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FIELD EMISSION IONIZATION GAUGE WITH RESTRICTED LINE OF SIGHT BETWEEN FIELD EMISSION ANODE AND ION COLLECTOR

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Fig. 3.

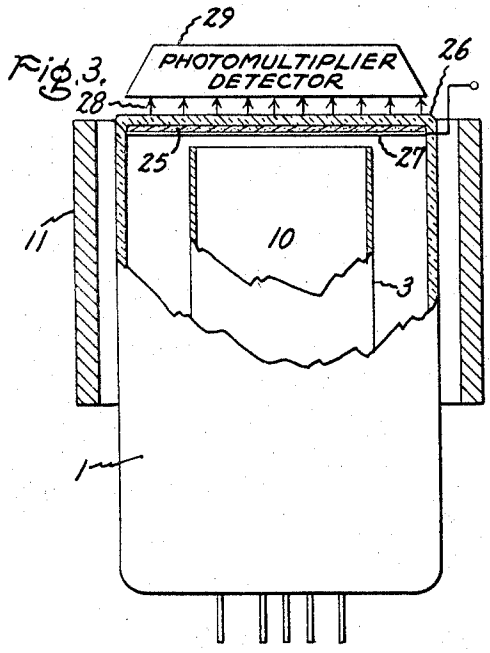


Fig. 1.

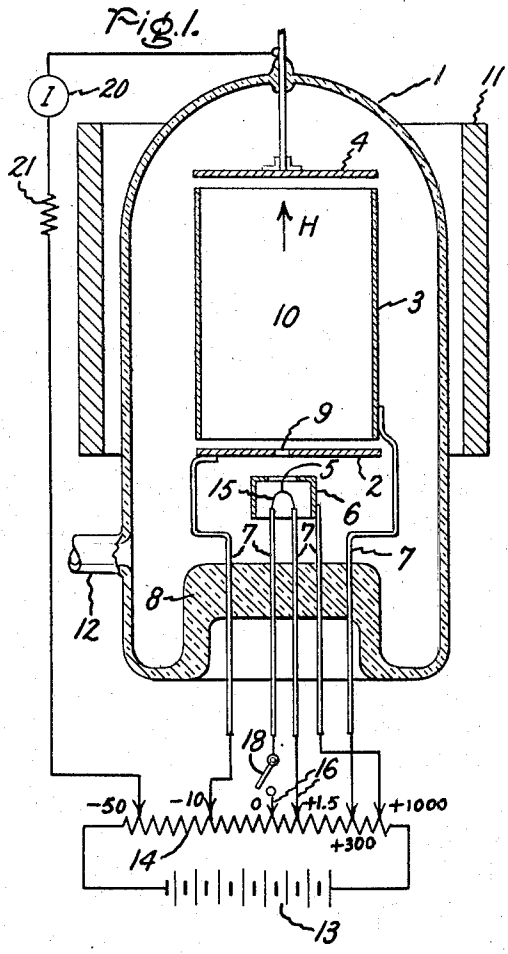
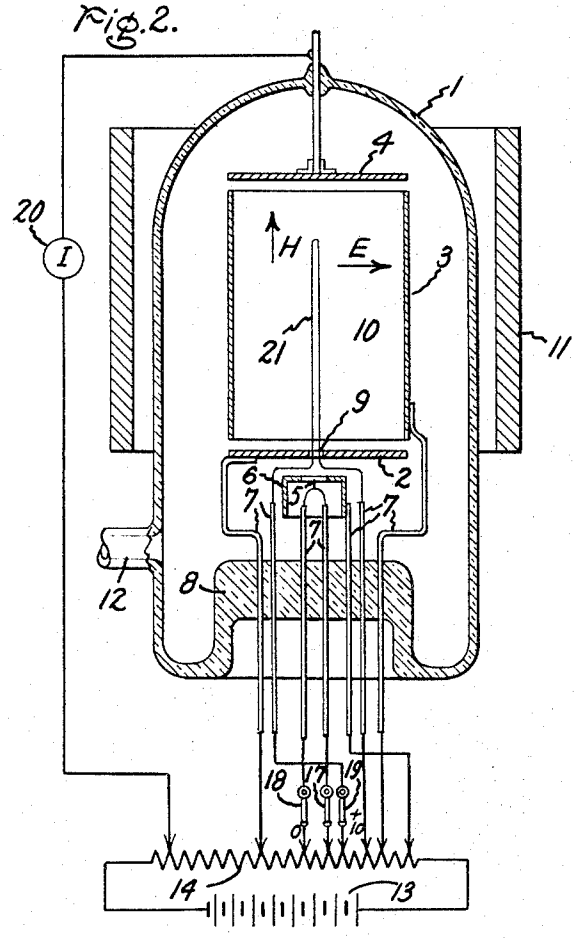


