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GAS DISCHARGE DEVICES

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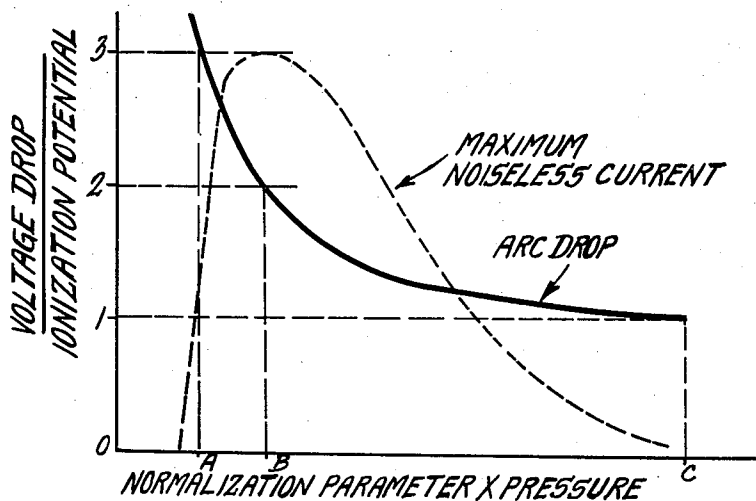
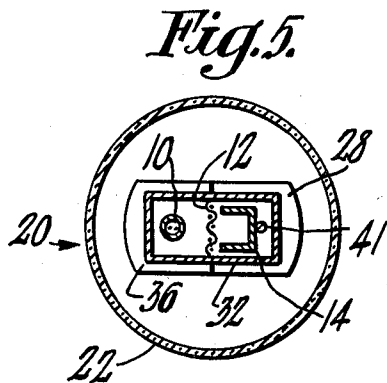
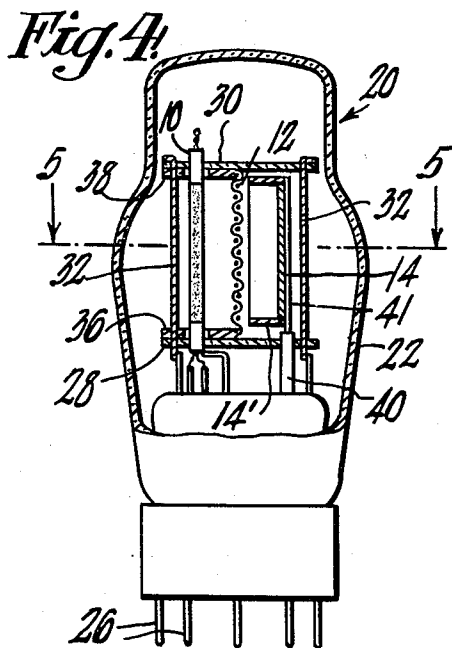
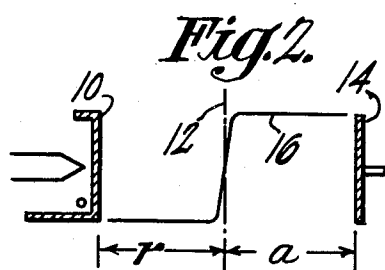
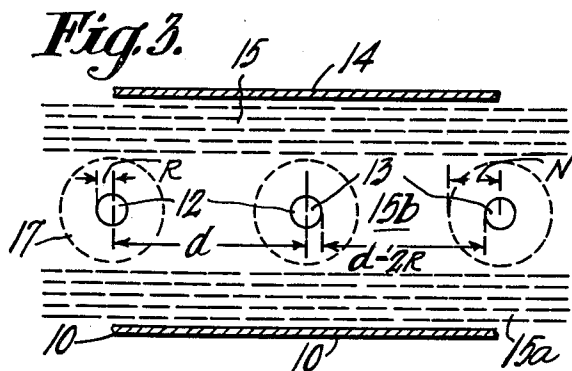


Fig. 1.



