

June 29, 1948.

P. W. STUTSMAN
GASEOUS ELECTRICAL SPACE DISCHARGE
DEVICES AND CIRCUITS THEREFOR

2,444,072

Filed Oct. 8, 1942

3 Sheets-Sheet 1

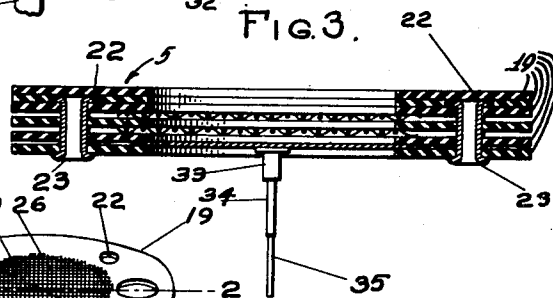
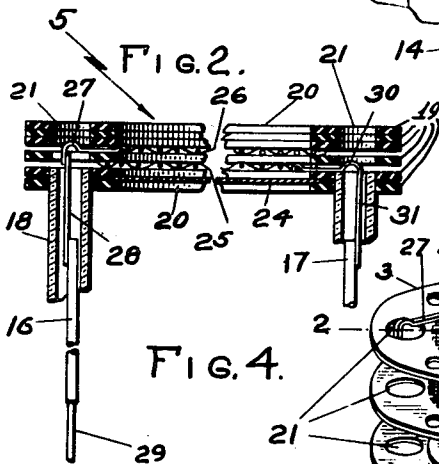
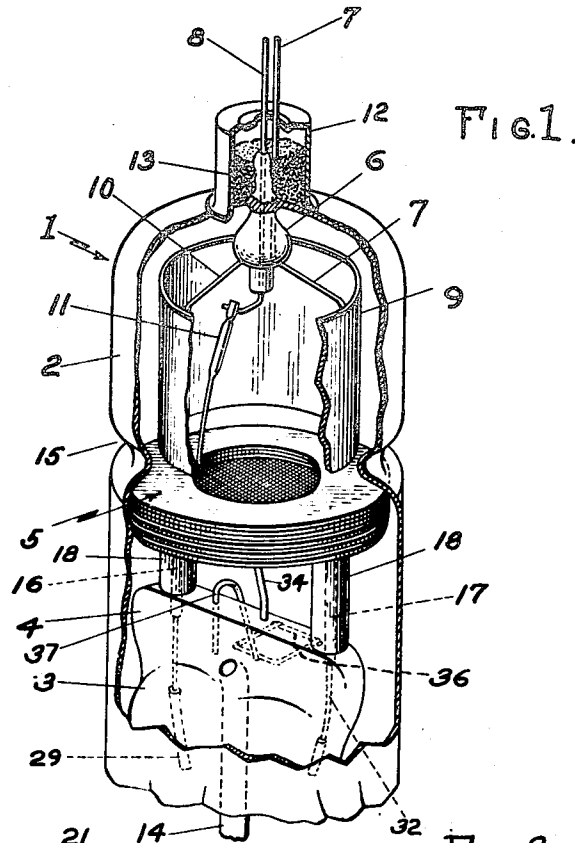
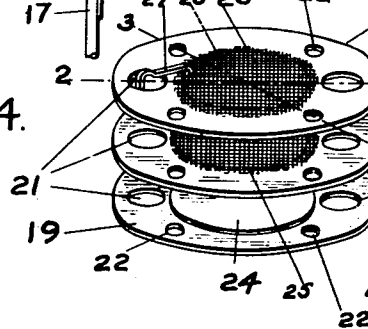


FIG. 4.



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FIG. 5.

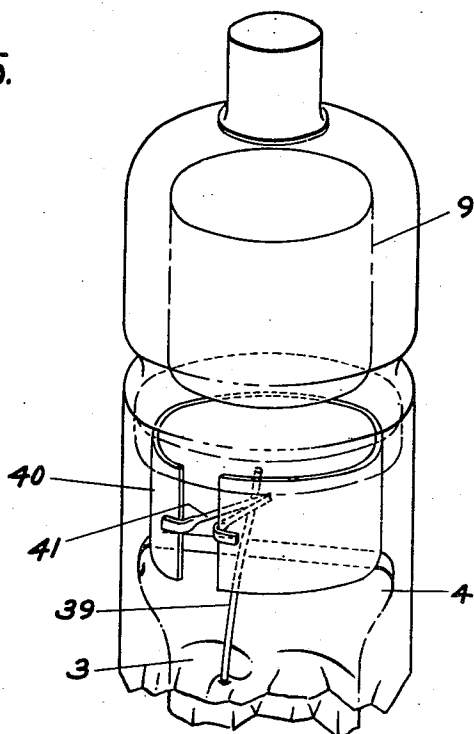


FIG. 6.

