June 26, 1962 W. J. KEARNS 3,041,492

GASEOUS DISCHARGE DEVICE

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FIG.1.

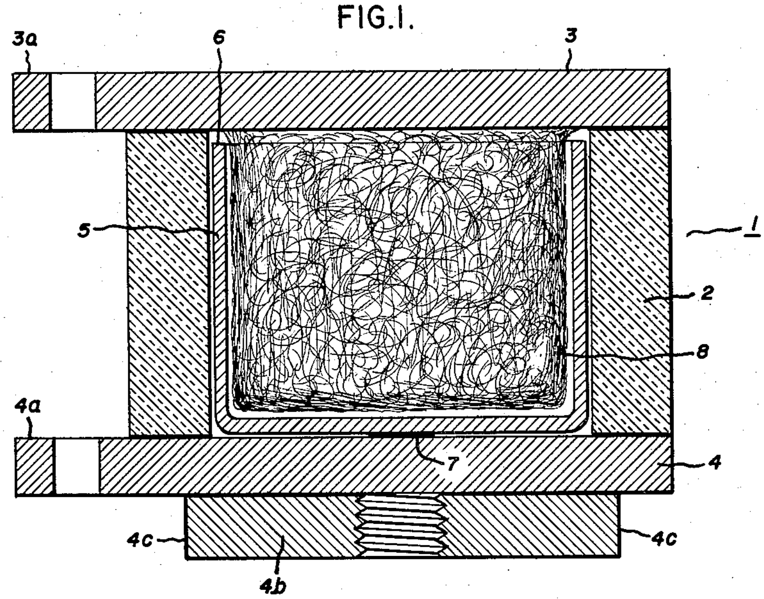
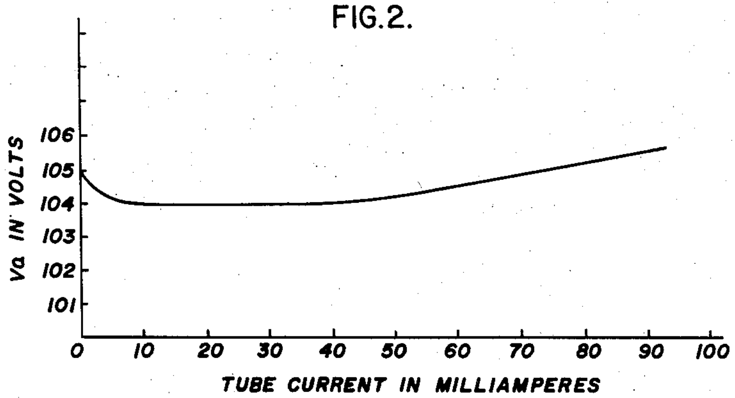


FIG.2.



VOLT–AMPERE CHARACTERISTIC CURVE

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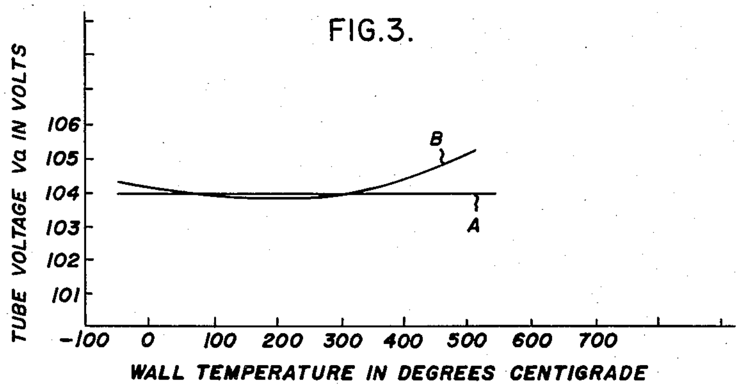
FIG.3.



VOLT-TEMPERATURE CHARACTERISTIC CURVE

FIG.4.

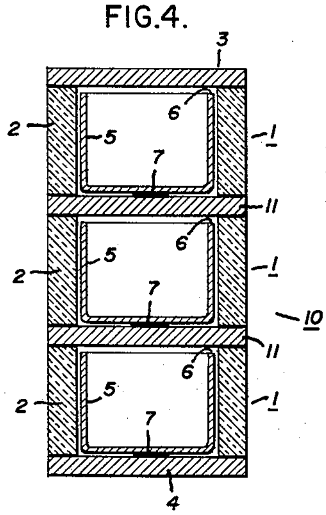


FIG.5.