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GAS DISCHARGE DEVICES

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10 Claims. (Cl. 313—191)

This invention relates to improvements in gas discharge devices, or tubes, of the noise-free variety described in a copending application of W. M. Webster et al., Serial Number 404,981, filed January 19, 1954.

In gas tubes constructed in accordance with the above identified copending application substantially all of the arc voltage drop across the device occurs in the plane of a control electrode. Due to this unusual location of the arc voltage the shielding of the various electrodes is extremely critical to prevent other types of discharges from occurring around the control electrode. Furthermore, when the required shielding is present in the devices of this type there are large surfaces of shielding elements which are exposed to the plasma, i. e., to a concentration of positive ions and free electrons of substantially equal densities. With the shielding elements exposed to the plasma, and when a negative potential is applied to the shield and the control electrode for purposes of cutting off the flow of current, input power losses may occur by reason of the relatively large positive ion current which is drawn to the shield.

It is therefore an object of this invention to provide a new and improved gas discharge device that is substantially noise free in operation and which includes a control electrode that is capable of on-off control.

Another object of this invention is to provide a new and improved gas discharge device that is efficient in operation.

A further object of this invention is to provide a new and novel gas discharge device that is adequately shielded to prevent spurious gas discharges from occurring.

These and other objects are accomplished in accordance with this invention by providing a gas discharge device including a cathode, a control electrode and an anode. Surrounding all of the electrodes and extending to the control electrode is a shield electrode. The electrodes are supported between two insulating spacers in such a manner as to prevent spurious gas discharge from occurring. Due to a novel shape of the anode, large areas of the plasma are not exposed to large areas of the shielding structure. In devices constructed in accordance with this invention there is a correlation between (1) the type of ionizable medium, (2) the pressure of the ionizable medium, (3) the control electrode to anode spacing, (4) the control electrode to cathode spacing, and (5) the size of the apertures in the control electrode. These items are so correlated that the device operates in only one type of discharge, i. e., wherein the arc drop across the device occurs within the plane of the control electrode, which is substantially noise free and which is capable of being extinguished by the application of potentials to the control electrode.

The above objects and other features and advantages of this invention will best be understood from the follow-

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ing description of the illustrated embodiment of this invention when read in connection with the accompanying single sheet of drawings and in which:

Figure 1 is a graph of a ratio of the arc voltage drop and the ionization potential versus a product of the normalization parameter and the pressure: superimposed on this graph, in dotted lines, is a graph representing the maximum noiseless current through the device versus the product of the normalization parameter and the pressure.

Figure 2 is a schematic diagram of the potential distribution along the conducting path existing in gas discharge devices in accordance with this invention;

Figure 3 is an enlarged fragmentary view of a discharge device in accordance with this invention showing some of the principles that are to be considered herein;

Figure 4 is a transverse sectional view of a gas discharge device in accordance with this invention; and

Figure 5 is a plan sectional view taken along line 5—5 of Figure 4.

Referring now to Figure 1 for a consideration of the parameters necessary to construct a gas tube in accordance with this invention, there is plotted, as a solid line, a ratio of the voltage drop "V" across the device to the ionization potential "V_i" of the ionizable medium enclosed therein versus the product of a normalization parameter "K" times the pressure "P" of the ionizable medium utilized.

The vast majority of the devices can be placed along the curve if the proper value of the normalization parameter "K" is determined by the following equation:

$$\text{Equation 1} \quad K = W\sqrt{a}Or$$

where:

"W" is a constant determined by the type of ionizable medium as will be hereinafter described;

"a" is spacing between an apertured electrode and an anode in cm.;

"O" is the optical transparency of the apertured electrode or when possible, the effective transparency; and

"r" is the spacing between a cathode and an apertured electrode expressed in cm.

The optical transparency is a ratio of the area of the openings to the total area of the apertured electrode, while the effective transparency takes into consideration the sheath thickness as will be explained hereinafter.

The normalization parameter "K" is a parameter that has been determined to relate the various types of gas discharge devices so that a noise free tube is developed without the necessity of utilizing widely different calculations for the various types, or applications, of gas discharge devices.