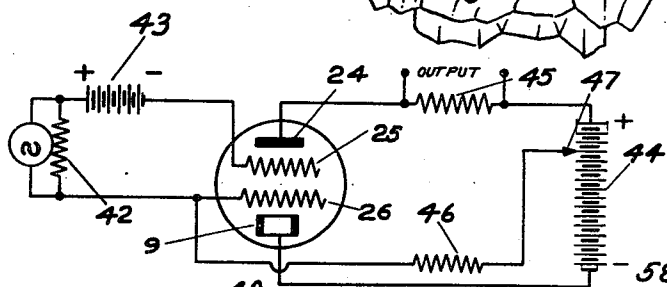
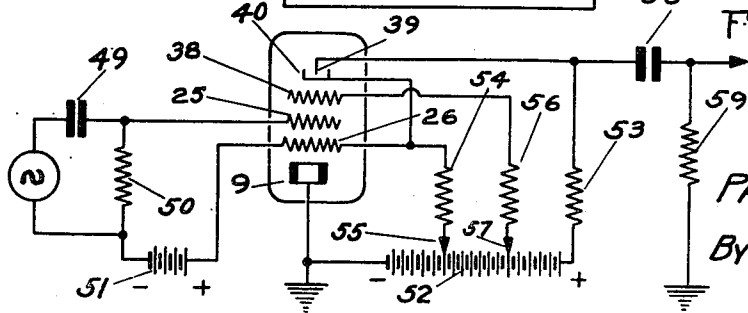


FIG. 7.



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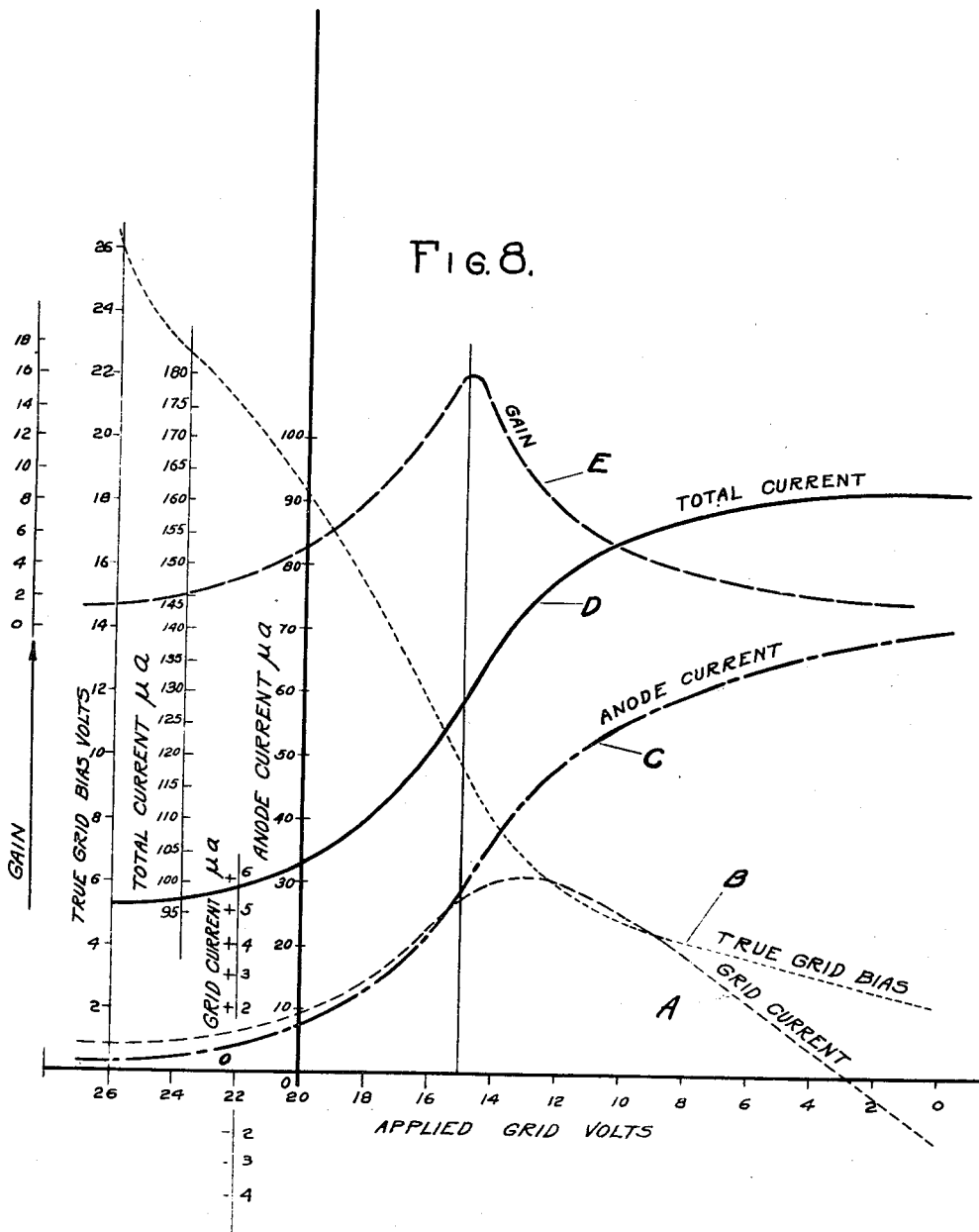
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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,444,072