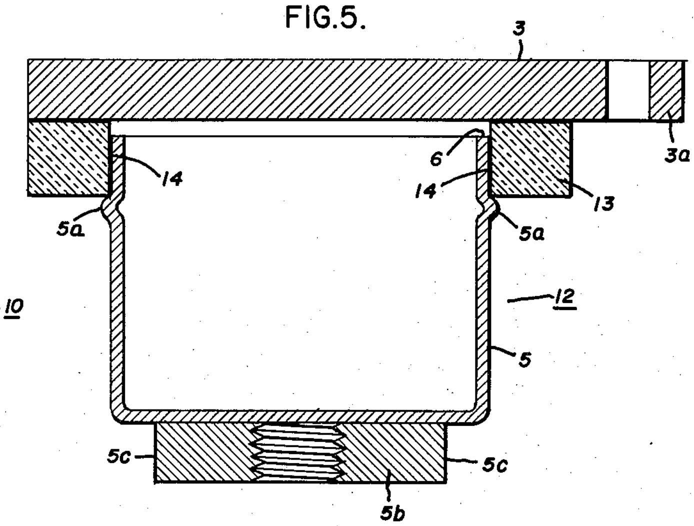
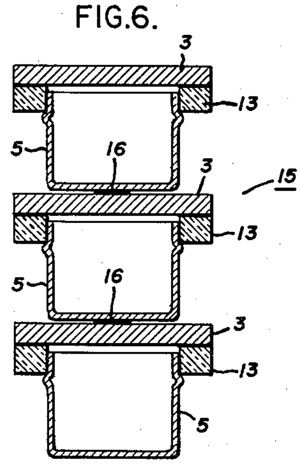


FIG.6.



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GASEOUS DISCHARGE DEVICE

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14 Claims. (Cl. 313—185)

My invention relates to gaseous discharge devices of the glow discharge type and more particularly to an improved glow discharge tube having a very low temperature coefficient of voltage.

Conventional glow discharge tubes generally comprise a gas-filled envelope containing cathode and anode electrodes. When a direct voltage is applied between the electrodes, the current flow through the tube can vary and yet the voltage drop across the tube will remain generally uniform or will experience relatively small variations. Consequently, such tubes have been effectively employed as voltage regulating and voltage reference tubes. However, the construction of the conventional glow discharge tube does not generally adapt it for high temperature applications. For example, the conventional device cannot withstand an ambient temperature range of −65° C. to 400° C. for an extended operating life. Additionally, it has been found that the voltage drop of a device of the above-described type tends to vary considerably when the device is employed in a high temperature environment, which variations render the device ineffective as a voltage regulating or a voltage reference device in such an environment. Furthermore, in prior art devices voltage jumping, or, in other words, sudden increases in voltage drop as the glow expands and current increases, has been excessive.

My invention contemplates the provision of a glow discharge device which overcomes the above-noted difficulties and, thus, is adapted for operation as a voltage regulator or voltage reference tube over a wide ambient range of envelope temperature and substantially independently of the temperature. Additionally, my invention contemplates the provision of structure adapted for minimizing voltage jumping and for extending the effective operating life of a device.

Accordingly, the primary object of my invention is to provide a new and improved glow discharrge device, the voltage characteristic of which is substantially independent of ambient temperature.

Another object of my invention is to provide a new and improved glow discharge device adapted for use as a voltage regulator or voltage reference device over a wide ambient temperature range.

Another object of my invention is to provide an improved glow discharge device having a temperature coefficient closely approaching zero.

Another object of my invention is to provide a new and improved glow discharge device adapted for operating over an ambient temperature of approximately −65° C. to approximately 400° C. with only slight variations in voltage drop per degree centigrade and while maintaining a substantially constant voltage with variations in current.

Another object of my invention is to provide a glow discharge device adapted for application as a voltage regulator or voltage reference tube in high temperature environments without the need for special cooling or temperature controlling means.

Another object of my invention is to provide a glow discharge device including improved means for minimizing voltage jumping.