The curve, as shown in Figure 1, is a graphic representation of the noise free region wherein a control electrode is capable of initiating and extinguishing a gas discharge. The curve is applicable to a great number of various structures that have been constructed and tested. It should be noted that noise will be present in the device, also the grid will not be capable of extinguishing the gas discharge, unless the pressure of the gaseous atmosphere lies between certain points. One of these points is encountered when V/V_i is greater than 3 and has to do with the nature of the ionizing processes. While the details of the mechanisms producing noise at low pressures are not well understood, the minimum pressure that may be used in a noise free gas discharge device constructed in accordance with this invention has been determined. This

minimum pressure is expressed by the following relation:
Minimum pressure in mm. of Hg.

$$\text{Equation 2} \quad P > \frac{.014}{W\sqrt{arO}}$$

where:

"W" is a constant determined by the type of ionizable medium as explained hereinafter;
"a" is the apertured electrode to anode spacing expressed in cm.;
"r" is the cathode to apertured electrode spacing expressed in cm.; and
"O" is the optical transparency or where possible, the effective transparency.

The width of the noise free, on-off region for most efficient operation of a device in accordance with this invention depends upon the size of the apertures in the apertured electrode. For large size apertures in the apertured electrode, the apertures still being less than the mean free path of the plasma particles, the noise free, on-off region is small. For smaller size apertures the region is much greater, and it has been found to include a pressure range as great as 10 to 1. It has been found that a mesh having about 200 apertures per square inch gives such a small region as to be comparatively useless for a noise free device. Due to manufacturing problems, the other extreme, i. e., a very fine mesh, is impractical also. It has been found that mesh sizes between 400 and 3,000 apertures per square inch will generally give the best results. This invention is not to be limited to these values but they are given merely as practical limits.

The other limit on the construction of the device is where the largest dimension of the apertures in the apertured electrode exceeds the mean free path of the plasma particles. Since mean free path is inversely related to pressure, this criterion places an upper limit on pressure for a given size foramina—or an upper limit on foramina dimension for a given gas pressure. A constant "G" may be defined to relate mean free path to pressure for various gases and the upper pressure limit may then be expressed mathematically in terms of "G" and the foramina dimensions by the relation:

Square foramina

$$\text{Equation 3} \quad P < \frac{G}{2(d-2R)}$$

where:

"G" is the mean free path in cm. of an electron of ionizing energy at a pressure of 1 mm. of Hg;
"d" is the distance between wires measured from center to center and expressed in cm.; and
"R" is the radius of the wire expressed in cm.

Round foramina

$$\text{Equation 4} \quad P < \frac{G}{2S}$$

where "S" is the radius of the foramina.

In Equations 3 and 4, "G" is determined by the type of ionizable medium and may be found by referring to any of the standard gaseous conductor handbooks or by the following table:

Table #1

Gas	"G"
Helium	.12
Argon	.014
Xenon	.007
Neon	.083
Krypton	.011

The type of ionizable medium determines the gas constant "W." It is known that "W" includes the differential ionization coefficient and a ratio of the ion mean free path length to an electron mean free path length

at the energy level involved. An experimental method of determining "W" is described in the above identified copending application.

If it is desired, one of the following ionizable mediums may be used for which the gas constant "W" has been determined and is as follows:

Table #2

Gas	"W"
Helium	is 1.8
Neon	is 1.8
Argon	is 13
Xenon	is 25

The point "A" on the graph of Figure 1 occurs at the point where the product of the normalization parameter "K" times the pressure "P" equals .02, point "B" occurs at .07, and point "C" occurs in the neighborhood of 0.2. For the above mentioned values the pressure is expressed in millimeters of mercury. The value for "K" was determined partially by analysis and largely by empirical means and has been tested for 0.1 cm. < "r" < 1.5 cm.; .1 cm. < "a" < 3 cm.; and .1 < "O" < 1.

