This invention relates to ion pumps of the cold-cathode discharge type. More particularly, the invention relates to an improved cold-cathode discharge ion pump. The invention is particularly useful for evacuating noble gases and other generally nonreactive ions.

Ion pumps may be generally classified into hot cathode types and cold-cathode discharge types. United States Patent No. 2,850,225, issued September 2, 1958, to R. G. Herb, relates to a hot cathode ion pump. A pump of the type referred to in U.S. Patent No. 2,850,225 is sold by Consolidated Vacuum Corporation, the assignee of the present application, under the trade name "Evapor-Ion." Such pumps are generally of high capacity, but have the relative disadvantage of being somewhat bulky and expensive.

A cold-cathode discharge device for measuring the pressure in an evacuated space is described in U.S. Patent No. 1,97,079, issued April 16, 1930, to Frans Michael Penning. The Penning device consists essentially of a ring anode contained between two cathodes within an evacuated envelope. The anode and cathodes are immersed in a strong magnetic field. A high positive potential with respect to the cathode is applied to the anode. The gas between the anode and cathode is ionized by ionizing a current flow therebetween. The magnitude of the ionization current indicates the pressure existing between the anode and cathodes. Such a vacuum measuring device has the disadvantage of disturbing the vacuum to be measured, as ions are pumped from the evacuated space into the surface of the cathode of the device. The vacuum is to be measured is thereby increased over the vacuum which would otherwise exist.

A practical vacuum pump may be made by combining a number of such Penning cold-cathode discharge devices into a single unit. A description of such a pump is contained in "Science," volume 128, pages 282-284, published August 8, 1958. A pump comprised simply of a plurality of Penning cold-cathode discharge devices suffers from a markedly poor noble gas evacuation characteristic, in that the pressure obtained in such a pump when pumping noble gases will oscillate rather than remain constant. The poor noble gas evacuation characteristic of such a pump results from the inability of the pump surfaces to "getter" the ions of noble gases pumped thereinto. By getter is meant to establish physical or chemical bonds between atoms and molecules of the pump surfaces and gas ions present. The failure of the pump surfaces to getter the ions of noble gases is due to the nonreactive nature of such ions.

Nonreactive ions, when driven to the surfaces of the pump by the fields of force therein, are entrapped physically in the outermost molecular layers of the pump surfaces. The entrapped ions are substantially neutralized during entrainment. This entrainment consists of the ions being driven beneath the surface molecular layers of the pump so as to be physically retained by the enclosing molecular layers. No appreciable physical or chemical bonding exists between the entrapping molecular layers and the entrapped nonreactive ions so entrapped.

As previously stated, the entrapped ions are neutralized, resulting in atoms of the nonreactive substances being entrapped. Removal of the entrapping molecular layers allows these nonreactive atoms to return to the evacuated area. Return of the nonreactive atoms to the evacuated area causes a rise in the pressure existing within the evacuated area, because of the addition to the evacuated area of the atoms formerly entrapped.

Entrapped atoms are freed from entrainment by a process known as sputtering. By sputtering is meant the ejection of particles of a surface in various directions from the surface. Sputtering is caused by the bombardment of the surface by ions traveling at high velocity. As the pump surfaces are sputtered, the molecular layers of surface material originally entrapping the nonreactive atoms are worn away. The nonreactive atoms thereupon escape back into the evacuated area.

The oscillatory nature of the nonreactive ion pumping characteristic of conventional cold-cathode discharge ion pumps is apparently due to a cumulative or avalanche effect in sputtering. When the surface molecular layers have entrapped all of the nonreactive atoms which they are capable of holding, further ion bombardment frees the entrapped atoms from the portions of the surfaces they strike. The freeing of these atoms has two immediate effects. First, the pressure in the evacuated area rises in relation to the number of atoms freed. Second, the increase in the number of atoms in the evacuated area increases the sputtering rate of the surface, since more ions are available to strike the entrapping surfaces.