Another object of my invention is to provide a new and improved glow discharge device unit which is particularly adapted for being utilized in combination with other similar units to provide a unitary device adapted for regulating any desired high voltage.

Another object of my invention is to provide a glow discharge device which can be constructed to occupy a relatively small space without thereby being subject to adverse operating effects from either self-generated heat or high ambient temperature.

Another object of my invention is to provide a new and improved glow discharge device which is particularly rugged and adapted for withstanding high amplitudes of shock and vibration.

Still another object of my invention is to provide a new and improved glow discharge device which is relatively simple in construction, includes improved mounting and contact means and can be easily and inexpensively manufactured.

Further objects and advantages of my invention will become apparent as the following description proceeds and the features of novelty which characterize my invention will be pointed out with particularity in the claims annexed to and forming part of this specification.

In carrying out the objects of my invention I provide a glow discharge device comprising a ceramic-and-metal envelope structure containing a single highly purified inert gas at a predetermined pressure, a planar anode and a discrete cup-like cathode formed of a substantially gas-free high refractory metal. The anode and cathode can comprise wall members of the envelope. The rim of the cathode and the anode define a suitable annular breakdown gap adapted to effect a discharge at a minimum voltage. Predetermined relations between the depth and diameter of the cathode and between the volume of the cathode and the volume of the envelope, the use of predetermined electrode materials, the texture of the active surface of the cathode, and other particular structural features of the device adapt the device for desired high temperature applications. Additionally, the individual units can be combined with others to provide a unitary series construction adapted for operating capabilities not obtaining with a single unit and for heating dissipating capabilities not obtainable with prior unitary series constructions.

For a better understanding of my invention reference may be had to the accompanying drawing in which:

FIGURE 1 is a vertical cross-sectional view of a single glow discharge unit constructed in accordance with one form of my invention;

FIGURE 2 is a voltage-current characteristic curve of a device as illustrated in FIGURE 1 and constructed in accordance with my invention;

FIGURE 3 is a voltage-temperature characteristic curve of a device of the type illustrated in FIGURE 1;

FIGURE 4 is a vertical cross-sectional view of a unitary series construction including a plurality of units of FIGURE 1;

FIGURE 5 is a vertical cross-sectional view of a single glow discharge device constructed in accordance with a modified form of my invention; and

FIGURE 6 is a vertical cross sectional view of a unitary series construction including a plurality of units of FIGURE 5.

Referring to FIGURE 1, there is shown a glow discharge unit generally designated **1**. The unit **1** comprises an envelope formed by a straight cylindrical ceramic insulator **2** having planar metal discs **3** and **4** hermetically joined to the upper and lower ends thereof, respectively. The ceramic can advantageously be the spinel-forsterite ceramic disclosed and claimed in co-pending U.S. application Serial Number 831,510 of R. H. Bristow, filed August 4, 1959 and assigned to the same assignee as the present invention. Due to the known highly desirable gettering qualities of titanium the discs **3** and **4** can be advantageously formed thereof.

The disc **3** serves as a planar anode and can advantageously include an integral laterally extending tab ***3a*** for making electrical contact to the anode. Positioned in the envelope and adapted for cooperating with the anode is a discrete cup-like cathode member **5**. In this arrangement the lip or rim **6** of the cathode is predeterminedly and uniformly spaced from the anode to define an annular breakdown gap therebetween.

The cathode **5** is formed of a highly refractory metal such, for example, as molybdenum, tungsten, tantalum, niobium, rhodium, rhenium, and the softer materials such as titanium, zirconium, nickel, iron or copper. The primary requisite of the cathode material is that it be as gas-free as possible. Vacuum melted or zoned refined metals have been found particularly suitable. The cathode is bonded at the bottom thereof at **7** to the disc **4**, and the bond **7** is intentionally limited to a central restricted area of the cathode to avoid thermal expansion mismatching between these elements and associated distortions which could adversely affect the predetermined uniform spacing between the cathode rim and anode in the discharge gap defined thereby. The disc **4** can be advantageously formed with an integral tab **4a** for making electrical contact with the cathode. Additionally, a centrally threaded nut-like mounting member **4b** can be bonded to the outer surface of the disc **4** whereby the device can be rigidly mounted on a threaded stud as on a chassis of equipment incorporating the device. This arrangement provides for substantially sturdy mounting of the tube and is also effective in dissipating heat from the device. If desired the circuit through the device can be completed through the member **4b** instead of through the tab **4a**. Additionally, the member **4b** is formed to include at least a pair of diametrically opposed flat lands **4c** to enable the use of a wrench in mounting the device on a threaded stud. If provided on both discs **3** and **4** the members **4b** can be employed with one or more interconnecting threaded studs to enable easy assembly of a stacked series of the described units.

