into a small enough radius to be captured at the grid 22. The angular momentum of electrons circulating around the grid is conserved as the field can apply no torque on the electrons about the pump axis. The electrons continue to orbit until they lose angular momentum by gas collisions or by perturbations of the cylindrical symmetry of the field. The axial components of the field near the ends of the pump serve to reflect the electrons back toward the center of the pump. Thus the electrons will traverse spirallike paths around the grid from one end of the pump to the other and back.

As electrons lose angular momentum, the majority become spent and finally fall in through the grid 22 and come under the influence of a relatively high electrostatic field between the grid 22 and anode 18 as established with the DC voltage source 29. The high field accelerates the electrons causing them to impinge upon and heat the gettering material 20 on the anode 18. By adjusting the accelerating voltage 29, the sublimation rate can be independently set to a desired value.

To maximize ion production, it is necessary that the average kinetic energy of the electrons be at that value corresponding to the maximum ionization rate of the inert gases present. The ionization cross section of gases starts at some threshold value of electron kinetic energy, rises quickly to a maximum value, and then decreases slowly with increasing electron kinetic energy. Therefore, if the average electron kinetic energy is more or less than the value corresponding to the maximum ionization cross section, then the average cross section may be considerably below the maximum. In ion-getter pumps of prior art in which the same electrons perform the dual functions of producing ionization and then sublimation, the average electron kinetic energy is considerably higher than corresponds to the maximum ionization cross section due to the need for a high voltage on the anode to produce sublimation temperatures. Thus, the ionization rate in those pumps is appreciably less than the maximum value possible. If the anode voltage in the prior art pumps were reduced to give the electrons the optimum average kinetic energy, the reduced sublimation rate would decrease the active gas pumping speed due to the reduced amount of gettering material available for combination with the active gas; in addition, the inert gas pumping speed would be reduced, even though the ionization rate would be increased, since the inert gases require both ionization and burial by the sublimed gettering material for permanent removal.

As taught in the present invention, the cylindrical grid 22 is held at the proper voltage V_2, to give the electrons the optimum average kinetic energy which corresponds to the maximum ionization rate. The proper grid voltage may be determined experimentally. In practice, there may be more than one inert gas present in the pump such as, for example, helium, argon, and methane. It may be desired to optimize the pump with respect to each gas separately in some sequential order, and this may also be done. To act as a guideline in varying the various parameters, one may use the following approximate equation:

$$V_2 = 2\ln\left(\frac{R}{r}\right)\left[\frac{T-E}{e}\right],$$

where V_2 is the voltage on the grid 22, R is the radius of the pump housing 12, r is the radius of the grid 22, T is the desired average value of electron kinetic energy, E is the total electron energy, and e is the electronic charge.

The anode 18 is held at whatever variable voltage is required to produce the desired sublimation rate. By the addition of the grid 22, the fields between the housing and grid, and grid and anode are decoupled. The process of sublimation and its requirements are thereby separated from the orbiting requirements for maximum ionization even though the same electrons still perform the dual tasks of ionization and sublimation. In addition, the use of separate fields permits a large quantity of gettering material to be mounted on the anode. In the prior art, with only a single field, a large amount of gettering material results in a large diameter anode which decreases the path length of the orbiting electrons. A large amount of gettering material also requires more power to be heated to its sublimation temperature due to its large radiating area. The high power requires a high field which further shortens the electron paths in the prior art. Thus, in the present invention, with the requirements for long electron paths and sublimation separated, a large amount of gettering material may be mounted on the anode to increase the operating lifetime of the pump without adversely affecting the ion pumping speed.

In order to permit replacement of the hot filament cathode **33** in the electron gun **31**, a straight-through valve **41** is mounted in the gun housing **34**. The valve **41** is provided with a passage **40** which is axially aligned with the central axis of the gun to permit passage of the cathode **33**, the focusing cup **35**, and the anode **37** to be positioned at any desired distance relative to an entrance aperture **39** of the pump as determined by a positioning bellows **46**. The cathode **33**, focusing cup **35**, and anode **37** are mounted on an insulating bushing **47** which is attached to the bellows **46** with electrical leads extending through the bushing for connection to respective voltage sources. In the event of the burnout of the filament **33**, the valve **41** may be closed to seal the pump housing by retracting the bellows **46**, and sealing the head **48** of the valve over the passage **40**. The cathode may then be removed and replaced without affecting the vacuum within the pump. This arrangement also permits adjustment of the spacing between cathode **33** and anode **37**. Upon replacement of the cathode **33**, the gun space may be evacuated through a port **42** prior to the opening of the valve **41** and extension of the bellows **46**. The valve **42** may be either a very small valve or a pinch-off tube. Thus the useful operating lifetime of the pump is further increased.

