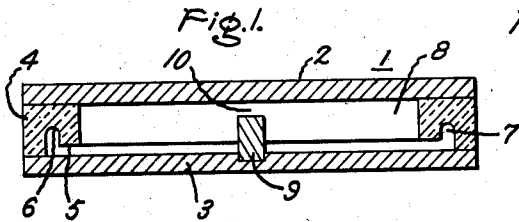
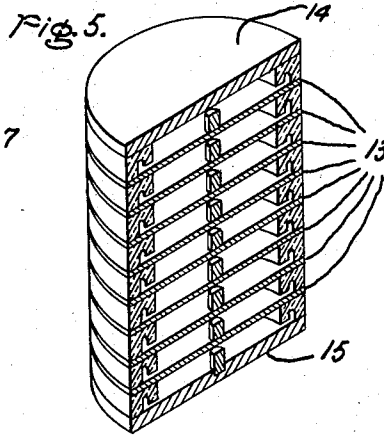
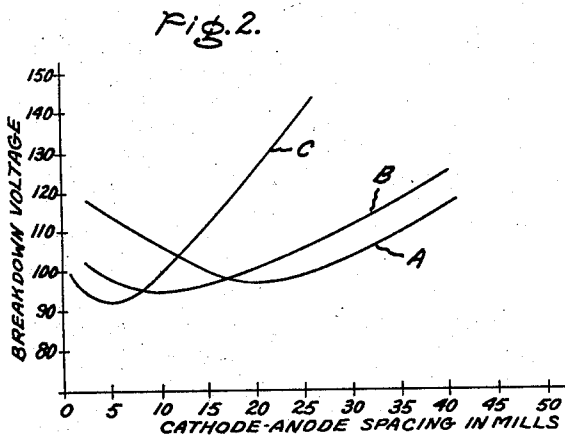
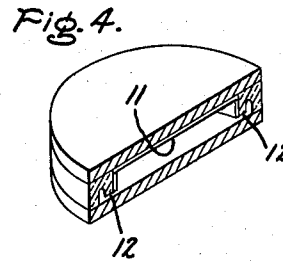
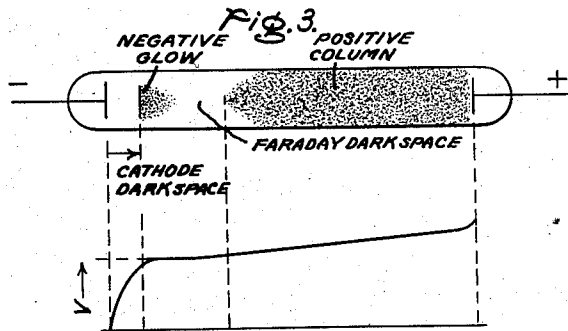
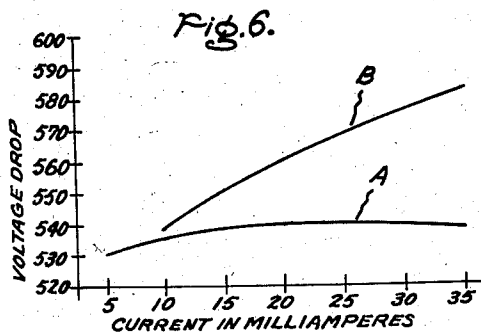


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J. M. LAFFERTY
GASEOUS DISCHARGE DEVICE

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GASEOUS DISCHARGE DEVICE

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10 Claims. (Cl. 315—36)

The present invention relates to gaseous electric discharge devices of the voltage-regulator type. More particularly, the invention relates to improved voltage-regulator tubes uniquely adapted for high voltage operation.

Voltage-regulator tubes are two-element cold-cathode gas discharge devices which are ionized to become conductive at a voltage denominated as "breakdown voltage," and sustain a glow discharge having a constant potential difference between the electrodes thereof over a substantial range of current. Although, ideally, this potential difference or "regulating voltage" is constant, in commercially available voltage-regulator tubes the regulating voltage varies greatly with current.

Since the regulating voltage in a voltage regulator tube is dependent primarily upon the gas and the cathode material utilized, in designing a gaseous voltage-regulator tube to regulate at a particular voltage, one may readily select the gas-cathode material combination which characteristically regulates at the desired voltage. The highest such regulating voltage which can be maintained stable in a gaseous voltage regulator device is approximately 400 volts. This voltage is obtained utilizing carbon dioxide gas and a copper cathode. Hydrogen gas with a copper cathode gives a stable regulating voltage of 325 volts. It is impossible to maintain a stable gas glow discharge at higher voltages utilizing a single voltage regulator tube. In order that higher voltages be regulated, it is necessary to operate a number of voltage regulator tubes in series. This has a number of disadvantages, among which are that it is highly wasteful of space and that the tubes, being subjected to different temperatures, operate under different conditions.