As can be seen from Figure 1, the maximum noise free current, i. e., the dotted curve, increases as the pressure decreases until the pressure is approximately 40 microns where the maximum noise free current capable of on-off control decreases slowly to zero. Since the arc voltage drop across the device decreases as the gas pressure increases, for a device to be practical, a compromise must be made between the maximum noise free current and the minimum arc voltage drop. It is for this reason that this invention is preferably utilized in the gas pressure range of 30 to 120 microns which permits a maximum noise free current of 400 to 200 milliamperes respectively.

Referring now to Figure 2, there is shown a schematic representation of a gas discharge device for a consideration of the parameters necessary to obtain the noise free current shown in Figure 1. In Figure 2 there is shown schematically a cathode 10, which may be of the conventional thermionic type of oxide coated cathode, an apertured control electrode 12, and an anode 14. The distribution of space potential between these electrodes is shown as a line 16. The space-potential diagram shown is the type of distribution attained for a noise free, on-off device constructed in accordance with this invention. It should be noted that the potential drop between the cathode 10 and anode 14, commonly referred to as the arc voltage drop, is almost entirely within a smooth plane located at the apertured electrode. When operating properly, one sees a glow uniformly filling the region between the apertured electrode 12 and the anode 14. While the region between cathode 10 and apertured electrode 12 should be "dark."

Due to the fact that the arc drop is made to occur in the plane of the apertured electrode 12, control over the gas discharge is obtained. When a potential that is negative with respect to the cathode is applied to the apertured electrode, the positive ion sheaths surrounding each individual wire of the control electrode overlap to cut off current flow between the cathode and anode. The potential required to cut off current flow depends upon the potential applied between the cathode and anode, and also the current being conducted as is explained more fully in the above identified copending application. It has been determined that the cut off time for devices of this nature is of the order of .5 of a microsecond or less.

Referring now to Figure 3 for a consideration of the items necessary to attain the space potential distribution shown in Figure 2, there is shown an enlarged fragmentary sectional view of a screen, or mesh, type of apertured electrode 12 while in a discharge device that is conducting. Proximate the apertured electrode 12 on both sides is a region of plasma, 15 and 15a. A plasma is a con-

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centrated region of equal densities of free electrons and positive ions which is consequently nearly equipotential. The openings, or foramina, between adjacent wires 13 are smaller than the length of the mean free path of the plasma particles. Due to the fact that the openings are smaller than the mean free path of the plasma particles, what might have been a continuous plasma, is divided into two separate plasmas, i. e., the anode plasma 15, and the cathode plasma 15a. Plasma region 15 lies between the apertured electrode 12 and the anode 14 of the discharge, and plasma region 15a lies between the cathode 10 and apertured electrode 12. Region 15 has a space potential nearly that of the anode electrode 14 while the potential of plasma region 15a is slightly negative with respect to the surface of cathode 10.

Between the two regions of plasma is a region of high electric field 15b, which extends through the foramina of the electrode 12. The positive ions which diffuse through plasma region 15 to the edge of region 15b are accelerated by the field in the direction of region 15a. Likewise electrons which diffuse to the edge of region 15a are accelerated in the direction of region 15. Some ions and electrons are intercepted by electrode 12, the remainder passing completely through the region 15b. The fraction of the electrons and ions intercepted is not only related to the optical transparency of the apertured electrode 12 but is more directly determined by the sheaths which surround the individual members (e. g. wires) which constitute the electrode 12. That is to say, the effective size of the foramina for penetration of ions and electrons is less than the actual size. Such sheaths are regions containing only positive ions, or negative electrons, en route to the electrode. A more detailed and complete explanation of the plasma, and sheaths, may be found in an article entitled, "Rapid determination of gas discharge constants from probe data" by Malter and Webster appearing in the RCA Review, volume 12, Number 2, June 1951.

Normally the effective transparency of an apertured electrode is somewhat less than the optical transparency. Thus the optical transparency for a mesh type of apertured electrode is equal to:

Square foramina

$$\text{Equation 5} \quad \frac{(d-2R)^2}{d^2}$$

where:

"d" is the distance between wires measured from center to center and expressed in cm.; and
"R" is the radius of an individual wire.