Tubing **45** is provided for circulation of a coolant for maintaining the pump housing **12** at a temperature substantially below the level at which thermal desorption of gas interferes with the pump's operation. The pump housing is thereby eliminated as a source of gas.

Although, as discussed hereinbefore, electrons may efficiently be directed in long spiraling paths with an electron gun mounted in a direction having an axial component and although it is convenient to mount the gun external to the housing to enable isolation of the gun, satisfactory operation of an ion pump according to the invention may be obtained with electron guns such as shown in FIG. 3 wherein two hot filament cathodes **50** are mounted and sealed in the lower end of the pump housing **12** and are biased at a level that is negative with respect to the space potential that would otherwise be present at the filament position and positive with respect to the housing **10**. The electrons are still made to move in spiraling paths since the cathodes **50** are located near the end of the housing where the field between the grid and housing has an axial component of direction which gives each electron an impetus in the axial direction. Alternatively, the electron injection means of FIG. **1** can be made to operate according to the same principle by which the electrons are injected into the pump shown in FIG. 3. This may be done by eliminating the anode **37** and focusing cup **35** and inserting the cathode **33** to a point inside the housing **12** where the positive potential in the first electrostatic field acts as a virtual anode to draw the electrons from the cathode **33**.

We claim:

1. A method for removing gas molecules from a space, comprising:

the steps of injecting electrons into an annular volume of said space, between a cylindrical grid and a coaxial cylindrical cathode to collide with and ionize the gas molecules;

applying a first voltage V_2 between the grid and cathode at a level that establishes a first electrostatic field between the grid and cathode that gives the injected electrons an average kinetic energy that corresponds to the maximum ionization cross section of the gas molecules, said first voltage being applied in a direction that causes the electrons to be attracted to the grid, said first voltage, V_2, being defined by the relationship:

$$V_2=2ln\left(\frac{R}{r}\right)\left[\frac{T-E}{e}\right], \text{where}$$

R is the radius of the cathode, r is the radius of the grid, T is the average kinetic energy in electron volts which corresponds to the maximum ionization cross section of the gas molecules, E is the total electron energy in electron volts, and e is the unit electronic charge; and

applying a second voltage between the grid and an anode that is coaxial with the grid and cathode, with the grid interposed between the anode and cathode, said second voltage being higher than said first voltage, thereby establishing a second electrostatic field for accelerating the injected electrons towards the anode to bombard gettering material attached to the anode and thereby cause the material to sublime on the cathode.

2. The method of claim **1**, wherein said gas molecules are constituents of a mixture of a plurality of individual gases, and further including the steps of applying successive voltages between the grid and cathode to establish the intensity of the first field to successively correspond to the maximum ionization cross sections of the individual gases of said plurality of gases.

3. The method of claim **1**, wherein successive different gases are exposed to said annular volume, further including the steps of applying successive voltages between the grid and cathode to establish the intensity of the first field to successively correspond to the maximum ionization cross sections of the successive different gases exposed to said annular volume.

4. The method of claim **1**, further including the step of adjusting the initial kinetic energy of the injected electrons.

5. The method of claim **1**, further including the steps of adjusting the first electrostatic field to have a potential gradient that is lower than the potential gradient of the second electrostatic field; and adjusting the second field for optimum sublimation of the gettering material.

6. The method of claim **1**, wherein the first electrostatic field is established to have a cylindrical symmetry about the grid, the first field having an elongated radial central zone for attracting electrons to the grid and ionized gas molecules to the cathode, the first field having end regions adjacent the central zone, said end regions having radial and axial components which exert a force on the electrons toward the central zone.

7. The method of claim **1**, wherein said electrons are injected tangentially and in a partially axial direction into the annular volume.

8. The method of claim **1**, wherein said electrons are injected from a source that is external to the annular volume.