Fig. 2.



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FIELD EMISSION IONIZATION GAUGE WITH RESTRICTED LINE OF SIGHT BETWEEN FIELD EMISSION ANODE AND ION COLLECTOR

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This application discloses various embodiments of ionization gauges, useful in measuring pressures at ultra high vacuum, in which ionizing and electrical discharge producing electrons are supplied to an interaction space by an externally disposed field emission point cathode. The point is associated with a high voltage electrode which is shielded from the interaction space to minimize X-ray photo-emission. The electrical discharge within the interaction space may be of the magnetron type or Penning type, depending upon whether a central co-axial cathode is present within the interaction space.

Ionization devices are gaseous discharge devices widely used for producing and measuring gas pressures under high vacuum conditions. Such devices generally include cathode and anode and an ion collector electrode. Electrons from the cathode undergo ionizing collision with gas molecules within the device to generate positive ions, which are collected by the ion collector. At low pressures, the probability is such that ionizing collisions are proportional to the number of gas molecules present. In such devices, therefore, the ion current to the ion collector is a measure of the gas pressure. Such devices are not only capable of measuring low pressures, but, in small volume systems the means for generating positive ions and collecting the same at a collector electrode, thus removing them from the system, provides a pumping action to obtain a very low pressure in an evacuable system. Generally, ionization devices presently utilized in the art usually fall within two main categories, one of which utilizes the so-called Penning-type oscillating discharge and is of the type set forth in U.S. Patent No. 3,080,104 to T. A. Vanderslice. The other type ionization device is the magnetron type which is shown, for example, in my U.S. Patent No. 2,884,550.

In the Penning, or oscillating type discharge device, a pair of oppositely disposed cathodes are separated by an apertured anode and means are provided to cause electrons to be present within the interaction space. A longitudinal magnetic field is provided and the electrons are accelerated toward one cathode by the electric field imposed by the anode and the longitudinal magnetic field. As an electron approaches a cathode it is repulsed therefrom and once again attracted through the cylindrical or annular anode and accelerated towards an oppositely disposed cathode, thus providing an oscillating motion of the electrons which provide a long path of traverse, which is highly conducive to electron-gaseous molecule collision and the subsequent production of positive ions. Removal of such ions by ion collectors both serves the purpose of evacuating an evacuable volume and, once such a volume has been evacuated, for measuring the gas pressure therein, since the ion collector current is proportional to the pressure within the volume.

In the magnetron type ionization gauge a cathode electrode, generally of the thermionic type is concentrically disposed within a cylindrical anode, thus providing a radial electric field and a longitudinal or axial magnetic field is superposed thereupon by the juxtaposition of an appropriate magnet. Electrons are thermionically removed from the cathode and attracted to the anode. The intensity of the electric and magnetic field are so regulated that the device is biased to "cut-off," a condition under which the emitted electrons traverse curvilinear

paths which cause them to just miss the anode and be returned within the interaction space. A long path from cathode to anode is thereby provided, thus providing a high probability of electron-gaseous molecule collisions with the accompanying high probability of the production of positive ions which may be both removed from the system to cause the evacuation thereof or which may be used at low pressures to produce an ionization or ion current which is indicative of the pressure within the chamber.