GASEOUS ELECTRICAL SPACE DISCHARGE
DEVICES AND CIRCUITS THEREFOR

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Application October 8, 1942, Serial No. 461,288

21 Claims. (Cl. 250—27.5)

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This invention relates to grid-controlled gaseous electrical space discharge devices of the type in which conduction therein is subject to a continuous control by the grid similar to that exercised by the grids in high vacuum tubes. Devices of this type are described in Patent No. 1,962,158 of Charles G. Smith, and in Patent No. 1,962,159 of James D. Le Van. This invention also relates to circuits for such devices.

In certain applications it is desirable that amplifying circuits employing electrical space discharge devices should have low power requirements. One such application occurs when such circuits are operated at isolated places where power from a supply line or from a local generator is unobtainable, and where the batteries which must be used as the power supply source cannot readily be replaced.

These above-mentioned conditions are most frequently encountered in connection with amplifying circuits which are used for standby purposes, that is circuits that must be ready over long periods of time to receive and amplify signals. Usually the length of time during which signals are received in such systems is insignificant compared to the length of the standby periods. Consequently the total energy consumed during the periods in which signals are received is relatively so small as to be negligible. It is principally during the long standby periods that the current drain must be kept at a minimum. The optimum condition would be one in which the standby current drain would be so low that the life of the batteries supplying energy to the system would not be substantially shorter than their normal shelf life. Where dry-cell batteries of standard types are employed, the current drain of such a circuit would have to be of the order of microamperes in order to approach such optimum condition.

The design and parameters of such a circuit are dependent upon the characteristics and constants of the electrical space discharge device which is to be employed therein. The current drain of such circuit is likewise dependent upon the electrical space discharge device. Since the current or power requirements of such circuit are dependent upon the tube employed, these will be hereinafter referred to as the current or power requirements of the tube, it being implied that the tube is arranged in a suitably designed circuit, and that the current or power required is that needed for the proper operation of the circuit and the tube included therein.

An object of this invention is the provision of a

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grid-controlled gaseous tube of the type described whose current requirements are so small that the life of standard types of dry-cell battery used with such tube is not substantially reduced by standby use below the normal shelf life thereof.

Another object of the present invention is the provision of a tube of the type described which, together with the circuit in which it is arranged, has a current drain of the order of microamperes.

It is to be understood, of course, that where the circuit is employed for standby purposes a greater current drain than that herein indicated may occur during the time signals are being received.

One of the difficulties heretofore encountered in designing tubes, having small current requirements of the order of magnitude here mentioned, is that when the wattage supplied to such tubes and their circuits is decreased, the voltage gain obtained from said circuits is also decreased. A further object of the present invention is the provision of a tube of the type described which has the small current requirements just described and with which a large voltage gain may be obtained.

As the power requirements of a circuit including a tube are reduced, the proportion of the power consumed in heating the cathode of such tube to produce the required emission increases. The power required for such heating has therefore made it difficult to obtain low power consumption in such systems. To avoid this limitation another object of this invention is the provision of a tube of the type described which utilizes a cold cathode. By the term "cold cathode" as used in this specification and the claims, I mean a cathode which operates at a temperature below the temperature at which substantial thermionic emission occurs. Therefore no external source of current is required for the purpose of heating the cathode.

The gaseous type tubes referred to herein are of the glow discharge type. Such tubes have heretofore found their main application when operating with the so-called "normal glow." In this specification I refer to the so-called "normal glow" as that discharge in which the cathode surface, the nature of the gas, and its pressure are so related to the current carried by the cathode that the discharge emanates from a portion of the cathode less than the total active area thereof, said portion of the cathode having a constant current density throughout this normal glow discharge region. In other words, in such a normal glow when the current is varied the portion of the cathode surface, which participates in the emission of electrons, varies so as to maintain this constant current density.

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In accordance with my invention I have discovered a different glow discharge region which I will term the subnormal glow region. In this region I have found that if the characteristics of the cathode surface are related to the nature of the gas used and its pressure, currents of the order of microamperes may be drawn from a relatively large cathode and the entire active cathode surface will participate in the passage of the current. The appearance of the cathode surface under these conditions is that the entire surface is covered with a very low intensity luminous glow spaced, however, a short distance from the cathode and overlying the entire active cathode surface. Variations in this subnormal current glow do not change the total surface of the cathode which thus participates in the discharge, and therefore the current density of the cathode varies in contradistinction to the conditions which exist in the normal glow discharge. It is particularly desirable in operating with the subnormal glow to have the cathode activated uniformly throughout its surface so as to have as large an effective active surface of the cathode as possible.