The cathode **5** includes straight cylindrical side walls and fits snuggly in the insulator **2**. Additionally, the cathode is substantially deep, with the diameter of the cathode being only approximately 1.3 times its depth. Further, the volume defined by the cooperating cathode and anode closely approaches the volume of the envelope defined by the insulator **2** and the disc **3** and **4**. Preferably the ratio between these volumes is unity or as close to unity as is practical. Still further, the active or inner surface of the cathode **5** is uniformly textured and macroscopically smooth or devoid of scratches or other markings or protrusions which would represent even small irregularities or non-uniform discontinuities in the smooth surface.

The envelope is filled with a highly purified inert gas atmosphere which is preferably neon and at a pressure in the range of approximately 40 to 60 mm. of mercury. Additionally, the atmosphere comprises only the single inert gas. The starting voltage of the device is established by selecting a cathode depth and ceramic insulator length which will provide a space between the rim **6** of the cathode and the anode disc **3** which is equal to the minimum distance for the breakdown as set by the well-known Paschen curves for the gas and pressure used.

In operation of the unit **1** at approximately 100 volts, a discharge or breakdown occurs between the rim of the cathode and the anode. This discharge initiates the formation of a glow discharge between the anode and the inner surface of the cathode in much the same manner as illustrated in the drawing and which column includes an ion sheath designated **8** spaced approximately 10 mils from the inner surface of the cathode.

As seen in FIGURE 2, the voltage of the unit **1** varies only slightly and substantially smoothly with increases in current. Due to the cup-like configuration of the cathode and the planar configuration of the anode the glow column is effective for covering substantially completely the active surface of the cathode in the manner illustrated in FIGURE 1. Thus, the glow column is not restricted to discrete areas of the cathode and is not subject to jumping from one area to another, which in prior art devices, has caused undersirable voltage jumping or abrupt changes in the volt-ampere characteristic curve. The smoothly textured active surface of the cathode also contributes to the avoidance of abrupt movements of the glow from one area of the cathode to another. I have found, for example, that scratches or slight irregularities in the active surface of the cathode can cause localization of the glow, and undesirable voltage jumps when the glow expands sufficiently to bridge the scratch or irregularity. The extremely smooth active surface provided in my structure minimizes any tendency for the glow to localize at any particular area of the cathode.

As shown by the curve A in FIGURE 3, ideally the voltage of a unit would be identical regardless of changes in ambient or wall temperature. As shown by the curve B in this figure, with my invention one can obtain a signal which is substantially constant or varies only slightly from the ideal over a substantially wide temperature range. For example, over the range of approximately −65° C. to approximately 400° C. the voltage is constant to within approximately 1%, the maximum variation being approximately 1 volt over the temperature range or only 2 to 3 millivolts per degree centigrade. Expressed another way, my invention enables the provision of a glow discharge device having a temperature coefficient of approximately 2.5 millivolts or less per degree centigrade. Thus, my device is particularly adapted, for example, as a voltage reference tube in maintaining constant to within a very small percentage, the voltage in equipment adapted for use in low as well as very high temperature environment.

A full understanding of the phenomena acting to enable the unit **1** to operate over such a wide ambient temperature range with such relatively small voltage variations as those described above is not currently had. However, the substantial stability of the above-described structure is believed attributable to the various described features in the manners now about to be discussed in detail.

Changes in ambient temperature are believed ordinarily to affect the temperature of a gas filler in a gas-filled device which is believed, in turn, to affect the voltage of such a device. More specifically, two discharge processes which are very likely to be operating in a gas-filled device and which are believed sensitive to gas temperature are charge exchange and dissociative recombination. Briefly, charge exchange processes can produce large quantities of slow ions with no disturbance of the net space charge density and tend to bring ions and gas atoms into thermal equilibrium. Dissociative recombination is more likely to occur when ions and electrons are moving slowly with respect to each other. Some measurements in the field of the above-described type of device have shown a definite inverse temperature dependence of the dissociative recombination process in the temperature range of approximately −65° C. to approximately 400° C.