Utilizing prior art devices as described hereinbefore, it has previously been possible to produce and measure vacua as a low as 10^{-13} mm. of mercury. At this time, however, inaccuracies and limitations are imposed upon the device, particularly when used as an ionization gauge for measuring ultra high vacua. One such inaccuracy and limitation is imposed by X-ray photo currents caused by the X-rays generated by the electrons striking the anode and causing photo-electric emission from the ion collector electrodes which is responsible for the production of a current which is indistinguishable from the ion current. One means for minimizing the limitation imposed by X-ray photo-emission upon ionization gauges has been disclosed and claimed in my U.S. Patent No. 3,109,115, issued Oct. 29, 1963, in which the ion collector is removed and there is substituted therefor an electron photomultiplier which is shielded from the incidence X-rays and, thus, the consequent contamination of the ionization current is avoided.

While the devices of the aforementioned patent are effective, they are complicated and expensive and it is desirable that means be provided to avoid the limitation of X-ray photo current upon ionization gauges without the complicated structure necessary in accord with that invention.

Another problem which limits the effectiveness of ionic pumps and ionization gauges at low pressures is the difficulty of starting and keeping operating such devices at low pressures when they use cold cathodes. This is because they generally require the presence of a substantial quantity of electrons to produce and maintain an electric discharge for the continuous production of ions to produce an ion current, the measurement of which is the means by which pressure is measured. In accord with the invention disclosed and claimed in Patent No. 3,280,365 to J. R. Young, issued Oct. 18, 1966, progress has been made in overcoming this limitation by the provision of an externally located means for injecting electrons into the interaction space to cause the initial ionization thereof. In a specifically disclosed embodiment thereof, however, a thermionic filament is utilized to provide the initial electron ionization. Such thermionic filaments can, however, be the source of gas contamination which further increases the inaccuracy of the measurement at very low pressures.

Accordingly it is an object of the present invention to provide electronic ionization devices capable of producing and measuring ultra high vacua of the order of 10^{-13} mm. of mercury or less.

A further object of the present invention is to provide ultra high vacuum ionization gauges which overcome the limitations placed upon prior art ionization gauges by photo-emission.

Still another object of the present invention is to overcome the limitations placed upon prior art ionization gauges at extremely low pressures by the utilization of thermionic filaments.

In accord with the present invention I provide, in one embodiment, an interaction chamber for the production of ions at a very low pressure comprising a cathode, an anode and means for causing an electric discharge between the cathode and anode. In one embodiment of the present invention, ions created by the electric discharge are collected by a collector anode and the ion current pro-

duced thereby is an indication of the pressure within the device.

In accord with another embodiment of the present invention, the ions created by the electric discharge are caused to impinge upon a light emitting phosphor screen and the light radiated by the excitation of the phosphor is detected externally of the ionization gauge. The magnitude of the light emission is then a measure of the pressure within the device.

In accord with another feature of the present invention, the ionizing electric discharge is maintained at very low pressures by the injection into the interaction space, of electrons from an externally positioned field emitting point which serves as the cathode of an auxiliary electric discharge, the purpose of which is to provide conduction carriers to initiate and maintain an electric discharge wi hin the ionization chamber at extremely low pressures when the concentration of gaseous molecules therein is insufficient to initiate and maintain such a discharge.

The novel features, believed characteristic of the invention, are set forth in the appended claims. The invention itself, however, together with further objects and advantages thereof, may best be understood with reference to the following detailed description taken in connection with the appended drawing in which:

FIGURE 1 is a vertical cross-sectional view of an ultra high vacuum ionization gauge constructed in accord with the present invention.