If in a normal glow discharge an attempt is made to reduce the current drawn from the cathode to the order of microamperes such as are involved in the present invention, I have found that such discharge tends to become extinguished probably due to the existence of a very steep negative voltage-current characteristic. If an attempt is made to maintain the current under these conditions by using higher values of voltage and resistance in series with the discharge, the power losses in the system rise to undesirable values. In the subnormal glow, however, this negative voltage-current characteristic is much less steep and, when using the preferred gases and pressure, is substantially non-existent to the point where it is very difficult to detect.

A still further object of this invention is the provision of an improved construction of tubes of the type described.

Still another object of this invention is the provision of circuits for tubes of the character described.

Other and further objects and advantages of this invention will become apparent and the foregoing will be best understood from the following description of exemplifications thereof, reference being had to the drawings in which:

Fig. 1 is a broken-away perspective view of a tube embodying my invention;

Fig. 2 is a sectional view of the mount assembly illustrated in Fig. 1 taken along the line 2—2 of Fig. 4;

Fig. 3 is a view similar to Fig. 2 taken along the line 3—3 of Fig. 4;

Fig. 4 is an exploded perspective view of the mount assembly of Fig. 1;

Fig. 5 is a perspective view partly in outline, of a modified form of a tube embodying my invention;

Fig. 6 is a schematic diagram of an amplifying circuit including a tube of the type illustrated in Fig. 1;

Fig. 7 is a schematic diagram of an amplifying circuit including a tube of the type illustrated in Fig. 5; and

Fig. 8 is a graph indicating various characteristics of a tube such as that illustrated in Fig. 1 when employed in a circuit such as that illustrated in Fig. 6.

Referring now to the embodiment illustrated in

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Figs. 1-4 and particularly to Fig. 1, the tube 1 there illustrated includes an elongated envelope 2 having a reentrant stem 3 formed at one end thereof at the top of which a press 4 supports the mount assembly 5. Through the opposite or upper end of the envelope 2 a glass bead 6 is sealed. A pair of conductors 7 and 8 are arranged within the glass bead 6, conductor 7 serving as the lead-in to the cathode 9, and conductor 8 being connected to a getter, as will be hereinafter described. The cathode 9 is preferably a relatively large hollow cylinder open at both ends thereof, and is suspended from the glass bead 6 by a plurality of supporting wires 10 each having one end thereof sealed in the glass bead 6 and the other end thereof attached to the top of the cathode. The walls of the cathode 9 are substantially parallel to the side walls of the envelope 2 and are of relatively large area. In one embodiment the cathode had a height of $\frac{1}{2}$ inch and a diameter of $\frac{3}{4}$ inch. It has been found that when the opening through cathode 9 is unobstructed better operation is achieved than when a cover is placed across the top or bottom of the cathode.

The cathode 9 may be formed of sheet metal, preferably of nickel, and is subsequently oxidized to form a coating of nickel oxide on the surface thereof. Particles of thorium oxide are pounded into the surface of the metal. This thorium oxide aids in producing a constant low starting-voltage characteristic for the tube. This is believed to be due in part to the ionization produced by the radio-activity thereof. Any other non-gasifying radioactive substance may be used for this purpose and it is not necessary that this radioactive substance be arranged on the cathode, though this arrangement is preferred. The nickel sheet is stamped out, bent into the form of a cylinder, and oxidized in air to form a coating of nickel oxide.

The surface of the cylinder is next coated with one of the alkaline earth metals or alkali metals, hereinafter termed alkaline metals. I prefer to use pure barium. The source of this barium may be a getter of the type commercially known as a "batalum getter." The batalum getter 11 has one end thereof connected to the lower end of the cathode 9, and the upper end of said getter may be connected with the conductor 8. By passing a current through conductors 7 and 8, the getter is flashed and the barium is deposited on the inner surface of the cathode 9. Before the getter 11 is flashed, however, the tube is assembled and baked out, while the exhaust pump is connected to the exhaust tube 14 which passes through the stem 3. After the getter is flashed, the cathode is heated inductively, during which heating some of the nickel oxide coating is reduced and the freed oxygen is taken up by the barium to form barium oxide. Complete reduction of the nickel oxide is to be avoided as the low drop starting characteristics of the cathode 9 will thereby be destroyed. In activating the cathode, the cathode is brought up quickly to a temperature of about 800 degrees centigrade and then heating is stopped immediately. The conductors 7 and 8 have their upper ends cut off and conductor 7 is soldered to a metal connecting cap 12 which is secured to the top of the envelope 2 by means of cement 13.

An indentation in the form of a shoulder 15 is formed in the side walls of the envelope 2 adjacent the lower end of the cathode 9. The top of the mount assembly 5 bears against the shoul-

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der 15, which latter thereby serves to impart rigidity to the internal structure of the tube. The shoulder 15 also serves the important function of cutting off any paths around the outside of the mount assembly 5, thus restricting the path of the discharge so that the discharge must take place through openings provided in the mount assembly as will be described hereinafter. The mount assembly is supported from the press 4 by wire standards 16 and 17 sealed into the press. These standards also serve as lead-in conductors. Each of the standards is surrounded by an insulating sleeve 18 which is used to the press 4 and also serves in supporting the mount assembly.