The charge exchange and dissociative recombination processes may well be the dominant generation and loss mechanisms in the plasma volume between the edge of the cathode sheath **8** and the anode **3**. At the cathode boundary a sheath only a few mils thick exists across which almost all of the tube voltage develops. Enough ions are generated in this sheath to produce the electrons required by the external circuit by ion bombardment. The energies of ions and electrons in their sheath being of the order of tens of volts, are so much greater than thermal energies of a few hundredth of a volt that ambient temperature changes have little effect on processes in the region of the sheath. At the anode boundary only electrons can be absorbed plus those ions which have enough kinetic energy to move against the field. To describe these processes qualitativity at this time is quite difficult because not all aspects of the steady state D.C. discharge are understood in the art.

However, qualitativity it is reasonable to consider the voltage across the tube as determined by the cathode fall plus any additional amount required to overcome losses due to radiation, recombination and wall losses. It is believed that to achieve the proper plasma energy balance wherein temperature changes in the gas produce no effect on the total tube voltage the proper tube dimensions, geometry and filling pressure would be required so that no temperature sensitive processes such as dissociative recombination can predominate or so that a compensating phenomenon is also present. The device of FIGURE 1 is adapted for meeting these requirements and thus minimizing temperature coefficient.

In the present structure the cup-like configuration of the cathode provides for a substantial cathode area required to afford the substantial plasma volume but at the same time enables the device to be reduced in diameter for a given cathode area. It will be seen that if the cathode were fully planar rather than cup-shaped the outside diameter of the unit would be substantially increased. Additionally, the cup-like configuration of the anode and specifically the substantial depth thereof, enables the conservation of approximately ¾ of the energy which would be lost by radiation if the cathode were shallow or planar. Specifically, by being cup-shaped and of substantial depth, the cathode is adapted for trapping ions, electrons and photons and effectively utilizing the interactions of same with the gas in the device.

As pointed out above, the atmosphere of the unit is constituted of only a single gas. The presence of other gases is undesirable due to the fact that different gases can have different mobilities at the same temperature and a mixture of gases would effect variations in operating voltages with temperature changes. Thus, I have provided a cathode which is substantially gas-free and which is refractory and therefore not subject to the release of any appreciable amount of absorbed gas due to the influence of impinging ions and metastable atoms. Also, in the presently disclosed structure the side walls of the cathode serves to shield the inner surface of the insulator **2**. Thus, the plasma is prevented from "seeing" or having charged particles thereof impinge upon the ceramic and releasing impurities which could contaminate the atmosphere and result in undesirable variations in the voltage.

The cup-like configuration of the cathode and the snug fit thereof in the insulator are also effective for disposing a substantial area of the cathode member in high heat transferring relation with the wall of the ceramic insulator. Thus, the cathode is adapted for radiating substantial quantities of heat to the ceramic insulator for dissipation thereby. This has the desirable effect of reducing the internal temperature which could affect the gas atmosphere and thereby deversely affect the voltage variation. Additionally, the presently described structure reduces substantially the required dissipation through the end caps or metal discs **3** and **4** of the envelope thereby better adapting the units for being assembled in series as shown in FIGURE 4. Without this decreased dissipation through the end caps a stocked series of units would be subject to greater heating with a tendency toward adverse effects on the voltage variation.

The limited area bond **7** between the bottom of the cathode **5** and the end cap **4** is effective for holding the cathode in place and producing a heat and current conducting path to the end cap **4** without introducing distorting stresses in the end cap which could adversely affect both the seal between the end cap and the ceramic **2** and the discharge gap.

As also pointed out above, the ratio of the discharge volume to the total volume of the unit envelope is desirably as close to unity as practicable. This is to avoid local gas density variations in the vicinity of the cathode

ion sheath **8** from contributing to the total temperature coefficient.