Round foramina

$$\text{Equation 6} \quad \frac{n^2 \pi S^2}{\text{cm.}^2}$$

where:

"n" is the number of foramina per square cm.; and
"S" is the radius of a foramina in cm.

Thus with the wire spacing "d," and the wire radius "R," the width of each foramina is "d-2R" as shown in Figure 3.

If the calculation of the transparency of an apertured electrode is to be completely accurate, the effective transparency "O" is calculated, i. e., the sheath thickness should also be taken into account so that the width of each square foramina is "d-2R-2N": where "N" is the thickness of a single sheath 17 measured from the edge of a wire 13 to the edge of its surrounding sheath 17 and expressed in cm.

The sheath thickness "N" varies with the voltage that is applied to the apertured electrode 12, as well as with certain other factors. However, in some instances it is possible to make a reasonable calculation of the sheath

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thickness "N". A method of calculating, to a first approximation, the sheath thickness "N" is found in the above-identified article by Malter and Webster, volume 12, Number 2 of the June 1951 RCA Review. An example of when this may be done is when the voltage applied to the apertured electrode 12 remains constant. When the sheath thickness "N" can be so computed, the effective transparency "O" of the apertured electrode 12 is used which is:

Square foramina

$$\text{Equation 7} \quad O = \frac{(d-2R-2N)^2}{d^2}$$

15 where:

"O" is the effective transparency;
"d" is the distance between wires measured from center to center and expressed in cm.;
"R" is the radius of an individual wire; and
"N" is the thickness of a single sheath measured from the edge of a wire to the edge of its surrounding sheath and expressed in cm.

Round foramina

$$\text{Equation 8} \quad O = \frac{n^2 \pi (S-N)^2}{(1 \text{ cm.})^2}$$

where:

30 "O" is the effective transparency;
"n" is the number of foramina per square cm.;
"S" is the radius of foramina; and
"N" is the sheath thickness expressed in cm.

35 Values of "O" for common sizes of mesh type apertured electrodes have been obtained from the wire spacing, wire diameter, and an estimate of sheath thickness are as follows:

Table #3

Number of Mesh Wires	Optical Transparency	Effective Transparency to ions "O"
45 16x16	.66	.65
24x24	.56	.52
40x40	.60	.25
50x50	.33	.10

50 It should be understood that other expressions for the dimensions, i. e., inches etc., may be used for the above formulas as long as all dimensions are expressed in the same scale.

The sheath thickness "N" is a second order consideration so that it may often be neglected if a variable voltage is to be applied to the electrode 12 or if some other feature of the device is present that will vary the sheath thickness "N" and thus make calculations extremely difficult. When the sheath thickness "N" is neglected, the design structure as given by this invention will usually be sufficiently exact.

Referring now to Figures 4 and 5, there is shown a gas discharge device 20 constructed in accordance with this invention. The device 20 comprises a sealed envelope which is processed in the usual manner and filled with an ionizable medium. Any ionizable medium may be utilized for which the constant "W" (of Equation 1) is known or has been calculated. In the specific tube described, the ionizable medium utilized is xenon for which the constant "W" is 13 from Table 2.

Supported within the device 20 is a cathode 10, a control electrode, or grid, 12 and an anode 14. The electrodes are supported by lead-ins 26 extending through a re-entrant portion 24 of envelope 20. The electrodes are supported between a pair of insulating spacers 28 and 30

which are covered in the area adjacent cathode 10 by metallic members 36 and 38 respectively. The metallic members 36 and 38 are utilized in the device 20 adjacent the cathode 10 in order to eliminate the building up of floating charges on the insulating members 28 and 30, and also to prevent leakage.

The electrodes in device 20 are surrounded by a shield element 32 which is connected to the metallic members 36 and 38 as well as to control electrode 12. As can be seen more clearly in Figure 5, the control electrode spans the entire space between the cathode 10 and the anode 14 and divides the space surrounded by shield 32 into two compartments. The purpose of surrounding the entire discharge space with the shield element 32 and the insulating members 28 and 30 is to insure that no leakage paths are available for spurious discharges to occur, i. e., for discharges of a type other than that schematically shown in Figure 2.