Referring now to Figs. 2, 3, and 4, the mount assembly includes a plurality of round insulating washers 19, preferably of mica, each having a relatively large central opening 20 through which the discharge occurs. In addition, each of the washers has a pair of openings 21 to accommodate lead-in conductors and a plurality of smaller openings 22 through which a plurality of eyelets 23, which serve to hold parts of the mount assembly together, pass.

Between the two lower washers of the mount assembly, a flat disc-like anode 24 is sandwiched. The anode 24 completely blocks the central openings 20 of said washers, but it does not extend to the other openings in these washers. A control grid 25 made of flat wire mesh is similarly arranged above the upper of the two washers sandwiching the anode, the grid completely covering the central opening 20 in said washer. An electrode 26, hereinafter called a cathanode, by which term I mean an electrode which acts as a cathode with respect to the anode 24 and as an anode with respect to the cathode 9, is arranged above the control grid and is separated therefrom by another of the washers 19, the cathanode likewise completely covering the central opening 20 of said washer. The cathanode like the grid may be made of mesh, preferably woven from fine nickel wire. The wire forming this mesh is preferably of small diameter, less than .005 inch and may be .003 inch. This mesh is preferably very flat, and to achieve the desired flatness it is sometimes desirable to crush the mesh somewhat. For most purposes a mesh having 60 x 60 (3600) openings per square inch is satisfactory, although mesh from about 30 x 30 (900) and as fine as 150 x 150 (22,500) openings per square inch may be employed. In general the finer mesh is used where a higher amplification μ is desired, and the coarser mesh where a lower amplification μ is sought. In general it is also preferable that the control grid 25 and the cathanode 26 be made of the same mesh and that the openings in the mesh of these two electrodes be aligned. The aforescribed assembly is held together by a plurality of eyelets 23 which pass through the smaller openings 22, the lower end of the eyelets 23 gripping the bottom washer, and the upper ends of the eyelets 23 gripping the washer arranged on top of the cathanode 26. Two additional washers may be arranged loosely above said last-mentioned washer and are retained in position by their contact with the glass shoulder 15 which presses against the upper of these last-mentioned washers.

Cathanode 26 is connected outside of the tube by means of conducting ribbon 27, conducting wire 28, standard 16, dumet wire 29 which is sealed in the press, and the usual lead-in wire.

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Likewise the grid 25 is connected through a similar conducting ribbon 30, a thin wire conductor 31, standard 17, and a dumet wire 32 which is sealed in the press 4 to the usual lead-in wire. A connecting tab 33 is sealed to the anode 24, and a conducting wire 34 is connected to the tab, the wire 34 in turn leading to a dumet wire 35 sealed in the press and connected with the usual lead-in wire (not shown). A getter 36 may be arranged at the lower end of the tube adjacent the press 4 and may be suspended from a bent standard 37 having one end thereof sealed in the press. The getter 36 may be in the form of a closed wire adapted to be flashed by induction. The lower getter 36 is flashed after the tube 1 has been exhausted and before gas is introduced into tube 1.

After the getter 36 has been flashed and the tube has been exhausted, a gaseous atmosphere is introduced. This gaseous atmosphere may consist of one of the rare gases, argon, krypton, or xenon, or a combination of these gases. I have found that these gases are preferable to the other rare gases of lower molecular weight. When an attempt is made to correlate the gas pressure of such lower molecular weight gases with the characteristics of the cathode surface and the current so as to operate in the subnormal glow region, I have found that such gases produce relatively steep negative current-voltage characteristics. Therefore, attempts to use such gases at the currents involved herein have resulted in the necessity of utilizing higher impressed voltages with higher values of series resistance, thus introducing considerably greater losses into the system. In many instances the power consumed by a system utilizing such a tube has risen to undesirable high values. However, with the higher molecular weight gases specified above, such negative voltage characteristic must be extremely small, since it is very difficult to detect its presence. Also with rare gases having a lower molecular weight than argon, certain additional difficulties have been encountered such as a tendency for the discharge to be unstable and for oscillations to occur.

The pressure of the gas in the tube is critical. I have found a critical region of about 300 to 1500 microns, within which such tubes will operate satisfactorily for the purposes indicated. In general a pressure of 550 microns has proven satisfactory. With pressures above one and one-half millimeters, the drop increases when operating with very low currents and there is an increased grid current. With pressure below 300 microns, the cathode drop increases and the necessary starting voltage also increases. Furthermore, there is the danger that the gaseous atmosphere will cleanup, making the tube inoperative.

The spacing between the various electrodes in this tube is of prime importance. The distance between the cathanode 26 and the anode 24 is preferably of the order of the mean free path of electrons in the gas at the pressure used or less. The purpose of this spacing is to prevent the production of substantial ionization in the region between the cathanode and the anode, as will be more fully explained hereinafter. The cathode is preferably arranged at a sufficient distance above the mount assembly so that a short circuit will not be produced by the deposit of getter material on top of the mount assembly making contact with the cathode.