Illustrated in FIGURE 4 is a unitary combination structure generally designated **10** and which includes a plurality of units each substantially identical to the unit **1** described above and illustrated in FIGURE 1. The combination structure **10** is adapted for employment where a higher operating voltage is desired than can be satisfactorily obtained with a single unit. The structure of FIGURE 4 comprises a plurality of devices of FIGURE 1, including the above-described predetermined single inert gas atmosphere and electrode arrangements and materials stacked in a vertical array or series. In the drawing identical numerals are used to identify elements which are identical in the structures of both FIGURES 1 and 4.

In view of the fact that there is no need for both an anode disc **3** and a cathode contact **4** for the intermediate units, a single disc **11** is provided for serving as both the anode and the element to which the cathode is bonded for adjacent units. The structure of FIGURE 4 is adapted for the same stable operation, or, in other words, a voltage characteristic substantially independent of ambient temperature, as the device of FIGURE 1 but is adapted for higher operating voltages than the previously described device. In practice, the operating voltage can be increased, as desired, by increasing the number of units stacked in the series.

FIGURE 5 illustrates a modified form of the glow discharge unit shown in FIGURE 1. The unit of FIGURE 5 is generally designated **12** and is adapted for increased cooling capacity. The unit **12** includes an anode disc **3** and a cup-like cathode **5** which can be identical to those of the unit of FIGURE 1 and, therefore, carry identical numerals. In the structure of FIGURE 5, however, the envelope of the device is completed by a short ceramic washer **13** which is sealed between the planar surface of the disc **3** and the lateral surface of the cathode rim, as at **14**. In this arrangement the rim of the cathode is inserted in the ceramic washer before sealing and to a point where the rim defines an annular breakdown gap with the planar anode. Protruding embossements **5**_a_ formed in the side wall of the cathode a predetermined distance from the rim can be utilized for controlling the insertion of the cathode in the ceramic.

The remainder of the cathode **5** is exposed to the normal atmosphere and thus is adapted for substantial heat dissipation. This has the desirable effect of reducing internal temperatures and avoiding undesirable voltage variations which can result from substantial heating of the internal gaseous atmosphere. Additionally, this structure can result in substantial cost reductions. The structure in FIGURE 5 is adapted for all the operational advantages of which the device in FIGURE 1 is capable and, additionally, because of its high heat dissipating capabilities, it is particularly adapted for use in a stacked series high voltage construction now about to be described. If desired a connector tab 3_a_ can be formed on the disc **3** in FIGURE 5. Also, if desired, a threaded nut-like mounting member 5_b_ can be employed on either or both the anode disc and cathode bottom surface for mounting the unit or enabling easy assembly of a stacked series thereof with the use of interconnecting studs.

In FIGURE 6 is illustrated a unitary combination structure designated **15** and comprising a series or stack of the units designated **12** in FIGURE 5. In this structure a plurality of the units of FIGURE 5 are stacked vertically and joined by central bonds **16** between the bottoms of the cathodes **5** and the outer planar surfaces of the anodes **3** of the adjacent units. The structure **15** is adapted for operating in the same manner as the structure **10** in FIGURE 4 but is adapted for greater heat dissipation due to the exposure of the outer walls of the cathodes **5**.

While I have shown and described specific embodiments of my invention I do not desire my invention to be limited to the particular forms shown and described and I intend by the appended claims to cover all modifications within the spirit and scope of my invention.

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

1. A glow discharge device adapted for having a voltage characteristic substantially independent of ambient temperature comprising, a hermetically sealed high refractory envelope containing an atmosphere of only a single inert gas at a pressure of approximately 40 to 60 mm. of mercury, a disc-shaped anode member, a discrete metal cup-shaped cold cathode, an annular ceramic insulator comprising a wall portion of said envelope and maintaining the rim of said cathode in predetermined spaced relation with said anode member for defining an annular breakdown gap, and said cathode having a depth closely approaching the diameter thereof and cooperating with said anode to provide a substantial glow volume which extends over the major portion of the surface of said cathode during a glow.

2. A glow discharge device according to claim 1, wherein the diameter of said cathode is approximately 1.3 times the depth thereof.

3. A glow discharge device according to claim 1, wherein the ratio of the discharge volume defined by said anode and cathode and the volume of said envelope closely approach unity.