As can be seen from Figures 4 and 5, the anode lead-in rod 41 is surrounded by a tubular glass member 40 which is to prevent spurious discharges from occurring to the anode wire 41. The tubular glass member, or pant leg 40, may be touching the anode lead-in rod 41 although this is not necessary. The pant leg 40 extends through insulating member 28 and may be closely spaced therefrom. The anode 14 is a hollow box-shaped metallic member, which is closely spaced from the inside of shield element 32 and from the top and bottom insulating members 28 and 30 respectively. The spacing between all portions of the anode 14 and all adjacent portions of the shield 32, as well as between the anode 14 and the insulating members 28 and 30, is preferably less than the mean free path of the plasma particles. This close spacing is to prevent the anode plasma 15 (Figure 3) from diffusing around the anode 14. If desired insulating tabs (not shown) may be inserted intermediate the anode 14 and the shield 32 to add additional mechanical strength to the structures. The anode is supported by means of a lead-in wire, or rod 41.

When a negative potential is placed on the control grid 12 to cut off current flow in the device 20, a large area of plasma, at a relatively high positive potential (see Figure 2), would normally be adjacent the shield 32 and the insulating members 28 and 30 on the anode side of grid 12. If this large area of plasma were adjacent the negative shield 32, a large number of positive ions would diffuse to the shield 32 resulting in an input power loss. However, due to the hollow box shape of anode 14, and the close spacing between anode 14 and the shield 32, the positive ions generated by the device 20 firing are not attracted to the negative shield. The purpose of the end areas 14' on anode 14 is to prevent the build up of an electrical charge on the insulating members 28 and 30. When it is desired to simplify the geometry of device 20 for mass production, the ends 14' of the anode may be omitted which results in a substantially U-shaped anode.

As can be seen from Figure 2, it is not necessary to shield the cathode plasma from the negative shield to make an efficient device for the cathode plasma is approximately at cathode potential which is already negative. However, metallic members 36 and 38 are preferably utilized in order to eliminate the building up of floating charges on the insulating members 28 and 30.

The specific structure shown utilizes a cathode 10 having a diameter of 50 mils, a control grid 12 of stainless steel mesh of 50 x 50 using 7 mil wire size, which has an effective transparency of 0.1, and a stainless steel anode 14 that is .25 inch deep, .145 inch wide, and .75 inch long. The spacing between the cathode 10 and the grid 12 is .210 inch while the spacing between the grid 12 and inside of the anode 14 is .382 inch.

For the specific structure shown, and using xenon, the minimum pressure is: using Equation 2, Table #2 for "W," and Table #3 for "O":

$$P_{\min} > \frac{.014}{(25)\sqrt{2.54 \times .382(.210 \times 2.54)(.10)}} = 10.7 \text{ microns}$$

The maximum pressure is, using Equation 3:

$$P < \frac{.007}{2(d-2R)} = \frac{.007}{2(2.54)(.02-.007)} = 113 \text{ microns}$$

Therefore, the pressure range for the device 20 is between 10.7 microns or 113 microns. The graph of Figure 1 shows as a dotted line a graph of the maximum noise free current which can be drawn through the device. In view of the necessary compromise between arc voltage drop and maximum current a gas filling of xenon at a pressure of 45 microns is preferably utilized in the specific structure described.

What is claimed is:

1. A noise free gas discharge device comprising a sealed envelope having an ionizable medium therein, a hollow conductive shielding element supported within said envelope, an apertured control electrode dividing the space enclosed by said shielding element into two compartments, a cathode in the first of said compartments, an anode in the other of said compartments, the size of the apertures in said apertured control electrode being less than the mean free path of the electrons of said ionizable medium, and the electrode geometry of said device being such that the ratio of the arc voltage drop to the ionization potential is less than 3.

2. A gas discharge device as in claim 1 wherein said anode is hollow and has an open area adjacent said control electrode.