Accordingly, it is an object of the present invention to provide a voltage regulator gaseous discharge device capable of providing a voltage reference at higher voltage than has heretofore been obtainable.

A further object of the invention is to provide a flexible voltage regulator device unit which can be combined with other similar units to form a single device capable of regulating any desired high voltage.

A further object of the invention is to provide compact voltage regulator gaseous discharge devices which occupy an extremely small space and which may be operated at extremely high temperatures.

In accord with the present invention I provide a noble gas filled voltage regulator unit comprising an anode and a cathode having plane parallel symmetry insulatingly joined together with a ceramic member providing a thin disk-like tube, the thickness of which is small with respect to the diameter thereof. A suitable breakdown gap is provided to cause breakdown to occur at a minimum voltage. The voltage regulator unit may be used separately, or may be formed in combination with the number of units in series so that any desired regulating voltage may be obtained.

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, together with further objects and advan-

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tages thereof may best be understood by referring to the following detailed description, taken in connection with the attached drawing in which:

Fig. 1 is a vertical cross-sectional view of a single voltage regulator tube unit constructed in accord with the present invention,

Fig. 2 is a graph showing typical Paschen curves for devices constructed in accord with the invention,

Fig. 3 is a diagram of the characteristic of a normal glow discharge such as is maintained in the devices constructed in accord with the present invention,

Fig. 4 illustrates one alternative embodiment to the device of Fig. 1,

Fig. 5 is a cut-away perspective view of a plurality of the devices of Fig. 1 assembled in series, and

Fig. 6 is a voltage-current characteristic of a multi-unit device as illustrated in Fig. 5, constructed in accord with the present invention.

In Fig. 1 voltage regulator unit 1 comprises a cathode disk 2 and an anode disk 3 in plane parallel spaced relation and hermetically joined by an annular insulating member 4 having a counterbore 5 at one longitudinal end thereof and an annular groove 6 in the surface of counterbore 5. Counterbore 5 and groove 6 form a shielded space 7 which is not in direct line with the main volume 8 of unit 1. A rod-like anode pin 9 is located at the geometrical center of the unit and is electrically and mechanically connected to the interior surface of anode disk 3 and forms with cathode disk 2, a breakdown gap 10. The entire interior volume of unit 1 is filled with a highly purified stable noble gas which may consist of helium, neon, argon, krypton, xenon or mixtures thereof. The exact gas or mixture of gases selected to fill the interior of the tube depends upon the desired regulating voltage, since the potential difference between cathode and anode during normal glow discharge of the tube is primarily a function of the gas and the cathode material utilized.

Although cathode disk 2 and anode disk 3 may be of any highly conductive metal, such as copper, they are preferably fabricated from titanium. Titanium is used to obtain optimum characteristics from the devices because of the unique gettering characteristics thereof. I have discovered that one of the conditions necessary for the achievement of a substantially uniform potential difference between cathode and anode of a noble gas voltage regulator gaseous electric discharge device over a substantial range of operating currents thereof, is the maintenance of high gas purity. If any small quantity of a chemically reactive gas other than the noble gas intended to be utilized is present within the tube, the characteristics change markedly with use. Accordingly, the voltage regulator tubes of the present invention are filled with an atmosphere consisting of a stable noble gas or a mixture of stable noble gases while the device is being sealed in accord with the invention disclosed and claimed in my copending application Serial No. 690,849 filed October 17, 1957, herewith and assigned to the present assignee.

In accord with my copending application gaseous discharge devices which utilize a noble gas filling are formed by the sealing of titanium members and a titanium-matching ceramic member or members while the tube is maintained in an atmosphere of the operating gas at a suitable pressure. When titanium is heated to the temperatures (of the order of 700° C. to 1100° C.) at which titanium may be bonded to titanium-matching ceramics, the metal is an excellent getter for chemically active gaseous impurities commonly present in noble gases such as CO₂, H₂, H₂O, N₂ and O₂ and the like. When the devices of the present invention are so formed the resultant atmosphere comprises highly purified noble

gases or a mixture of noble gases. As a result of this, the voltage at which the device maintains a stable glow discharge remains constant for several orders of magnitude, a condition heretofore unobtainable in prior art voltage regulator tubes.