FIGURE 2 is a vertical cross-sectional view of an alternative embodiment of the present invention utilizing a thermionic filament for high pressure ionization and field emitting point for low pressure ionization, and

FIGURE 3 is a vertical view with parts broken away of an alternative embodiment of the invention utilizing a photo-multiplier detector in lieu of an ion collector electrode for the measurement of ion currents.

In FIGURE 1, an ultra high vacuum ionization gauge, as constructed in accord with the present invention, includes an evacuable envelope **1** which may be a vitreous glass bulb, a combination cathode and shield electrode **2**, an anode electrode **3**, an ion collector electrode **4**, a field emitting cathode **5**, and a high voltage anode **6**, all mounted and supported within vitreous glass envelope **1** upon suitable support and lead members **7** which pass through a re-entrant pinch **8** in vitreous envelope **1**. Cathode and shield member **2** and ion collector member **4** are conveniently, but not necessarily, substantially disc-shaped members which are disposed at opposite ends of a cylindrical anode member **3** to define an interaction space **10**. An axial magnetic field symbolized by arrow H is provided within interaction space **10** by the juxtaposition, external of envelope **1**, of a cylindrical magnet **11** which may conveniently be a permanent magnet or an electromagnet. A tubulation **12** is connected to vitreous envelope **1** and is utilized for connection to a vacuum system, the pressure of which is to be measured. Appropriate voltages are supplied to the various device electrodes by a power supply represented generally by battery **13** and voltage divider **14**. Field emitting cathode **5** is supported upon filament member **15** which is connected between contacts **16** on voltage divider **14** and may be disconnected therefrom by the operation of a switch **18** in one line thereof. Instead of a vitreous enevelope, a disc-seal structure composed of ceramic and metal members may be utilized.

Anode electrode **3** is maintained at a potential which is positive with respect to cathode and shield member **2**. Field emitting anode **6** is maintained at a potential which is positive with respect to anode **3** and more positive with respect to field emission cathode **5**, which in turn is not as negative as cathode and shield member **2**. Ion collector electrode member **4** is the most negatively biased electrode, and is connected to voltage divider **14** through a current measuring micro-ammeter **20** and a suitable current limiting resistance **21**.

In operation, the device is first connected to a system, the pressure of which is to be measured, by tubulation **12**, and, after a reasonable vacuum has been obtained and is to be measured, switch **18** is closed to allow filament **15** to cause out-gassing of the device. After a few minutes of out-gassing, switch **18** is opened and no thermionic elements are operative with the device. Since field emitting point **5** is negative by a matter of 1000 to 3000 volts approximately with respect to field emission anode **6**, a current is emitted from the tip of cathode **5**. This current is only of the order of micro-amperes. By virtue of the field emission from field emission cathode **5**, additional electrons are projected through the aperture in field emission anode **6** and, by their initial kinetic energy and the attraction of positively biased anode **3**, are attracted through the aperture within shield and cathode member **2** into the interaction space. These electrons are then subjected to the forces described hereinbefore to establish a classic operating Penning-type discharge with electrons alternately accelerated and decelerated between ion collector **4** and cathode and shield member **2** under the influence of parallel electric and magnetic fields. During the operation of the discharge, any collision with a gas molecule present with space **10** causes the production of a positive ion which is accelerated to the most negatively biased ion collector electrode **4** causing flow of ion current through micro-ammeter **20**, which current is an indication of the pressure within the system.