4. A glow discharge device according to claim 1, wherein the cathode material is substantially gas-free and the inner surface of said cathode is uniformly textured and macroscopically smooth for minimizing voltage jumps.

5. A glow discharge device according to claim 1, wherein the inert gas is neon.

6. A glow discharge device comprising a straight cylindrical ceramic insulator, a metal disc bonded to each end of said insulator to provide hermetically sealed envelope, said envelope containing an atmosphere of only a single highly purified inert gas at a pressure of approximately 40 to 60 mm. of mercury, one of said discs constituting an anode, a discrete metal cup-shaped non-thermionic cathode formed of a substantially gas-free refractory metal, said cathode being positioned in said envelope with the rim thereof predeterminedly spaced relative to said anode for defining an annular breakdown gap therebetween and having the bottom surface of said cathode bonded to the other of said discs, the depth of said cathode closely approaching the diameter of said cathode, and the ratio of the volumes defined by said anode and cathode and by said envelope being approximately unity.

7. A glow discharge device according to claim 6, wherein at least said anode disc includes an integrally formed laterally extending connector tab and a threaded nut-like mounting member is bonded to the outer surface of at least said other of said discs.

8. A glow discharge device according to claim 6, wherein the bond between the bottom of said cathode and said other disc is restricted to only a relatively small central area thereof.

9. A glow discharge device comprising a unitary envelope structure including a plurality of axially aligned ceramic cylinders, a disc-like anode bonded to said adjacent cylinders and to the outer end of the endmost cylinder, providing a plurality of separate hermetically sealed compartments, each of said compartments containing an atmosphere of only a single highly purified inert gas at a pressure of approximately 40 to 50 mm. of mercury, one of the discs bonded to each cylinder constituting an anode, a discrete metal cup-shaped cold cathode formed of a substantially gas-free refractory metal position in each compartment, said cathode being positioned in said compartment with the rim thereof determinedly spaced relative to said anode for defining a breakdown gap therebetween, the bottom surface of each cathode being conductively connected to the disc opposite said anode in each compartment, the depth of each cathode closely approaching the diameter thereof and the ratio of the volume defined by each anode and cooperating cathode and the volume of the respective compartments being approximately unity.

10. A glow discharge device according to claim 9, wherein the connection between the bottom of each cathode and said disc opposite said anode is a metallic bond restricted to a relatively small central area thereof.

11. A glow discharge device comprising, a disc-like anode, a discrete cup-shaped cold cathode formed of a substantially gas-free refractory metal, a ceramic washer of substantially short length relative to the depth of said cathode bonded to said anode, said cathode being positioned in said washer with the rim thereof predeterminedly spaced from said anode to define a predetermined breakdown gap therebetween and bonded to said washer for completing a hermetically-sealed envelope, the depth of said cathode closely approaching the diameter of said cathode, the ratio of the volume defined by said anode and cathode and the volume of said envelope being approximately unity, and said envelope containing an atmosphere of only a single highly purified inert gas at a pressure of approximately 40 to 60 mm. of mercury.

12. A glow discharge device according to claim 11, wherein said disc-like anode includes an integrally formed laterally extending connector tab and a threaded nut-like mounting member is bonded to the outer surface of the bottom of said cup-shaped cathode.

13. A glow discharge device comprising a unitary structure including a plurality of axially spaced disc-like anode members, each anode member having a cup-shaped cold cathode associated therewith and formed of a substantially gas-free refractory metal, a ceramic washer of substantially short length relative to the depth of said cathode bonded to said anode member, each said washer having the rim of one said cathodes positioned therein in predetermined spaced relation with its associated anode for defining a predetermined breakdown gap and bonded to said washer for completing a hermetically-sealed compartment, the depth of said cathode closely approaching the diameter of said cathode, the ratio of the volume defined by each said anode member and its associated cathode and the volume of said compartment being approximately unity, the bottom of each said cathode being conductively connected to the next adjacent anode member, and said compartments being axially aligned and each containing an atmosphere of only a single highly purified inert gas at a pressure of approximately 40 to 60 mm. of mercury.

14. A glow discharge device according to claim 13 wherein the connection between the bottom of each cathode and the adjacent anode member is a metallic bond restricted to a relatively small central area thereof.

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