According to my present understanding of the

theory of operation of such tubes, a discharge occurs between the cathode and cathanode when a proper potential is applied therebetween. This discharge produces ionization in the region above said cathanode. Because of a positive charge on the cathanode, ions formed in this region are repelled so that the amount of ions passing through the cathanode into the lower control region between the cathanode and the anode is insufficient to form the neutralizing ion sheath around the control grid, which is typical of the operation of such tubes as the thyatron. Thus the discharge entering this lower region may be considered as purely an electron stream, although some ions do undoubtedly enter this region. Inasmuch as the distance between the cathanode and the anode is of the order of the mean free path of electrons in the gas, very little additional ionization will be produced in this region. Therefore, the control grid maintains complete control of the electron space charge in the control region between the cathanode and the anode, and this control is similar to the control exercised by the control grids in high vacuum tubes. It thereby becomes possible to introduce additional control elements, such as an additional control grid which functions in a manner similar to the screen grid in high vacuum type tubes. Furthermore, it becomes possible to utilize the principle of multiplication in the same manner as this principle is utilized in gaseous photoelectric cell tubes. A gaseous tube of this type utilizing a screen grid and employing the principle of multiplication is illustrated in Fig. 5.

Referring now to Fig. 5, the tube there illustrated is similar to the tube illustrated in Figs. 1-4 except in the following particulars. In place of the anode 24 another control element, to wit, a screen grid is utilized. This screen grid may be made of the same mesh as the control grid. In this embodiment the anode consists of a wire 39 sealed into the stem 3 and projecting to a point a short distance below the screen grid. An additional electrode 40, which may be called an ion collector or multiplier 40, is arranged on top of the press 4 and consists of a hollow, incompletely cylindrical metal member of comparatively large size approximating that of the cathode 9. The multiplier 40 may be formed of nickel having a nickel oxide coating and may have barium flashed thereon from a suitable getter 41. The getter may be arranged as illustrated in the figure and flashing thereof is produced by an induced current circulating through the multiplier 40 and the getter 41. Barium oxide is formed on the surface of the multiplier 40 in the same manner as hereinabove indicated in connection with the cathode 9 and the multiplier may be activated in the same manner as the cathode 9. Other details of the construction of the tube illustrated in Fig. 5 will be apparent from the drawing and the description of the tube illustrated in connection with Fig. 1.

According to my present understanding of the theory of operation of the tube illustrated in Fig. 5, electrons are emitted from the cathode 9 and produce substantial ionization in the region above the mount assembly. However, while electrons pass through the cathanode into the region below, ions are substantially prevented from so doing. The flow of electrons in the region below the cathanode is readily controlled by the grid and the screen grid in a manner similar to the control exercised by similar electrodes in a high vacuum tube. However, electrons passing into

the region below the screen grid again travel through long paths in the gas in said region and produce substantial ionization. The ions thus produced are attracted to the multiplier 40 which is maintained at a lower potential than the anode. These ions serve to draw out electrons from the surface of the multiplier 40, which surface has a low work function. These additional electrons are added to the stream of electrons which are drawn towards the anode 39, and thereby produce greater currents. By the arrangement shown in Fig. 5 large amplification is obtained.

In some instances the anode 39 may be omitted and the screen grid 38 may be utilized as the main anode. In this arrangement an electron stream is first accelerated through the screen grid 38. Upon passing into the region adjacent the multiplier 40 the multiplication described above is produced and the electrons are then drawn back onto the screen grid 38 acting as an anode.

In Fig. 6 there is illustrated a circuit in which the tube described in connection with Figs. 1-4 may be employed as an amplifier. An incoming signal is impressed across a grid resistor 42. One end of the grid resistor 42 is connected to the cathanode 26, the other end of said resistor being connected to the positive side of a bias battery 43, the negative side being connected to the control grid 25. The cathode 9 is connected to the negative side of a battery 44, the positive side of said battery being connected through a load resistor 45 to the anode 24. The output may be taken off across opposite ends of the resistor 45. The cathanode 26 is made positive in respect to the cathode 9 by connecting said cathanode 26 through a suitable current-limiting resistor 46 to a tap 47 on battery 44. Typical parameters for this circuit will be described hereinafter in connection with Fig. 8.

Referring now to Fig. 7, the circuit there illustrated is adapted for the tube illustrated in Fig. 5. The incoming signal voltage is impressed through a coupling condenser 49 across the grid resistor 50. One end of the grid resistor 50 is connected to the control grid 25, the other end of said grid resistor being connected to the negative side of a grid-biasing battery 51. The positive side of said biasing battery is connected to the cathanode 26. The cathode 9 is connected to the negative side of a battery 52, the positive side of which is connected through a suitable anode resistor 53 to the anode 39. The cathanode 26 and the multiplier 40 are connected together and in series with a suitable current-limiting resistor 54 to a tap 55 on battery 52. The screen grid 38 is connected through a current-limiting resistance 56 to another tap 57 on battery 52, the potential impressed upon screen grid 38 being greater than the potential on the cathanode 26. The signal output from anode 39 passes through a coupling condenser 58, through a coupling resistance 59 to ground and through ground back to the cathode 9, the output signal voltage being taken off across said resistance 59. It is of course to be understood that the circuit here described is only an illustration intended to show one way in which the tube illustrated in Fig. 5 may be arranged.