Although it is known that the residual gas within low pressure glass ionization gauges is primarily helium, and is hydrogen in ceramic-metal vacuum systems, at very low pressures of the order of 10^{-13} mm. of mercury, I have discovered that there is a substantial presence of a gas of mass **28** which does not diminish with the operation of the ionization devices or with pumping thereof. I have determined that this presence of a gas of mass **28** imposes a limitation upon the accuracy of low pressure measurements of ionization gauges of the type described hereinbefore. It is believed that this gas is carbon monoxide that is generated by high temperature refractory metal thermionic filaments as, for example tungsten, in devices of the prior art. This is believed due to a reaction of residual oxygen with carbon in the filament or by atomic hydrogen, released from the filament, reacting with the envelope wall. Accordingly, in the device of FIGURE 1, I have provided a source of ionization-producing electrons comprising a pointed field emitting cathode which is not dependent upon thermionic processes for the production of ionizing electrons, thus removing the presence of a hot refractory metal member and minimizing the possibility of carbon monoxide being present within the device to affect the accuracy or effectiveness of measurements at very low pressures. Thus, the only limitation upon the device of FIGURE 1 should be that of X-ray generated photo emission. Soft X-rays are usually generated by the impingement of electrons upon positively biased anodes. Accordingly, in accordance with this one feature of the present invention, the aperture **9** within shield and cathode member **2** is so small that no portion of field emitting anode member **6** may be within "line-of-sight" juxtaposition to ion collector member **4**. Therefore, no soft X-rays generated by the small current between field emission cathode **5** and field emission anode **6** may impinge upon ion collector electrode **4** to cause the generation of photo-electrons to render inaccurate the measurement of vacua by the device of FIGURE 1.

FIGURE 2 of the drawing illustrates, in vertical cross-sectional view, an alternative embodiment of the invention utilizing a magnetron-type discharge in an ionization gauge as opposed to the Penning-type discharge utilized in the device of FIGURE 1. Since the structures are similar, like numerals are used in FIGURE 2 to identify like elements to those in FIGURE 1. In FIGURE 2, evacuable envelope **1** includes a cathode and screen elec-

trode 2, a cylindrical anode 3, an ion collector electrode 4, field emission cathode 5, field emission anode 6, all of which are mounted on a lead and support pins 7 through pinch 8 in vitreous envelope 1. In addition to these elements which are identical to those in the embodiment of FIGURE 1, a filamentary "hair-pin" shaped thermionic cathode 21 is mounted upon a pair of lead-in and support pins 7 and extends through the aperture 9 in cathode and shield member 2 along the longitudinal axis of the interaction space 10 and concentric with anode member 3. Filament cathode 21 is biased negative with respect to anode 3 by from 300 to 500 volts and establishes with anode 3 a radical electric field denominated by arrow E in interaction space 10. Cylindrical magnet 11 establishes a longitudinal magnetic field indicated by arrow H. Due to the crossed electric and magnetic fields E and H, during operation, electrons are thermionically emitted from cathode 21 and are directed in curvilinear paths outwardly toward anode 3. As is described hereinbefore, the magnitude of the electric and magnetic fields is adjusted so that the curvilinear path of the electrons just miss the anode and the device is biased to cut-off, causing each electron to describe an elongated curvilinear path favoring a high probability of electron-gas molecule collision and the production of a substantial number of gaseous ions in proportion to the pressure of the gas within interaction space 10.

This mode of operation is utilized at higher pressures, of for example, 10^{-11} mm. of mercury or higher, both for pumping and measurement where the presence of the thermionic filament does not cause degradation of the accuracy of the pressure measurement by virtue of the presence of carbon monoxide which may be caused by the reaction of trace amounts of oxygen with carbon in the filament or the reaction of atomic hydrogen evolved from the cathode wtih the material of the envelope 1. During this operation, switch 17 and 18 are both opened, while switch 19 is closed, and field emitting point 5 is not activated since a sufficient supply of electrons for ionization is provided by cathode electrode 21. As in the device of FIGURE 1 the pressure within interaction space 10 and hence, the pressure within the vacuum system to which the device is connected by means of tubulation 12, is indicated by ion current as measured by microammeter 20. When low pressures of the order of 10^{-11} mm. of mercury are reached and the possibility of degradation of the accuracy of the reading due to the presence of thermionic filament 21, switch 19 is opened, thus causing the flow of current through thermionic filament 1 to cease. Switch 17 is closed, and switch 18 is closed, momentarily to out-gas the field emitter tip 5. Switch 18 is then opened, causing the field emission members to operate in the identical manner as described with respect to the device of FIGURE 1. Additionally, since cathode 21, although no longer heated, is still at a negative potential of several hundred volts with respect to anode 3, the magnetron mode of operation continues. The embodiment illustrated in FIGURE 2 provides a dual mode of operation namely the thermionic emitter at higher pressures and the field emitter operation at low pressures.