Annular insulating member 4 comprises a refractory ceramic insulating material, the coefficient of thermal expansion of which is a close match for that of titanium, and which hence may be suitably bonded at high temperatures to form hermetic seals with titanium cathode disk 2 and anode disk 3. Such a ceramic is a sintered agglomerate of silicon oxide, magnesium oxide and aluminum oxide denominated as Forsterite. One such Forsterite ceramic and the method of preparation thereof is disclosed and claimed in the copending application of A. G. Pincus, Serial No. 546,215, filed November 10, 1955, and assigned to the assignee of the present invention.

The shape of annular insulating member 4 is of great importance in the devices constructed in accord with the present invention. Since the device is extremely thin it is necessary that complete insulation be maintained throughout the life of the device between cathode 2 and anode 3. For this reason, insulating member 4 is, of course, electrically non-conductive. However, during the life of the tube metal is sputtered from the cathode onto the inner side wall of insulating member 4 forming a metallic surface. Such a metallic surface can constitute a leakage path which effectively short-circuits the tube. This is avoided, however, by counterbore 5 and annular groove 6 in insulator 4 which structure effectively forms a surface region which is not in direct contact or within the line of sight of the cathode. Accordingly, the metal which is sputtered on the walls does not cover this surface portion and insulation between cathode 2 and anode 3 is maintained throughout the life of the device.

Anode pin 9 may be constructed of iron, titanium, tungsten, molybdenum, stainless steel or any other material conventionally used for electrodes in electron or gaseous discharge devices which does not readily alloy with the titanium anode 3 at the sealing temperature.

Electrode 9 terminates short of cathode 2 and defines therewith a breakdown gap 10. In a voltage regulator tube it is desirable that the breakdown voltage be as close to the regulating voltage as is possible. From Paschen's law it is known that the potential at which gaseous breakdown occurs between two electrodes in a particular atmosphere, for that particular atmosphere and for the particular cathode material utilized, is a function only of the product of the gas pressure times the gap length. One may plot the well-known Paschen curves, a group of which are illustrated in Fig. 2 of the drawing. In Fig. 2, the breakdown potential for varying gap lengths for argon gas at a pressure of 10, 20 and 40 mm. of mercury are represented by curves A, B and C respectively. From these curves it may be seen that there is a particular gap length-gas pressure product at which the breakdown voltage is a minimum. Accordingly, breakdown gap 10 in device 1 is chosen to be substantially that distance which, in combination with the gas pressure and cathode material utilized, causes breakdown to occur at the minimum of the Paschen curve for the gas, gas pressure, and cathode material utilized.

In accord with another feature of the present invention, anode pin 9 may be omitted. In this embodiment it is necessary that another breakdown gap be established. This may be done as follows: anode pin 9 is omitted in construction. Once formed the tube is subjected to a supply voltage of approximately 100 volts in excess of its designed regulating voltage. Breakdown then occurs, and a glow discharge fills space 8. The current is then pulsed intermittently at a value of approximately 1 ampere per square centimeter for several hours. This high-current glow discharge causes a large amount of

metal to be sputtered from the cathode and deposited upon the inner surface of annular insulating member 4. The annular gap between counterbore 5 of member 4 and anode disk 3 then constitutes the breakdown gap for the device. In this embodiment this gap is adjusted to the criteria set forth with respect to gap 10, so that the gap distance-gas pressure product is substantially equal to the minimum of the Paschen curve for the gas and cathode material utilized.

In devices constructed in accord with the present invention a distinct advantage is attained by the unique geometry wherein cathode and anode are extremely close together. This geometry is not conventional and is not derived merely by placing anode and cathode as close together as is possible. In order to understand the criteria governing the juxtaposition of anode and cathode in devices in accord with the present invention, reference is made to Fig. 3 of the drawing. In Fig. 3, the characteristic normal glow discharge, which characteristic is universal for inert gases, is represented schematically. The most important portions of the glow in Fig. 3 are the cathode dark space, the negative glow, the Faraday dark space, and the positive column, all of which are identified with captions in Fig. 3. The curve of Fig. 3 is a graphical representation of the potential distribution between anode and cathode in the tube illustrated, and corresponds thereto. As may readily be seen, the greatest portion of the potential difference between the cathode and the anode is found in the region of the glow denominated the cathode dark space with only a gradually varying and small potential difference between the beginning of the negative glow and the anode.