Referring to Fig. 8, the graph indicates certain characteristics of the tube described in connection with Figs. 1-4 in a circuit such as that shown in Fig. 6 where no signals are being received and the output is disconnected and the D. C. grid voltage is varied. The following are the constants of the circuit used: resistor 42—one megohm; resistor 46—one megohm; resistor

45=two megohms; battery 44=270 volts; tap 47 on battery 44=180 volts; and grid bias battery 43 was varied from minus 26 to zero volts.

In the graph applied grid volts are plotted against anode current in microamperes, grid current in microamperes, total current (including grid, anode and cathanode current) in microamperes, true grid bias in volts, and the voltage gain. The curves indicate variations of the foregoing in response to variations in the applied grid voltage. Curve A indicates variations in the grid current in microamperes, and curve B indicates how the true grid bias varies, account being taken of the drop in voltage across grid resistor 43. Curve C indicates the anode current in microamperes and curve D indicates the total current in microamperes in the system. The cathanode current is not indicated as it is not varied substantially by variations of the applied grid volts. The cathanode current is approximately constant at 94 microamperes. Curve E indicates the gain and the greatest gain coincides with a point on the steepest portion of the anode current curve C.

It is to be noted that a gain of approximately 16 to 1 is obtained when the total current is about 130 microamperes and the anode current is slightly less than 30 microamperes. Translated into terms of power a voltage gain of 16 is obtained with a total consumption of the order of milliwatts, in this instance .025 watt.

From the foregoing it will be apparent that I have provided tubes which will in a proper circuit give a large gain with extremely low power consumption. Such tubes are particularly adapted for standby applications. While I have described specific embodiments of such tubes, it will be apparent that certain modifications may be made in the construction thereof without departing from the teachings thereof. For example, additional control electrodes may be employed therewith and various changes in the configuration of the electrodes may be made without departing from this invention. In addition it is to be understood that the circuits here disclosed are only for purposes of illustration and are not intended to limit the applications of such tubes. It is accordingly desired that the appended claims be given a broad interpretation commensurate with the scope of the invention within the art.

What is claimed is:

1. A gaseous electrical space discharge device comprising an envelope containing an ionizable gas, a cold cathode, and an anode, said cathode having a radioactive material incorporated therewith, and an electron emissive coating on the active surface thereof.

2. A gaseous electrical space discharge device comprising an envelope containing an ionizable gas having a molecular weight at least equal to that of argon, a cold cathode, an anode, and a control electrode, said cathode having a radioactive material incorporated therewith, and an electron emissive coating on the active surface thereof.

3. A gaseous electrical space discharge device comprising an envelope containing an ionizable gas having a molecular weight at least equal to that of argon and a pressure of the order of about 300 to 1500 microns of mercury, a cold cathode, an anode, and a control electrode, said cathode having a radioactive material incorporated therewith, and an electron emissive coating on the active surface thereof.

4. A gaseous electrical space discharge device

comprising an envelope enclosing an atmosphere of a rare gas, a cathanode dividing said envelope into a plurality of regions including an ionizing region and a control region, a cold cathode in said ionizing region, said cathanode being provided with from about 900 to about 22,500 perforations per square inch, a control electrode in said control region, and an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

5. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas at a pressure of about 300 to 1500 microns of mercury, a cathanode dividing said envelope into a plurality of regions including an ionizing region and a control region, a cold cathode in said ionizing region, said cathanode being provided with from about 900 to about 22,500 perforations per square inch, a control electrode in said control region adjacent said cathanode, and an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

6. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas at a pressure of about 300 to 1500 microns of mercury, a cathanode dividing said envelope into a plurality of regions including an ionizing region and a control region, a cold cathode in said ionizing region, said cathanode comprising a wire screen insulating means preventing communication between said regions except through said screen, a control electrode in said control region adjacent said cathanode, and an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

7. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, a cathanode dividing said envelope into a plurality of regions including an ionizing region and a control region, a cold cathode in said ionizing region, a radioactive substance for ionizing the gases in said ionizing region, a control electrode in said control region adjacent said cathanode, and an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

8. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, a cathanode dividing said envelope into a plurality of regions including an ionizing region and a control region, a cold cathode in said ionizing region, said cathode having a coating including a nickel oxide and an oxide of an alkaline metal thereon, said cathanode being provided with from about 900 to about 22,500 perforations per square inch, a control grid in said control region adjacent said cathanode, an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

9. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas having a molecular weight at least equal to that of argon at a pressure of about 300 to 1500 microns of mercury, a cathanode dividing said envelope into a plurality of

regions including an ionizing region and a control region, a cold cathode in said ionizing region having a coating including a metallic oxide, barium oxide, and said radioactive material, a cath-anode being provided with from about 900 to about 22,500 perforations per square inch, a control grid in said control region adjacent said cath-anode, and an anode on the side of said control electrode remote from said cathanode and spaced from said cathanode by a distance of the order of the mean free path of electrons in said gas.