An increase in the sputtering rate of the entrapping surfaces frees nonreactive atoms entrapped therein at a faster rate. The pressure within the evacuated area therefore continues to rise until the rate of removal of nonreactive atoms from the entrapping surfaces due to sputtering no longer exceeds rate at which the sputtered surfaces are able to entrapping nonreactive ions. Thereupon, the sputtered surfaces again entrap the bombarding nonreactive ions until the entrapment capacity is reached. Further nonreactive ion bombardment thereupon commences to free entrapped nonreactive atoms at a rate faster than the rate at which other nonreactive ions are entrapped, repeating the above described process. Thus, the oscillatory nonreactive ion evacuation characteristic of the conventional cold-cathode discharge ion pump is not due to an inability to pump nonreactive ions into the surfaces of the device, but is rather due to an inability of the surfaces to retain such ions pumped thereinto.

According to the present invention, the oscillatory noble gas or nonreactive ion evacuation characteristic of conventional cold-cathode discharge ion pumps is eliminated by depositing evaporated replacement material on the sputtered portions of the cathode surfaces, into which the nonreactive ions already have been pumped. This deposited replacement material provides additional entrapping capacity for the sputtered cathode surfaces.

A pump constructed according to the present invention has a cellular anode and a source of evaporated replacement material contained within an evacuated envelope in a fixed physical relation to each other. At least one pump cathode is also contained within the envelope. The anode, evaporated replacement material source, and cathodes are positioned so that one portion of each cathode is initially adjacent the anode and another portion of the cathode is initially adjacent the evaporated replacement material source.

Relative motion is initiated between the anode and the cathodes of the pump so as to move sputtered portions of the cathodes away from the anode and move unsputtered portions of the cathodes adjacent the anode. The replacement material deposit is deposited on the sputtered cathode portions, thereby providing a new layer of entrapping material which covers the sputtered portions. The portions of the cathodes having the newly deposited replacement material thereon are then returned adjacent the
Anode and additional nonreactive ions are pumped thereinto and entrapped therein. By utilizing a rotary relative motion, continuous evaporated replacement material deposited on the nonreactive ion pumping are achieved and the oscillatory pressure characteristic of conventional cold-cathode discharge ion pumps entrapping nonreactive gases is eliminated.

The invention may be more readily understood by reference to the accompanying drawing in which:

FIGURE 1 is an elevation of a Penning cold-cathode discharge device;

FIGURE 2 is a sectional plan view, partially broken away, of an ion pump consisting of a plurality of Penning cold-cathode discharge devices;

FIGURE 3 is an elevation, partially in section, taken along of FIG. 2;

FIGURE 4 is a graph showing the oscillatory evacuation characteristic of the ion pump of FIG. 2 when evacuating argon;

FIGURE 5 is a plan view, partially broken away, of an ion pump according to the invention; and

FIGURE 6 is an elevation taken along line 6—6 of FIG. 5 and including magnets for providing the required magnetic field and a cathode rotary drive system.

Referring to FIG. 1, the Penning cold-cathode discharge device consists of an evacuated envelope 20 containing an anode 21 and two cathodes 22. The anode 21 is connected by a lead 23 to a high voltage terminal 24 extending through the evacuated envelope. The two cathodes 22 are connected by a common lead 25 to a cathode terminal 26 extending through the evacuated envelope. An electromagnet 27 creates a magnetic field between the anode 21 and the cathodes 22. An inlet 28 connects the device to an evacuated space.

Anode 21 has a ring configuration so that electrons may pass through the anode with a relatively small chance of striking the anode surface. The cathodes 22 are of solid construction, so that ions reaching the cathodes will strike their surfaces. A high positive potential from a high voltage source (not shown) is applied to the anode terminal 24, and the cathode terminal 26 is grounded through a common connection (not shown). Electrons in the evacuated envelope 20 therefore tend to move toward the anode due to the attraction between the positive potential of the anode and the negative electron charge.

As an electron tries to approach the anode, the magnetic field set up by the magnets 27 is such that the electrons spiral between the anode and cathodes rather than continue to move directly toward the anode. During this spiralling process, the electrons produce ionization in the area of the magnetic field by striking free molecules and atoms of the gas contained in the envelope. These ions are attracted to the cathodes 22 and, upon striking one of the cathodes, impinge in the surface molecular layers of the cathode. The removal of these ions from the gas phase in the evacuated envelope therefore reduces the pressure within the envelope.

FIGURE 2 shows a conventional ion pump which consists essentially of thirty-six Penning cold-cathode discharge cells. The ion pump of FIG. 2 has a cellular-shaped anode 30 contained within an evacuated envelope 31. An anode lead 32 connects the cellular-shaped anode 30 to a high-voltage connector 33.