Accordingly, I have found that it is possible to construct voltage regulator tubes in accord with the present invention by pushing the anode up through the positive column and into the Faraday dark space near the negative glow region so that actually only a portion of the conventional glow discharge is utilized. The portion utilized, however, contains the greatest portion of the potential difference normally found in more extended discharges. Accordingly, the distance between the cathode and the anode in the device of Fig. 1 is substantially the distance between the cathode and the beginning of the Faraday dark space in Fig. 3 of the drawing. While this distance varies for different gases, different pressures, and cathode materials utilized, the distances for the inert gases and the cathode materials utilized in the present invention may be readily determined by those skilled in the art so that it is relatively easy to determine the precise distances which satisfy the condition that the cathode and anode be separated by a distance substantially equal to the width of the cathode dark space and the negative glow for the gas, electrodes, and pressure utilized. Thus, for any given gas and electrode material combination, the distance from the cathode to the Faraday dark space times the gas pressure is a constant. Accordingly, the distance to the Faraday dark space can be computed for any gas at any pressure once this constant is known. For titanium electrodes, these constants are: 0.64 for argon, 0.80 for xenon, 0.90 for neon and 1.72 for helium, where the pressure is expressed in mm. of Hg and the distance is expressed in cm.

In accord with a further feature of my invention, greater flexibility may be attained in the matter of adapting the voltage regulator tubes for different voltages. This is attained by coating the interior surface of cathode disk 2 with a low work function material to attain a low regulating voltage. Thus, for example, to attain a regulating voltage of 75 volts, for a single unit, an atmosphere of argon may be combined with a surface of barium. This may be achieved by coating cathode disk 2 with a layer approximately 0.001" thick or less of barium aluminide prior to assembling the tube. Other materials which may be similarly used are cerium ($\phi=2.8$ v.) and magnesium ($\phi=3.6$ v.). A single unit which utilizes

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such a coating, and in which the anode pin has been eliminated is illustrated in perspective in Fig. 4. In the device of Fig. 4, coating 11 is the cathode surface and annular gap 12 is the breakdown gap.

A decided advantage of the present invention is that in addition to the fact that the regulating gas and cathode material may be chosen to provide a given regulating voltage within a range of from approximately 75 to 180 volts, a plurality of devices as illustrated in Fig. 1 may be combined when a voltage higher than that which may be regulated with a noble gas is desired to be regulated. In Fig. 5 of the drawing there is illustrated a device comprising a plurality of the units as illustrated in Fig. 1 each of which comprises a separate noble gas filled compartment combined to regulate a high voltage. Devices such as illustrated in Fig. 5 comprise a plurality of the devices as illustrated in Fig. 1 stacked in series. Since there is no necessity for having both anode and cathode disks for the intermediate tube units, a single disk 13 forms anode and cathode for adjacent tube units and is substantially thinner than cathode end wall member 14 and anode end wall member 15. These devices may be made in accord with the invention described and claimed in my aforementioned copending application, thus achieving the advantages of high noble gas purity and, consequently, a stable regulating voltage over a wide range of currents. Tubes such as those illustrated in Fig. 5 of the drawing have been constructed with ceramic annular members as small as 0.068" thick. Since, in these tubes the thickness of the anode and cathode plates when the tubes are stacked together is approximately 0.015", one achieves a design parameter of approximately 2 volts per 0.001" or 2 kilovolts per inch of the tube length utilized.

In tubes constructed in accord with the present invention, the diameter of the tube determines its current carrying capacity. The tubes of the present invention are capable of carrying extremely high currents, considering the size utilized. Utilizing xenon gas and titanium cathodes for example it has been found that the ratio j/p^2 where j is the current density and p is the pressure of gas utilized, which ratio is a figure of merit for voltage regulator tubes, has been found to be 14×10^{-6} amperes per square centimeter per millimeter of mercury squared. As a practical matter, in tubes constructed in accord with the present invention, approximately twice this current density has been drawn without appreciably increasing the regulating voltage exhibited by the tube.

In Fig. 6 of the drawing, there is shown the voltage-current characteristic (curve A) for a three cell tube similar to the one illustrated in Fig. 5 having a diameter of 1" with an effective cathode diameter of 0.7". This tube was charged with approximately 20 mm. of xenon and the electrodes were of titanium. This characteristic may be compared with curve B which is a similar characteristic for 3 standard OD3V-R tubes and one OA3V-R tube connected in series which regulate in the same voltage range. As may be seen from the drawing, the tube constructed in accord with the present invention exhibits an extremely flat characteristic denominating a nearly constant regulating voltage over a substantial range of current. Since the devices of this invention contain only metal and ceramic they may be operated at extremely high temperatures.