10. An electrical discharge device comprising an electrode assembly of a plurality of annular insulating washers having coextensive perforations providing a central opening, a flat disc-like electrode sandwiched between said washers, a control grid of flat foraminate material spaced from said electrode by one of said washers and completely covering said central opening, a second electrode of flat foraminate material spaced from said control grid by one of said washers and completely covering said central opening, and a plurality of rivets extending through the peripheral portions of said washers fastening said washers together and clamping said electrodes therebetween.

11. An electrical discharge device comprising an electrode assembly of a plurality of annular mica washers, a flat disc-like electrode sandwiched between two of said washers, a control grid of flat foraminate material spaced from said electrode by one of said washers and completely covering the central opening in said washer, a second electrode of flat foraminate material spaced from said control grid by another of said washers and completely covering the central opening in said washer, and a plurality of rivets extending through the peripheral portions of said washers fastening said washers together and clamping said electrodes therebetween.

12. An electrical discharge device comprising an electrode assembly of a flat imperforate electrode, a second electrode of flat foraminate material, a flat washer of insulating material, said washer having a central perforation of lesser diameter than the diameter of said electrodes, said washer being positioned between said electrodes and holding the same in spaced parallel planes with said electrodes completely covering said central perforation and with said imperforate electrode closing said central perforation, and means securing said electrodes and washer together in a rigid unitary electrode assembly.

13. An electrical discharge device comprising an electrode assembly including an anode of flat imperforate sheet metal, a plurality of electrodes of flat foraminate material, a plurality of flat washers of insulating material, said washers having central perforations of lesser diameter than the diameter of said electrodes, said washers being positioned between said electrodes and holding the same in spaced parallel planes with said electrodes completely covering said central perforations, said anode closing said central perforations, said washers having aligned openings in the peripheral portions thereof to accommodate lead-in conductors for at least one of said electrodes, and means securing said electrodes and washers together in a rigid unitary electrode assembly.

14. A gaseous electrical space discharge device, comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a con-

5 control region, said regions communicating only through the foramina of said electrode, electrode means for producing a subnormal glow discharge in said ionizing region, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

10 15. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas having a molecular weight at least equal to that of argon, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only through the foramina of said electrode, means in said device for producing a subnormal glow discharge in said ionizing region, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

20 16. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas at a pressure of about 300 to 1500 microns of mercury, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only through the foramina of said electrode, means in said device for producing a subnormal glow discharge in said ionizing region, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

40 17. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only through the foramina of said electrode, electrode means for producing a subnormal glow discharge in said ionizing region including a cold cathode and an additional electrode between which said discharge occurs, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

50 18. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only through the foramina of said electrode, electrode means for producing a subnormal glow discharge in said ionizing region including a cold cathode, and a radioactive material in said ionizing region, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

70 19. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only

through the foramina of said electrode, electrode means for reducing a subnormal glow discharge in said ionizing region including a cold cathode, and thorium oxide on said cathode, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

20. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing and a control region, said regions communicating only through the foramina of said electrode, electrode means for producing an ionizing discharge in said ionizing region, the foramina of said electrode being pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, means for controlling the electron flow in said control region, a multiplier electrode adjacent the path of the electrons flowing through the control region, and an anode towards which said electrons flow.

21. A gaseous electrical space discharge device comprising an envelope enclosing an atmosphere of a rare gas, means including a foraminous electrode dividing said envelope into a plurality of regions including an ionizing region and a control region, said regions communicating only through the foramina of said electrode, electrode means for producing an ionizing discharge in said ionizing region in which the current flowing as a result of such discharge is of the order of microamperes, the foramina of said electrode being

pervious to electrons but limiting the passage of ions to a quantity below that required to maintain a gaseous discharge, and means in said control region for controlling the electron flow.

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Certificate of Correction

Patent No. 2,444,072.

June 29, 1948.

PAUL W. STUTSMAN

It is hereby certified that errors appear in the printed specification of the above numbered patent requiring correction as follows: Column 5, line 13, for the word "used" read *fused*; column 6, line 21, for "krypton" read *krypton*; column 11, line 4, claim 9, for "said radioactive material, a" read *a radioactive material, said*; column 12, line 3, claim 14; line 47, claim 17; line 62, claim 18; column 13, line 2, claim 19; line 16, claim 20; line 33, claim 21; after "means" insert *in said device*; column 12, line 17, claim 15, and line 32, claim 16, before "means" insert *electrode*; column 13, line 2, claim 19, for "reducing" read *producing*; line 14, claim 20, after "ionizing" insert *region*; line 30, claim 21, for "region" read *regions*; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 14th day of September, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.