FIGURE 3 shows an elevation, partially in section, of the ion pump of FIG. 2. Two cathodes 34 are adjacent the upper and lower surfaces of the anode 30. A cathode terminal 35 passing through the evacuated envelope 31 is connected to the two cathodes 34 by a connecting lead (not shown). An inlet 36 is connected to the space to be evacuated.

The cathodes are constructed of a reactive material; for example, titanium, magnesium, aluminum, molybdenum or various of the rare earths may be used. A positive potential with respect to the cathodes of approximately 3,000 volts is applied to the anode 30 by means of the high voltage connector 33.

A gaseous discharge, occurring in the same manner as described above with respect to the Penning device, is initiated. The ions within the gaseous discharge are driven into the cathode surfaces and entrapped under the surface molecular layers thereof. Some of the reactive ions are then moved by physical or chemical bonding with atoms and molecules of the cathode material.

Due to the high potential difference between the anode and the cathode, ions strike the cathode with a relatively great velocity. Therefore, material on the surface of the cathodes is sputtered therefrom in the general direction of the anode and the opposite cathode. The removal of material from the cathode surface exposes the entrapped nonreactive neutralized atoms in the next succeeding molecular layer. These entrapped atoms are thereby permitted to escape.

A portion of the material sputtered from one cathode is deposited on the opposite cathode. Sputtered material is also deposited on the anode and on the envelope walls. Consequently, the rate of removal of material from a cathode due to sputtering is reduced to the rate of deposition on the cathode of material sputtered from the opposite cathode, resulting in an over-all loss of cathode material. Thus, it is apparent that after a short period of operation, the oscillatory pumping characteristic occurs when nonreactive ions, for example, of a noble gas, are being pumped.

FIGURE 4 is a graph of the actual pressure measured in a pump of the type illustrated in FIGS. 2 and 3 when pumping argon, a noble gas. A positive potential of 3,000 volts with respect to the cathode is applied to the anode. The pressure within the evacuated envelope varies from a minimum of 0.75×10^-6 mm. Hg to a maximum of 2.5×10^-6 mm. Hg. The periods between maximum pressure peaks are approximately six minutes.

FIGURE 5 is a plan view, partially broken away, of an ion pump 40 according to the invention. The ion pump 40 has an envelope 41 with an inlet 42. The inlet 42 is connected to the space (not shown) which is to be evacuated. Two cathodes 43 are contained within the envelope 41. A cellular anode 44 within the envelope 41 is connected to a high voltage source (not shown) by means of an anode lead 45 and a high voltage connector 46. Replacing the anode 30 of FIG. 2 with a crucible 48 which is held in the position shown by an insulating support member 49 attached to the wall of the envelope. A filament 50, which may be constructed of tungsten, is positioned beneath the crucible 48. Two filament terminals 51 provide means for applying a potential across the filament of approximately three volts to heat the filament and evaporate electrons therefrom. A crucible high voltage terminal 52 and a crucible high voltage lead 53 provide a means for applying a positive potential, preferably four to five kilovolts, to the crucible. Electrons are emitted from the filament 50 and strike the crucible 48 at a high velocity, so as to cause heating of the crucible. The replacement material contained in the crucible 48 is evaporated by this heating. A magnetic shield 54 provides magnetic shielding for those portions of the cathodes adjacent the crucible 48. However, the use of such a shield is not essential.

FIGURE 6 is a sectional elevation of the ion pump 40 taken along line 6—6 of FIG. 5. FIGURE 6 illustrates one means for rotating the cathodes 43. The cathodes 43 are mounted on a shaft 55. At one end of the shaft 55 is a permanent horseshoe magnet 56 which functions as the driven magnet in a magnetic clutch assembly. An anode lead is journaled on the envelope 41. Magnets 57 provide the magnetic field required to sustain a Penning type discharge, as has been previously described. A motor 58 is connected to a permanent horseshoe magnet 59 by a drive shaft 60. The two permanent horseshoe magnets 56 and 59 form a
magnetic clutch with the permanent horseshoe magnet 59 forming the driven portion of the clutch. Rotation of the drive magnet 59 causes the driven magnet 56 to rotate in response thereto, thereby rotating cathodes 43 about the axis of the shaft 55.