While the invention has been described hereinbefore with respect to specific embodiments thereof, it will be readily apparent to those skilled in the art that many changes and modifications may be made without departing from the invention. Accordingly, I intend by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

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

1. A noble gas voltage regulator gaseous electric dis-

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charge device comprising: a disk-shaped cathode member and a disk-shaped anode member in plane parallel spaced relation, the distance between said anode and said cathode being substantially equal to the distance from the cathode to the Faraday dark space on the normal glow discharge characteristic for the gas, gas pressure, and electrode material utilized; an annular insulating member interposed between and forming hermetic seals with said cathode and said anode members, said insulating member having a re-entrant cross-section which provides a surface portion thereof which is shielded from the volume defined by said cathode and said anode members; a highly purified noble gas atmosphere filling the interior of said device; and means electrically connected between said anode and said cathode defining a closely spaced breakdown gap between.

2. The device of claim 1 wherein said anode and cathode members are of titanium.

3. A noble gas voltage regulator gaseous electric discharge device comprising: a disk-shaped cathode member and a disk-shaped anode member in plane parallel spaced relation, the distance between said cathode and said anode being substantially equal to the distance from the cathode of the Faraday dark space on the normal glow discharge characteristic for the gas, gas pressure, and electrode material utilized; an annular insulating member interposed between and forming hermetic seals with said cathode and said anode members, said insulating member having a counterbore in one surface thereof and an annular groove in said counterbore; a highly purified inert gas filling the interior of said device; and means electrically connected between said cathode and said anode defining a closely spaced breakdown gap therebetween.

4. The device of claim 3 wherein said anode and cathode members are of titanium.

5. A high voltage noble gas voltage regulator gaseous electric discharge device comprising in parallel spaced relation, a disk-shaped metallic cathode end wall member, a disk-shaped metallic anode end wall member, and at least one disk-shaped metallic member interposed between said cathode and said anode, the distance between adjacent metallic members being substantially equal to the distance from the cathode to the Faraday dark space on the normal glow discharge characteristic for the gas, gas pressure, and electrode material utilized; a plurality of annular insulating ceramic members separating said metallic members from one another, hermetically sealed to said separated members, and forming a plurality of separate sealed compartments, each of said insulating members having a reentrant cross-section providing a surface portion thereof which is shielded from the volume defined by said metallic members juxtaposed thereto; a highly purified noble gas atmosphere filling each of said compartments; and means connected between each of said juxtaposed pair of metallic members providing a closely spaced breakdown gap therebetween.

6. The device of claim 5 wherein said metallic members are of titanium.

7. A high voltage noble gas voltage regulator gaseous electric discharge device comprising in plane parallel spaced relation, a disk-shaped metallic cathode end wall member, a disk-shaped metallic anode end wall member, at least one disk-shaped metallic member interposed between said cathode and said anode; a plurality of annular insulating ceramic members separating said metallic members from one another, hermetically sealed to said separated members, and forming a plurality of separate sealed compartments, said insulating members each comprising an annulus having a counterbore in one end thereof and an annular groove in the surface of said counterbore; a highly purified noble gas atmosphere filling each of said compartments; and means electrically connected between each pair of juxtaposed metallic mem-

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bers providing a closely spaced breakdown gap therebetween.

8. The device of claim 7 wherein said metallic members are of titanium.

9. A high voltage noble gas voltage regulator gaseous electric discharge device comprising in plane parallel spaced relation, a disk-shaped metallic cathode end wall member, a disk-shaped metallic anode end wall member, and at least one disk-shaped metallic member interposed between said cathode and said anode, the distance between adjacent metallic members being substantially equal to the distance from the cathode to the Faraday dark space on the normal glow discharge characteristic for the gas, gas pressure, and electrode material utilized; a plurality of annular insulating ceramic members separating said metallic members from one another, hermetically sealed to said separated members, and forming a plurality of separate sealed compartments,

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said insulating members each comprising an annulus having a counterbore at one end thereof and an annular groove in the surface of said counterbore; a highly purified noble gas atmosphere filling each of said compartments; and means electrically connected between adjacent metallic members providing a closely spaced breakdown gap therebetween.

10. The device of claim 9 wherein said metallic members are of titanium.

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