In FIGURE 3 of the drawing an alternative embodiment of the invention, which may be utilized with respect to either the embodiments of FIGURE 1 or 2 is illustrated. Since the electrode structure within the device of FIGURE 3 is identical with that of either the device of FIGURE 1 or 2 the configuration of the electrodes other than that of anode electrode 3 is omitted. The ion collector electrode 4 of FIGURES 1 and 2 is deleted from the embodiment of the device of FIGURE 3 and the purpose thereof is served by the presence of a luminescent phosphor coating 25 upon the flattened upper surface 26 of envelope 1. Thus, this device does not rely upon the direct collection of positive ions which are generated by electron-gas molecule collisions within interaction space 10 for the production of a measureable ion current to measure the gas pressure within the system to which the device is coupled by means of tubulation 12. Rather, the phosphor layer is utilized to provide a measureable signal indicative of pressure. Additionally, in this embodiment of the invention metallic layer 27, which is biased to the same high negative potential that ion collector electrodes 4 of FIGURES 1 and 2 are biased, serves as a means of protecting phosphor layer 25 from soft X-rays and prevents any spurious photoelectric emission. Thus, soft X-rays generated by the impingement of electrons on anode 3 or field emission anode 6 are absorbed by metallic film 27 and do not penetrate to phosphor film 25. This completely removes photoelectric emission as a lower limit of the detectable ion current.

In operation, the positive ions created by electron-gas molecule collisions within interaction space 10 are accelerated by a highly negative potential of the order of 1000 to 3000 volts, which is applied to a thin metallic film 27 overlaying phosphor layer 25, and impinge upon phosphor layer 25 exciting it to luminescence. The phosphor of layer 25 is chosen to be selectively energizable to photoluminescence by the impingement of the positive ions and emits light of a predetermined wavelength in accord with the degree of excitation thereof by positive ions. Such a phosphor may for example be zinc oxide or silver activated zinc sulfide. This light is radiated outwardly from layer 25, as by arrows 28 and is incident upon photo-multiplier detector 29, which may be any state-of-the-art photo-multiplier, and provides an indication of the ion current and consequently the pressure within the system.

In summary, I provide, in accord with the present invention, ionization devices and, more particularly, ionization gauges, which are adapted accurately and sensitively to measure ultra high vacuum pressures of the order of 10^{-13} mm. of mercury or less and which may operate upon the principle of a Penning-type discharge or a magnetron-type discharge. Actually, in a practical operating device, some elements of both type discharge are present, due to the fringing fields at the edges of the various electrodes, causing the electric fields which are normally radial to have an axial component and those which are normally axial to have a radial component. Thus, some elements of both types of discharge are usually present.

In accord with one embodiment of the present invention I rely primarily upon a Penning-type discharge in which the discharge is continuously kept supplied with ionizing electrons by virtue of a field-emitting cathode disposed externally of the discharge interaction space and adapted to inject electrons thereinto in the complete absence of heated filaments which may contribute other gaseous impurities which contribute to the degradation of the accuracy and sensitivity of the measurement. This injection of electrons into the interaction space is continuous and is not utilized merely to initiate a discharge, since at the pressures of ultra-high vacuum, even after a discharge is started, it needs externally supplied electrons in order to continue in operation, because of the very low concentration of gas molecules, and hence, the low probability of a sufficient concentration of ionized particles to sustain such a discharge. In accord with the present invention, this continuous supply of electrons is provided wholly without the use of any operating thermionic element within the device.