When the pump is actuated, nonreactive ions in the vicinity of the anode 44 are driven into the surfaces of the cathodes 43 immediately adjacent thereto. The pumping of the nonreactive ions into the cathode surfaces entraps the ions in the surface molecular layers of the cathodes where they are neutralized, as has been described previously. The cathodes 43 are continuously rotated by means of the motor 58 and the magnetic clutch to rotate sputtered cathode surfaces away from the area of the discharge prior to the time when the sputtered surfaces reach their entrainment capacity. The rotation of the cathodes 43 in response to the rotation of the magnetic clutch by the motor 58 moves the sputtered cathode surfaces adjacent the crucible 48 of replacement material. Atoms are evaporated from the replacement material in the crucible 48 in response to the heating of the electronic heating of the crucible 48. This evaporated material is deposited on the sputtered surfaces of the cathodes 43 while the sputtered surfaces are in the vicinity of the shield 54. The rate at which material is evaporated and deposited on the replacement material cathodes is controlled by the heating applied to cause evaporation. This rate is adjusted to be at least equal to the rate of over-all loss of material from the cathodes due to sputtering, in order to achieve optimum operating characteristics.

The deposition of a layer of replacement material on the sputtered cathode surfaces provides these surfaces with a new entrapping layer. The new entrapping layer now allows additional nonreactive ions to be driven into the cathode surfaces without reaching entrainment capacity. As the cathodes continue to be rotated, these sputtered surfaces are again positioned adjacent the anode 44. Additional nonreactive ions are then driven into the sputtered surfaces. However, because of the additional entrapping layer of replacement material, the oscillating pressure characteristic of the conventional cold-cathode discharge ion pump is not encountered.

The pump of the present invention need not have cathodes constructed of reactive material. Similarly, the replacement material need not be a reactive substance. Such a pump relies on entrainment to evacuate the envelope. If reactive gases are to be pumped, higher capacity can be achieved by using reactive materials for either or both the cathodes and the replacement material.

We claim:

1. An improved ion pump of the cold-cathode discharge type comprising an evacuated envelope, a cellular anode contained within the envelope, a source of replacement material contained within the envelope, a cathode contained within the envelope, the anode and the replacement material source being fixed in physical relation so that a first portion of the cathode is initially adjacent the anode and a second portion of the cathode is initially adjacent the replacement material source, means for causing the relative motion of the cathode with respect to the anode and replacement material source so that said first cathode portion is periodically adjacent the replacement material source and said second cathode portion is periodically adjacent the anode, and means operable when energized to evaporate material from the replacement material source, whereby the evaporated replacement material is deposited upon the surface of said first portion and said second portion of the cathode when that portion of the cathode is adjacent the replacement material source.

2. An improved ion pump of the cold-cathode discharge type comprising an evacuated envelope, a cellular anode contained within the envelope, a source of replacement material contained within the envelope, the anode and the replacement material being fixed in physical relation to each other, at least one cathode rotatably contained within the envelope so that a first portion of the cathode is initially adjacent the anode and a second portion of the cathode is initially adjacent the replacement material source, means for rotating the cathode, and means operable when energized to evaporate material from the source of replacement material, whereby the evaporated replacement material is deposited on the surface of that portion of the cathode remote from the anode.

3. An improved ion pump of the cold-cathode discharge type as defined in claim 2 in which the means for rotating the cathode includes a magnetic clutch assembly, one portion of which is external of the envelope.

4. An improved ion pump of the cold-cathode discharge type comprising an evacuated envelope, two cathodes contained within the envelope, a cellular anode positioned in a first portion of the envelope, a replacement material source positioned in a second portion of the envelope for replacing material sputtered from the cathodes, the anode and the replacement material being positioned between the two cathodes, means for rotating the cathodes, and means for evaporating material from the replacement material source, whereby the evaporated material is deposited on sputtered surfaces of the cathodes in said second envelope portion at a rate at least equal to the rate of over-all loss of material from the cathodes due to sputtering.

5. An improved ion pump of the cold-cathode discharge type as defined in claim 4, and including a magnetic shield enclosing said second envelope portion.

6. An improved ion pump of the cold-cathode discharge type as defined in claim 4 in which the means for rotating the cathodes includes a magnetic clutch, a portion of which is external of the envelope.

7. An improved ion pump of the cold-cathode discharge type as defined in claim 6 and including a magnetic shield enclosing said second envelope portion.

References Cited in the file of this patent

UNITED STATES PATENTS

2,893,624 Frische July 7, 1959