3. A gas discharge device as in claim 1 wherein all of said electrodes are supported between a pair of insulating members, a pair of conducting shields, and each of said conduction shields covering one of said insulating members adjacent to said first of said compartments.

4. A substantially noise free gas discharge device comprising an envelope containing an ionizable medium having a given ionization potential, a hollow shield electrode within said envelope, an apertured control grid connected to the inside of said shield electrode and dividing the space surrounded by said shield electrode into two compartments, the size of the apertures in said control grid being less than the mean free path of the electrons of said ionizable medium, a thermionic cathode in one of said compartments and spaced from said shield, an anode in the other of said compartments substantially conforming to the shape of said shield and closely spaced from the inner walls of said shield, and means for establishing a discharge between said cathode and said anode and through said control grid, said discharge having a voltage drop such that the ratio of said voltage drop to said ionization potential is less than 3.

5. A substantially noise free gas discharge device comprising an envelope containing an ionizable medium having a given ionization potential, a hollow elongated shield electrode within said envelope, a pair of insulating members each closing one end of said shield electrode, an apertured control electrode connected to the inside of said shield electrode and extending to both of said insulating members to divide the space surrounded by said shield electrode into two compartments, a cathode in the first of said compartments, a pair of conductive members each covering one of said insulating members in said first compartment and connected to said shield electrode, an anode in the other of said compartments, said anode being hollow and having an open area facing said control electrode, and said anode substantially conforming to the shape of said other compartment and closely spaced from said shield electrode.

6. A gas discharge device as in claim 5 wherein the apertures in said apertured control electrode are less than the mean free path of the electrons of said ionizable

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medium, and the electrode geometry of said device is such that the ratio of the arc voltage drop to said ionization potential is less than 3.

7. A gas discharge device as in claim 5 wherein the pressure of said ionizable medium is within the range determined by the following relationship:

$$\frac{.014}{W\sqrt{arO}} < P < \frac{G}{(d-2R)\sqrt{2}}$$

where:

"P" is a range of pressures expressed in mm. of mercury;
 "W" is a constant determined by the type of said ionizable medium;

"a" is distance in cm. between said apertured control electrode and said anode;

"r" is the spacing in cm. between said apertured control electrode and said cathode;

"O" is the effective transparency of said apertured electrode;

"G" is the mean free path in cm. of an electron of ionizing energy at a pressure of 1 mm. of mercury;

"d" is the distance in cm. between adjacent solid portions of said apertured electrode measured from center to center; and

"R" is the radius in cm. of said solid portions of said apertured electrode.

8. A noise free gas discharge device comprising an envelope containing an ionizable medium having a given ionization potential, a hollow elongated shield electrode within said envelope, an apertured control electrode connected to the inside of said shield electrode and dividing the space enclosed thereby into two compartments, a thermionic cathode in one of said compartments, an anode in the other of said compartments, said anode being substantially U-shaped and having the open area adjacent to

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said control electrode, and said anode being closely spaced adjacent to said shield electrode.

9. A gas discharge device as in claim 8 wherein the apertures in said apertured control electrode are less than the mean free path of the electrons of said ionizable medium, and the electrode geometry of said device is such that the ratio of the arc voltage drop to said ionization potential is less than 3.

10. A gas discharge device as in claim 8 where:

$$\frac{.014}{W\sqrt{arO}} < P < \frac{G}{(d-2R)\sqrt{2}}$$

where:

"P" is a range of pressures expressed in mm. of mercury;
 "W" is a constant determined by the type of said ionizable medium;

"a" is distance in cm. between said apertured control electrode and said anode;

"r" is the spacing in cm. between said apertured control electrode and said cathode;

"O" is the effective transparency of said apertured electrode;

"G" is the mean free path in cm. of an electron of ionizing energy at a pressure of 1 mm. of mercury;

"d" is the distance in cm. between adjacent solid portions of said apertured electrode measured from center to center; and

"R" is the radius in cm. of said solid portions of said apertured electrode.

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