In accord with another embodiment of the present invention a concentric cathode which may be a thermionic emitter is present and is utilized as a thermionic emitter at higher pressures at which the presence of a thermionic filament does not contribute a sufficient quantity of gas to contaminate the pressure measurement within the device. Once the pressures of ultra-high vacuum are attained, and a thermionic filament may contaminate the device, means are provided to de-activate the thermionic emission of the cathode and rely upon the field emitting

cathode, as described above, to supply the electrons necessary to sustain an ionizing electric discharge within the interaction space of the device.

In both embodiments of the invention described hereinbefore the aperture in the shield member through which the supply of field emitted electrons, necessary to sustain the electric discharge, enter the interaction space is made small enough so as to minimize the entrance from the field emission apparatus of any soft X-rays which may impinge upon the collector electrode and cause a photo-current which may supply a lower limitation upon the operation of the devices.

In yet another embodiment of the present invention, the possibility of X-ray photo emission constituting a limit upon the low pressure at which the device may be operated is further minimized by utilizing a luminescent phosphor screen as the ion collector and causing the luminescence caused by the impingement of positive ions thereupon to be directed to a photo-multiplier or equivalent type light detector for measurement, the intensity of which is a measure of the ion current, and hence, of the pressure within the ionization gauge of this embodiment of the invention.

While the invention has been set forth hereinbefore with respect to specific embodiments thereof, many modifications and changes will readily occur to those skilled in the art. Accordingly by the appended claims I intend to cover all such modifications and changes as fall within the true spirit and scope of the foregoing invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An ionization device adapted to produce or measure ultra high vacua in a closed system of the order of 10^{-13} mm. Hg or less and comprising an evacuable envelope adapted to be connected to a vacuum system and including:

(a) A cylindrical anode member;

(b) A cathode and shield member at one end of said anode member and electrically insulated therefrom,

(b1) Said cathode and shield member having a small aperture at substantially the center thereof which is substantially along the longitudinal axis of said cylindrical anode member;

(c) An ion collector means at the end of said anode opposite from said cathode and shield member and electrically insulated therefrom;

(d) Said anode member, said cathode and shield member and said ion collector means defining an interaction space wherein electrons, may describe elongated curvilinear paths with a high probability of collision with gas molecules to produce positive ions,

(e) Means external of said interaction space for injecting electrons through said apertured cathode and shield member and including

(e1) A pointed field emission cathode, and

(e2) A cylindrical field emission anode surrounding said field emission cathode and located substantially on said longitudinal axis, said field emission anode having a central aperture on said axis larger than said small aperture, whereby the area of said ion collector within line of sight of said field emission anode is minimized.

2. The device of claim 1 wherein a thermionic cathode of generally hairpin configuration extends through the aperture in said cathode and shield member and means are provided to activate said thermionic cathode at high gas pressures and deactivate said cathode at pressures within the ultra high vacuum range.

3. The device of claim 1 wherein said field emission cathode is co-linear with the longitudinal axis of said anode member.

4. The device of claim 1 wherein the ion collector means is a substantially disc-shaped electrode and is connected to a means for measuring ion current to determine the pressure in said device.

5. The device of claim 1 wherein the ion collector means is a luminescent phosphor with an associated conducting backing and is adapted to emit light of a predetermined wavelength when energized by the impingement of positive ions thereupon.

6. The device of claim 5 and including means for detecting and measuring the intensity of said emitted light as a measure of the pressure within said envelope.

7. The device of claim 6 wherein said detection and measuring means is external of said envelope.

8. The device of claim 1 and including means for maintaining said anode positive with respect to said cathode and shield means, said field emission anode positive with respect to said anode, said field emission cathode intermediate said anode and said cathode and shield member, and said ion collector means negative with respect to said cathode and shield member.

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